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APPLIED ANATOMY AND KINESIOLOGY

WILBUR PARDON BOWEN, M.S.

18/

THE PHYSICAL EDUCATION SERIES

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APPLIED ANATOMY AND KINESIOLOGY

THE MECHANISM OF MUSCULAR MOVEMENT

BY

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PREFACE TO THE FOURTH EDITION.

THE fourth edition presents the most complete revision of the "Applied Anatomy and Kinesiology" that has been made. We have tried to eliminate all errors of previous editions, improve the clearness of thought and description where needed, and bring the book up to date. With the latter point in view, the chapter on posture has been entirely rewritten, the section on defects of the foot likewise, and some changes have been made in the treatment of certain athletic events in which the standard form has undergone development as coaches and trainers have had longer experience. Less stress is now being laid on formal gymnastics, especially those systems borrowed from foreign countries; dancing has progressed in many ways.

The use of skeleton diagrams on which students sketch the muscles has proved helpful in giving a clear mental picture of the position and mechanical conditions under which each works. Charts on which the student can summarize quickly the actions of all the joint-mechanisms of the body in any exercise have also proven helpful; copies of both can be had from the author. Teachers are advised to refer students during the study of the muscles to the illustrations in the appendix, which also aid in perfecting the mental picture of each muscle.

Several teachers using the text have helped in this revision by calling our attention to needed corrections; thanks are especially due to Prof. Charles D. Giauque of Ohio University for many such suggestions. The U. S. Lawn Tennis Association and Charles Scribner's Sons have kindly permitted the use of excellent figures, and Miss Donnabel Keys has provided some fine pictures to illustrate the so-called "Natural Dancing."

W. P. B.

YPSILANTI, MICH.

PREFACE TO THE FIRST EDITION.

Kinesiology is the science of bodily movement. It includes a study of the principal types of muscular exercise, with inquiry as to how they are performed, how they react on the body, and their relation to the problems of bodily development, bodily efficiency, and the prevention and cure of certain defects and deformities. To make such a study it is necessary to analyze complex movements into their simplest elements, note carefully what bones, joints, and muscles are involved, what part each muscle has in the work, and under what mechanical conditions its work is done. There are two main reasons for our interest in the subject.

The first of these reasons which may be mentioned is the scientific one. All complex problems challenge our ability and stimulate a desire to master them. People are especially interested in the use of force to accomplish results, and show wonder and curiosity whenever they see a printing press, a steam thresher, a dynamo, or a locomotive in action. Interest in such machines is largely due to their complexity, which hides the manner of their action and stimulates curiosity as to how they work. The human body is a machine more complex and adaptable to a greater variety of work than any other to be found in the whole range of nature and invention. Machines have been built that are larger than the body and that are capable of greater speed, but no machine has been made nor is likely to be made that can walk, swim, climb, throw, lift, or strike, as occasion demands, although the body is considered very defective unless it can do all these things and many more. When we think of the really complex and difficult feats the body can perform, as illustrated by the performances of ball players, acrobats, jugglers, etc., it is plain that the body is in a class by itself as a marvellous piece of machinery. This is why no spectacles draw such crowds nor create such enthusiasm as exhibitions of human skill;

it is also the reason why there are no problems more fascinating to the student of science than those of Kinesiology.

The second reason for our interest in Kinesiology is practical. The work done by the machine reacts on the machine, modifying its development and the efficiency of its action. The maxim of biologists that "Function determines structure" is nowhere more true or more important than in muscular work. Although heredity has some part in it, nevertheless what we are depends largely on what we have done. The difference in physique between the athlete and the bookkeeper is in great measure the result of different kinds and degrees of activity. The reaction of the work upon the body is not only developmental but mechanical, for it influences the posture of the joints and the shape of the bones. Those who examine large numbers of men soon learn to tell almost immediately from the look of a man what his previous occupation has been. It follows that anyone who wishes to keep his own bodily machinery up to a fair grade of efficiency will do well to study Kinesiology, while those who plan to direct the bodily activities of others with a view to development and health need to have its main principles constantly in mind.

The study of Kinesiology brings us into a fascinating borderland lying between the fields of several sciences. We must first of all study something of anatomy, because we need to be very familiar with the size, structure, and location of the muscles, the exact points where they join the bones that act as levers, the nature of the joints on which they act, etc.; even those who have studied anatomy for other purposes can afford to review briefly the points of most importance here. We must note the way muscles do their work, which brings us into the field of physiology. A brief excursion into the field of mechanics is necessary to make us familiar with the problems of leverage and of the composition and resolution of forces. Finally, in studying the causes and conditions of certain bodily defects we touch upon the domain of pathology and therapeutics; and all the time we are close to the field of personal hygiene.

The real test of the mastery of this subject by the student is the ability to analyze and solve problems of Kinesiology that occur daily in the practice of the physician and the physical educator. Even if the main problems, as stated and explained here, are learned thoroughly, they occur in actual practice in such infinite variety and with such constant change of form that no one can deal with them effectively without the exercise of some ingenuity. Many physicians and teachers are so little versed in Kinesiology that they never see many of these problems that are constantly presenting themselves, to say nothing of solving them, much to the misfortune of their patients and pupils. Many cases are so complex and difficult that they should be referred at once to specialists; a fairly efficient student of Kinesiology can determine such cases at once.

W. P. B.

EDITOR'S PREFACE.

The first experience of most medical students in the dissecting room is one of disappointment at the apparently unfavorable position in which the muscles appear to be placed for the work that they are supposed to do, and it is only after more careful study that the intricate and exquisite adjustment of position to action is discovered. Increased knowledge stimulates appreciation of this intricacy until the student of Kinesiology will cheerfully argue all night about the real action of the biceps, already overworked as an illustration, but whose action is seldom correctly stated, or on the less obtrusive intercostals the functions of which have divided scholars into two hostile camps for the last hundred years.

The understanding of accurate muscular action is most vague, even in the minds of otherwise well-trained physicians, and I have seen committees of learned doctors absolutely at a loss to explain how a frail little woman could resist with ease the united strength of four strong men or how she could apparently change her weight at will. These wonderful feats which seem out of all proportion to her visible power are but examples of muscular action diverted to deceive those who are ignorant of the subject treated in this book, and the fact that so few detect them illustrates the density of the fog that in most minds envelops the simplest problems of muscular action.

The less theatrical application of these principles is employed by the American Posture League, in designing clothing, furniture, machinery and even car seats so that the mechanical construction of the body may be respected and not deformed. Its committees are doing much by the study of the principles discussed by the author to slacken the constant and insidious strain of nerve, muscle, ligament and bone that pulls down the efficiency of both young and old.

But there is still more urgent need of knowledge on this subject at the present time.

During and after the World War, behind every battle front, in hospitals and camps, tens of thousands of crippled soldiers have been brought back to strength and usefulness, largely by the reëducation of muscular movements.

In undertaking the editorship of this physical education series, of which this is rightly the first volume, I see the possibility of doing a real service to education and medicine by helping to place physical education on the plane that its importance and dignity demand.

Both by training and inclination, Mr. Bowen is especially well adapted to write the initial volume; a practical teacher and a close student of applied anatomy for many years, his pen has not been idle, and in the following pages he has gathered the fruits of his ripened experience and mature judgment for the large audience that awaits him.

R. Tait McKenzie, M.D.,
Editor.

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APPLIED ANATOMY AND KINESIOLOGY.

PART I.

GENERAL PRINCIPLES.

CHAPTER I.

MUSCULAR STRUCTURE AND ACTION.

THE muscles are the immediate source of all the energy the body can use to move itself and other things. Originally derived from the sun, this energy is caught and stored by plants in latent form in the food materials they produce. These are eaten, digested, absorbed, and then built up anew into the structure of the muscles, where the energy so long imprisoned can be set free to do work. With the long series of chemical changes involved in this storage of energy, its preparation, its rebuilding into muscle tissue, and its final dissolution during muscular action we are not concerned here. The way muscles use the energy, however, when it is set free, is related to their internal structure, and something of this we must now observe.

The entire muscular system includes nearly 200 pairs of muscles, but only about 75 pairs are involved in the general posture and movement of the body, and our study will be limited to this number. The others are smaller and are concerned with such minute mechanisms as those controlling the voice, facial expression, and the act of swallowing. The muscles, like the bones, are of various sizes and shapes, every one of the 75 pairs being recognizable by its size and form. Some are in flat sheets, like the trapezius (Fig. 30) and the transversalis (Fig. 144); some are long and slender, like the sartorius (Fig. 92) and the peroneus longus (Fig. 113); some are spindle-shaped, like the biceps (Fig. 50) and the pronator teres (Fig. 69); most of them are of such irregular shape that a classification based on form is not practicable. Each pair is named, some of the names indicating the form, as in the case of the rhomboid and teres major; some indicating action, as the levator and the supinator; some indicating location, as intercostal and supraspinatus; a few are named from the bones they join, as the brachioradialis and the sternomastoid.

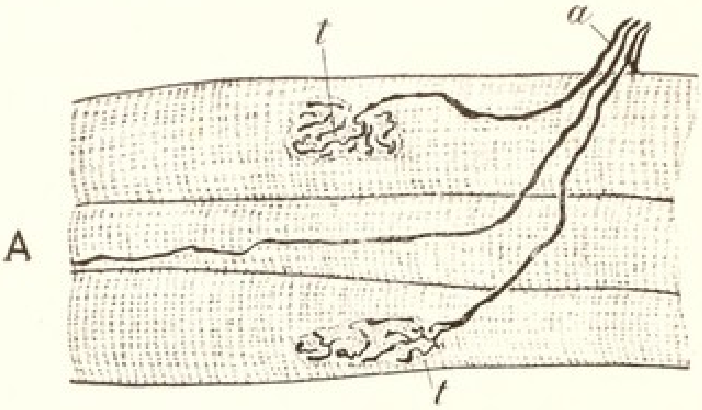


FIG. 1.—Muscle magnified, showing the muscle fibers and the nerve fibers. (Gray.)

Each muscle is composed of thread-like fibers, the number in a muscle varying from a half dozen to several hundred thousand. Each muscle fiber is an independent unit, having its own individual connection with the nervous system by a nerve fiber, through which it receives the influences that control its action. The muscle fibers vary in length from 200 to 1000 times their width, and lie close together, parallel to one another, with minute spaces between for the lymph on which they feed and into which they pour their

FIG. 2.—Fibers of muscle and tendon, showing striping and nuclei in the muscle fibers and a sensory nerve ending in the tendon. (Klein.)

waste products. The fibers are too small to be seen readily with the unaided eye; they can be so stained that when seen through a microscope both the muscle and nerve fibers are visible. Notice in Fig. 1 the parallel muscle fibers and the smaller and more darkly stained nerve fibers (*a*) going to them and terminating in the motor endings (*t*).

Fig. 2 shows nuclei and the junction of muscle and tendon. The muscle fibers are shown below and the tendon above. The muscle fibers are seen to be crossed laterally by alternate bands of dark and light, and in each of them are seen the dark oblong nuclei irregularly placed. Each fiber is really a cylindrical mass of jelly-like protoplasm enclosed in a thin and transparent membrane called the sarcolemma. The sarcolemma keeps the protoplasm of the different fibers from merging into a single mass of jelly and isolates each one from all the rest, so that they can act as separate units.

A portion of one muscle fiber, highly magnified, is shown in Fig. 3. Notice that here we are observing the finer structure of a single muscle fiber, not a muscle. Fine threads running lengthwise of the fiber have on them certain enlargements, alternately spherical and cylindrical. The fine threads are called fibrils, and the clear space between them is filled with a semiliquid substance called sarcoplasm. It is readily seen that the enlargements on the fibrils, regularly placed, are what give the striped appearance of muscle fibers under lower magnification. In the arrangement of fibers into a muscle they are usually grouped into bundles, each bundle having a sheath, and then the bundles are bound together by the sheath of the muscle. The fibers of many muscles are joined directly to the bones, but more often there is a strip of flexible tissue called a tendon (Fig. 2), to which the fibers join and which connects them with the bone. Each fiber is attached by its sarcolemma, and tendons are in reality formed by the fusion of all the sarcolemmas and sheaths of bundles with the sheath of the muscle.

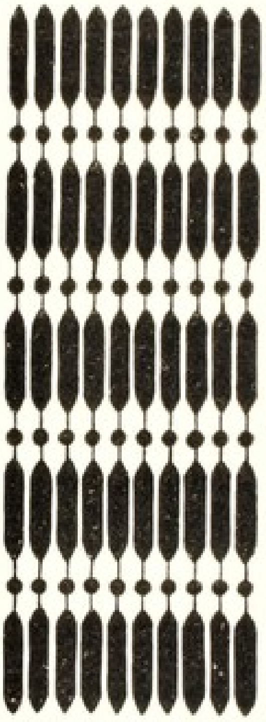


FIG. 3.—Portion of a single muscle fiber highly magnified. (Gerrish.)

Muscular work is done by a change in the form of the muscle called contraction, which includes a shortening and bulging out sidewise. A relaxed muscle exerts a slight pull on its attachments because of its elasticity, but when it contracts it pulls with greater force. The contraction is due to the shortening of the separate fibers, and each fiber as it shortens swells out laterally, stretching its sarcolemma and the other sheaths surrounding it and thus making the muscle feel harder to the touch than when relaxed. This hardening of muscles as they contract serves as a convenient test of muscular action, since it enables one to tell by the senses of touch and pressure whether a certain muscle is taking part in a movement or whether it is idle.

The lateral swelling of a muscle in contraction may be used to exert force, as is easily shown by tying a band of cloth about the upper arm tightly and then forcibly bending the elbow. The muscles that bend the elbow swell out as they shorten and press out strongly on the band. Professional "strong men" often exhibit their great power in this way, breaking ropes and log-chains drawn tightly around the arm by a sudden bend of the elbow. Such a way of doing muscular work, however, is no more than a curious novelty; the bodily machinery is made to work by the pull of the muscles on the bones to which they are joined and its structure is developed on that plan. The lateral enlargement has this practical importance, that all the force used in stretching sheaths, clothing, or anything else that resists the free swelling of the muscles is so much force wasted. There will always be a small loss due to this cause, but each practice of an exercise diminishes it by making the sheaths more distensible from the repeated stretching they receive.

When a muscle contracts strongly it is apt to move both of the bones to which it is attached, but to simplify the problem it is usually assumed that the bone moving least is stationary. The point where the muscle joins the stationary bone is called the *origin* of the muscle, and its point of junction with the moving bone is called its *insertion*. Evidently the insertion is the place where the force is applied to the moving lever, and the distance from the insertion to the joint which serves as the axis of movement is the force-arm of the lever. Now it frequently happens in muscular exercise that the bone that acts as a lever in one exercise is stationary in another; for example, when one lies on his back and then lifts his feet the trunk is stationary and the lower limbs are levers, but when from the same position on the back he rises to sitting posture the limbs are stationary and the trunk is the lever. The same muscles do the work in the two cases, and it is evident that origins and insertions are reversed when the exercise is changed. The question as to which end of a muscle is origin and which is insertion depends therefore on the movement made. Although this is a matter of much importance in kinesiology, we shall for the sake of clearness of description follow the custom of anatomists and call the end nearer the center of the body the origin. The true origin and insertion can be told with ease when any mechanical problem is involved.

The term "muscular tone" is frequently used in speaking of muscles and so needs explanation. Everyone is aware of the fact that we can contract a muscle at will to any desired degree of force up to its full strength and then can relax it at will down to any desired degree until complete relaxation is reached; in other words, instead of simply contraction and relaxation there are many possible grades of condition between the two. It can also be observed, although it is not so easy to notice, that there are different degrees of relaxation when we consider the muscles at rest. For example, if we feel of our muscles during or soon after a time of great excitement, such as a ball game or a thrilling play at the theater, we find them harder than usual, and further observation will show that we are less able than usual to keep from making all sorts of bodily movements, including talking, and that there is a feeling of tenseness in the muscles. After a night of good rest the tenseness and hardness are gone. These changes in the tension of muscles when they are not in ordinary contraction are called changes of "tone." They are caused by changes in the condition of the nervous system which are communicated to the muscles through the nerve fibers going to them. Muscular tone is greatest during excitement, less when one is quiet, still less when asleep; it is reduced still further by the action of anesthetics and most of all by paralysis or severing of the nerve fibers. A very high degree of tone shades off imperceptibly into mild contraction, as illustrated by shivering and by the tendency to act when excited.

Muscles that are much used are apt to have more tone than those used less; when this is the case between two antagonists the position of the joint upon which they act is apt to be out of normal position because of the greater tension of the one most used. For example, many women use the extensors of elbow so little and work with arms in front of the chest so much that their elbows are in a habitual posture of half-flexion, from which they cannot be fully extended. When a muscle is paralyzed we see a still more marked example of the same kind; notice in Fig. 33 on page 66 that the right shoulder blade is not only lowered because the paralyzed muscle does not fully support its weight, but it is also drawn away from the median line by the tonic pull of the muscles on the front of the chest.

The amount of work done by a contracting muscle is a combination of two elements of equal importance: the amount of force used and the distance or extent of movement. Stated mathematically, the amount of work is the product of the force by the distance ($W = F \times D$). One unit of work is the amount involved in exerting one unit of force through one unit of space, so that we measure work in gram-centimeters, foot-pounds, kilogram-meters, foot-tons, or car-miles, according to the units of force and distance employed.

In this connection it is important to notice two facts in the working of muscles: first, that the *force* a muscle can exert depends on the *number* and *size* of its fibers; second, that the *extent* through which it can contract depends on the *length* of its fibers. It follows from the first that the strength of muscles is proportional to their cross-section, with the understanding that this cross-section is taken at right angles to the fibers and includes all of them; the second is related to the fact that a normal muscle fiber can contract to half its full length. It has been found that human muscle in good condition can exert a force of 6 kilograms per square centimeter of cross-section, which is practically the same as 85 pounds to the square inch. A muscle that has 8 square inches of cross-section and fibers 6 inches long should therefore do 170 foot-pounds of work at a single contraction ($85 \times 8 \times 3 \div 12 = 170$).

The internal structure of muscles bears an important relation to the force and distance of their contractions, as the principles just stated indicate. We have noticed how greatly muscles differ in outward form; they differ quite as much in internal structure, which is a matter of arrangement of fibers. Two main types of structure are recognized, the *longitudinal* and the *penniform*, but there are many variations from each type. The longitudinal is the simpler of the two types; in its simplest form it can be well illustrated by the pronator quadratus (Fig. 70), a small muscle on the front of the forearm just above the wrist. This muscle consists of a single flat sheet of parallel fibers extending across the forearm, joining the radius on the outside and the ulna on the inside, covering a space about 2 inches square. This gives us fibers 2 inches long and therefore able to contract through about 1 inch of distance.

In order to illustrate how muscular structure is related to muscular work, let us assume, for the sake of argument, that this muscle has 800 fibers, each 4 cms. long and each able to exert a force of 1 gm. (Fig. 4, *A*). Under this supposition the muscle can exert a force of 800 gms. through a distance of 2 cms., doing 1600 gm. cms. of work at one contraction. Now suppose the muscle split lengthwise and the halves placed end to end, making a muscle of exactly the same bulk, with half as many fibers twice as long (Fig. 4, *B*); it can now pull with a force of 400 gms. through 4 cms. of distance, doing 1600 gm. cms. of work as before. Now let it be split in the same way again and its length doubled, giving a muscle of 200 fibers 16 cms. long (Fig. 4, *C*); now it can lift 200 gms. through 8 cms., doing the same amount of work. Evidently the number of variations in the arrangement can be multiplied indefinitely, showing that a longitudinal muscle having a certain bulk will do its work in different ways according to number and length of its fibers, still doing the same amount of work in every case.

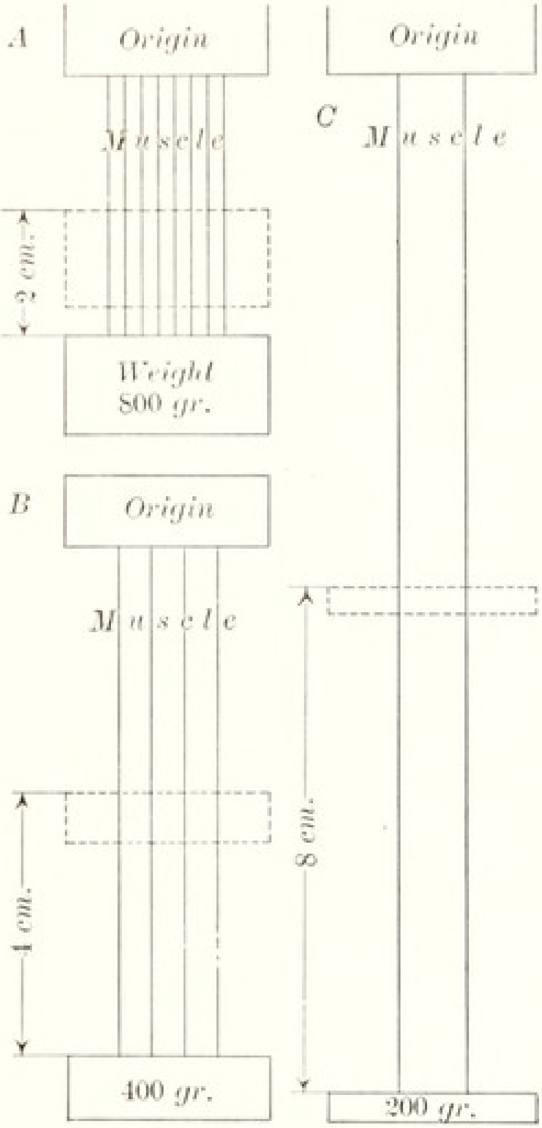


Fig. 4.—Diagram of three longitudinal muscles, showing how number and length of fibers affect power and extent of movement. *A* has 800 fibers 4 cms. long, *B* has 400 fibers 8 cms. long, and *C* has 200 fibers 16 cms. long. Arrows indicate extent of contraction.

As a matter of fact the many longitudinal muscles in the body illustrate just so many different arrangements on the same general plan, alike in consisting of parallel fibers running lengthwise of the muscle and differing in bulk and in the number and length of fibers. As two extreme instances we may take the sartorius (Fig. 92), which is a narrow band of extremely long fibers, suited to perform a movement with little force through an enormous distance, and one of the intercostals (Fig. 138), consisting of a great number of very short fibers joining two adjacent ribs and able to draw them nearer together through a slight distance with a great force.

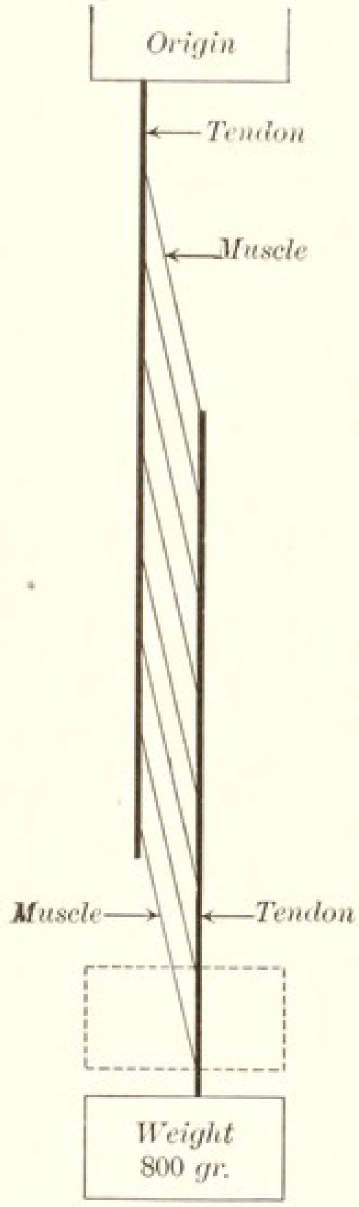


FIG. 5.—Diagram to show how a penniform arrangement of its fibers can give a long, slender muscle, like *C* in Fig. 4, the same lifting power as a short, thick muscle like *A*.

It is evident from the above that any muscle arranged on the longitudinal plan must be short and broad to have much strength of contraction; if it is long and slender it is sure to be weak, although it can shorten through a proportionately great extent. Fully three-fourths of all the muscles are situated where they need to exert more strength than a longitudinal muscle would have, while the greater extent of contraction would be wasted, and as a consequence the longitudinal plan is replaced by the penniform.

The simplest penniform arrangement is illustrated by the peroneus longus (Fig. 113). This muscle, almost as long and slender as the sartorius, must be able to lift the whole weight of the body and therefore must consist of a great many short fibers instead of a few long ones. To secure this structure a long tendon extends far up the outside of the leg parallel to the bone and the muscular fibers arise from the bone and join the tendon after extending diagonally downward and sideward for an inch or thereabout. The biceps (Fig. 50) presents a similar case. It is nearly a foot long but the movement it needs to make is not far from 3 inches; at the same time it must have great force. A longitudinal muscle would be able to shorten more than is useful here while it would lack force. To get the exact proportion of force and distance called for by the work to be done two tendons extend downward from the shoulder and one tendon from below extends upward between these two; fibers just long enough to give the needed extent of movement pass diagonally across from the upper to the lower tendon, giving a bipenniform muscle. Many examples of this plan of structure will be noticed as we proceed with the study of individual muscles. Probably the most notable example is the gastrocnemius (Fig. 113), which contains several penniform sheets and bundles formed into a well-rounded muscle.

It is easy to get a fair estimate of the strength of longitudinal muscles, for by cross-sections made in the dissecting room the area can be readily obtained with a fair degree of accuracy, and the parallel direction of all the fibers makes it easy to get cross-sections at right angles to the fibers. When we wish to know the strength of a penniform muscle the problem is very different, for a simple cross-section of such a muscle is oblique to the direction of its fibers and may not include half of them. In complex cases there is no apparent way to get the true cross-section. This method of learning about the strength of muscle is also lacking in that it gives us no knowledge as to the condition of the muscle and we have to assume it to be some arbitrary percentage of what it ought to be to make an estimate at all. Another way to determine muscular strength is by using a dynamometer. There are two types of dynamometer used for this purpose: one to test the muscular system as a whole and the other to test isolated groups of muscles. The first type of dynamometer is illustrated by the kind used in colleges to test the strength of lift (Fig. 6); the second by the kind used to test strength of grip. The former is useful to test a man's general strength, and requires but little time; if we wish to know how a man's strength is distributed we have to use a form of dynamometer that will test the strength of each muscle group separately (Fig. 7). This method does not give the actual pull of each muscle but its effective pull through its leverage as it normally works; this can be compared with the strength of other men, giving us after all a fair estimate of condition.

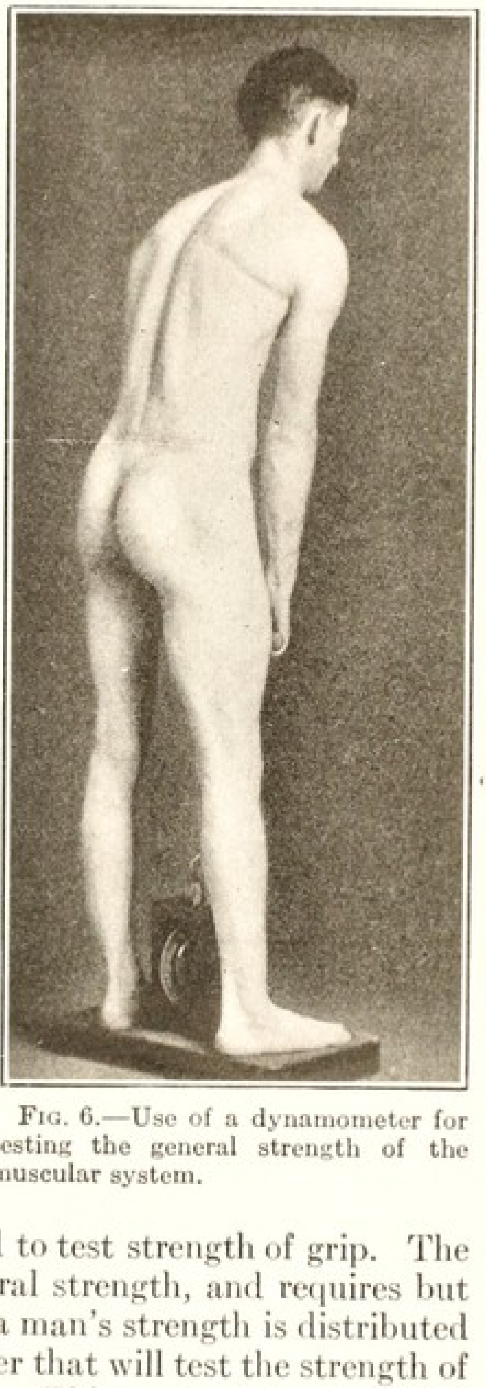


FIG. 6.—Use of a dynamometer for testing the general strength of the muscular system.

A muscle can exert its greatest force when it is fully extended, and as it shortens its force diminishes. It follows that if we load a muscle with all it can lift it will be able to lift it but a short distance. The question arises, how large a load should be put upon a muscle if we wish it to work with best results? This is a problem frequently tested out in the physiological laboratory, using the muscles of frogs. The following table shows the type of result uniformly obtained from this test. The muscle is given a constant stimulus:

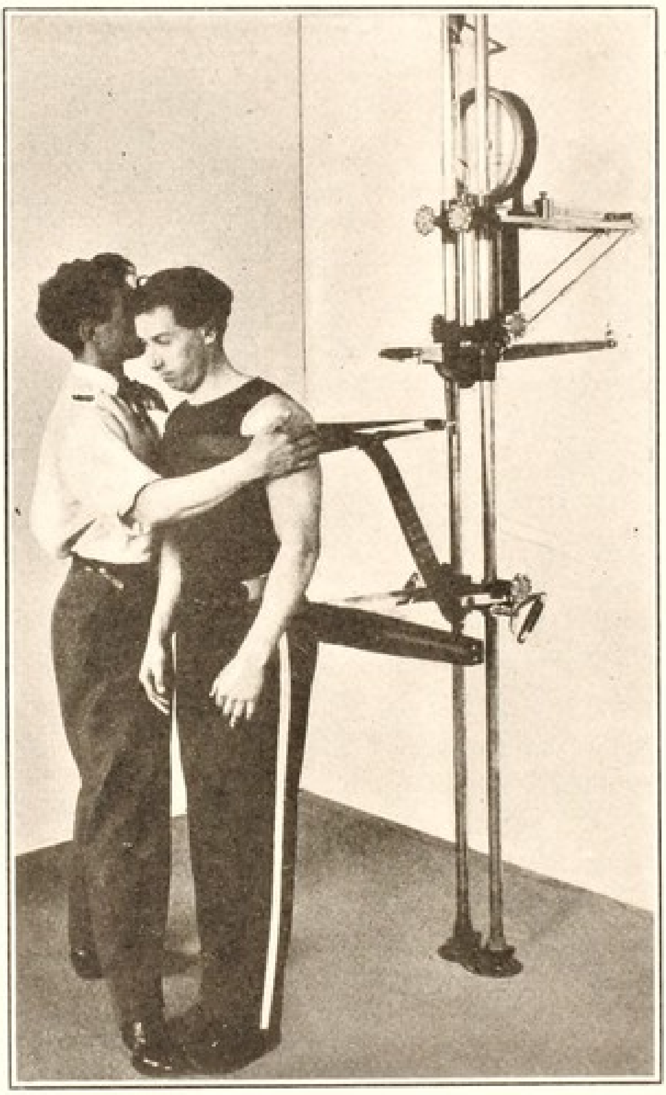


FIG. 7.—Use of a dynamometer for testing the strength of separate muscle groups. The abdominal group is being tested. (Kellogg.)

Weight.	Height.	Work.
0	10	0
1	10	10
2	9	18
3	8	24
4	7	28
5	6	30
6	5	30
7	4	28
8	3	24
9	2	18
10	1	10
11	0	0

The column marked weight gives the number of gram weights used to load the muscle in the successive tests; the figures for height are the numbers of centimeters the weight was lifted; the figures for work are the products of weight and height in gram-centimeters. Notice that the work accomplished is least with the lightest and heaviest weights, and is most when the weight is about half of what the muscle can lift. It means that when we use muscle to get work done it pays to take moderate weights, avoiding the extremely light and extremely heavy ones. This has been applied in manual labor, and certain companies who employ shovelers furnish them with shovels that will hold just 21 pounds, which has been found to be the most favorable weight for the average man. There is reason to believe that such a load for a muscle is not only best for efficiency but also best for training, although it would appear to be wise to use heavier loads for a small part of the time.

An important condition is illustrated in the last line of the above table, where the weight is too great for the muscle to lift. If we apply the formula $W = F \times D$ we get 0 for the work. This means that in the mechanical sense no work is done, although if we watch the muscle we see that it contracts and exerts force, which involves destruction of tissue and consequent fatigue. It is usual to say, in explanation of the apparent contradiction, that in such a case a muscle does internal work but no external work. We shall see later that the muscles of the body do a great amount of useful work without causing motion, as illustrated in standing, sitting, holding a weight in the hand or on the shoulder, or hanging by the hands; also in holding a bone solidly in place that it may serve as a firm support for the pull of another muscle. Such contractions are called static contractions; they result in some muscular development but are not so good for that purpose as those that cause motion.

A further extension of the same principle is shown when we use muscles to oppose a movement but not strongly enough to stop it, as in lowering a weight slowly, walking down stairs or in wrestling with a stronger opponent. Such actions of muscle may be called lengthening contractions to distinguish them from the static and from the usual shortening contractions. Each kind of action has its use. We may summarize by saying that muscular work may involve shortening, static, or lengthening contractions according as the force of contraction exceeds, equals, or is less than the resistance.

Football players have known for many years that a man can start quicker and push harder if he is in a crouching posture, and a few years ago it was discovered that sprinters can get the quickest start by assuming a similar attitude. This is for the same reason that men stoop low when they have to lift heavy loads and racing bicyclists stoop low over their handle bars in making their best efforts. Since every muscle can pull with most force when it is fully elongated, all those who are trying to exert all the force at their command naturally take a position that will put the muscles that are to be used on a stretch. Everyone will think of instances of this kind in sport and industry.

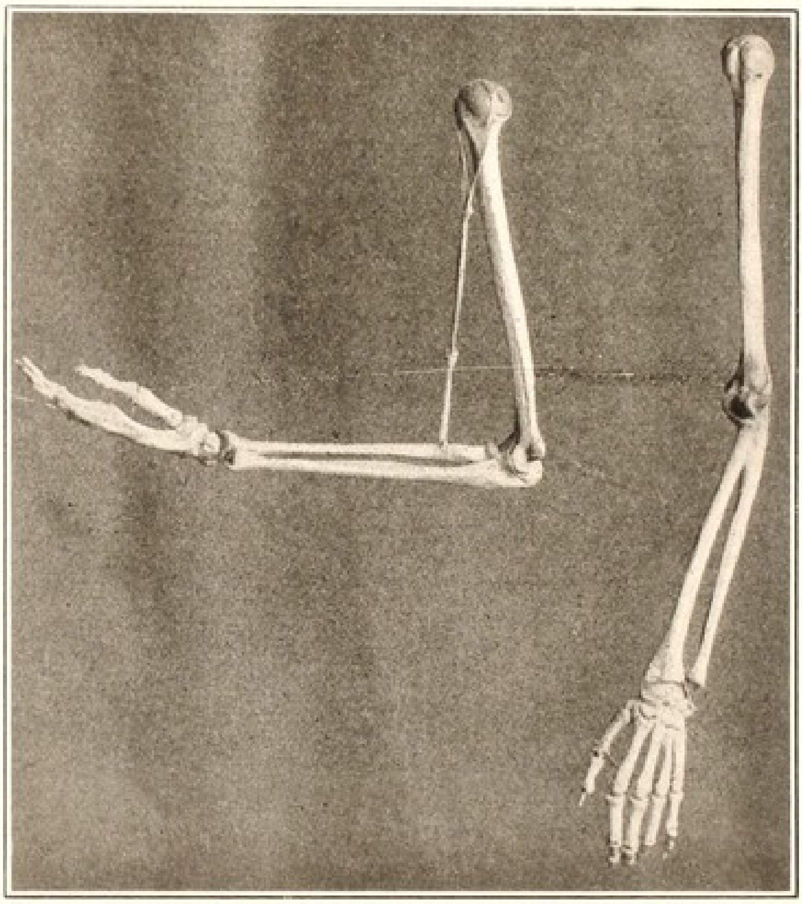


FIG. 8.—How a rubber band aids in studying the action of a muscle.

METHODS OF STUDYING MUSCULAR ACTION.

There are at least five ways of studying a muscle to find out its action.

1. Study of the conditions under which a muscle acts by the use of a mounted skeleton, noticing its points of attachment, direction of pull, leverage, and any other points bearing upon the problem that can be discovered. This is a method of study that is of the greatest value to every student of kinesiology; it is practically impossible to get a clear idea of muscular action without it. By the use of cords and rubber bands to indicate the direction of pull, the study can be made objective and thus aid the memory as well as the reason (Fig. 8).

2. By pulling upon the partly dissected muscles of a cadaver and noticing the resulting movements. This method has its advantages and was used by the ancient anatomists in studying the question, but for the average student it can hardly take the place of the preceding method. When apparatus for support of the body can be arranged, as in case of Mollier's experiments, the method gives excellent results.

3. Stimulation of individual muscles by electric current and noticing the resulting movements. This method, thoroughly tried in the classic researches of Duchenne, has corrected many conclusions obtained by the two preceding methods, especially in cases where the direction of pull and leverage of a muscle make it very hard to tell which of two things it will do. It is not difficult to apply this method to superficial muscles, but those lying deeper could only be reached by it in cases such as Duchenne was able to find, where the overlying muscles had been destroyed by disease, leaving the deeper ones intact.

4. The study of subjects who have lost the use of certain muscles to find what loss of power and movement has resulted and whether any abnormal postures have been produced. Studies of this kind are very interesting and some of them have added materially to our knowledge of muscular action, as we shall see later. It would be difficult, however, to find such a variety of defective subjects as is necessary to study the muscles in a systematic way by this method.

5. Study of the normal living body, to find what muscles contract in certain exercises and what movements call certain muscles into action. This and the first are the most practical methods of study, not only for the beginning student, but also for those who are engaged in the solution of unsettled problems. Normal subjects are always at hand and are plentiful in the swimming-pools and dressing-rooms of college gymnasia. Whatever we may learn from other methods, this one must give the final decision, for neither observation of a skeleton or electric stimulation can tell what a muscle *will* do, although these methods may tell with certainty what it *can* do. We need to learn not only what action a muscle is able by its position and leverage to perform, but also what, in an actual case of exercise, the nervous system calls upon it to do and when it permits it to lie idle. Some of Duchenne's most brilliant discoveries by means of electric stimulation have been shown to be misleading, because observation of the living body shows that certain muscles which might help greatly in an exercise actually never do so.

The interest of the student of kinesiology is stimulated by constantly recurring practical problems of muscular action to which he must bring the best evidence secured by all these methods, and try to verify the commonly accepted solutions by his own observation of the skeletal mechanism and the action of the living body. The student who is hopelessly addicted to the study of books as his only source of information is sure to fall by the wayside.

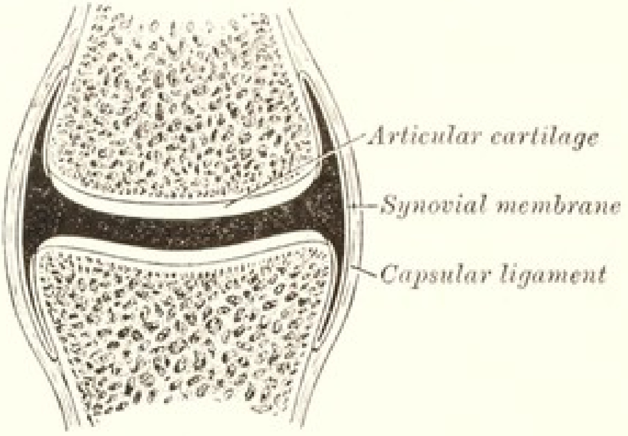


Fig. 9

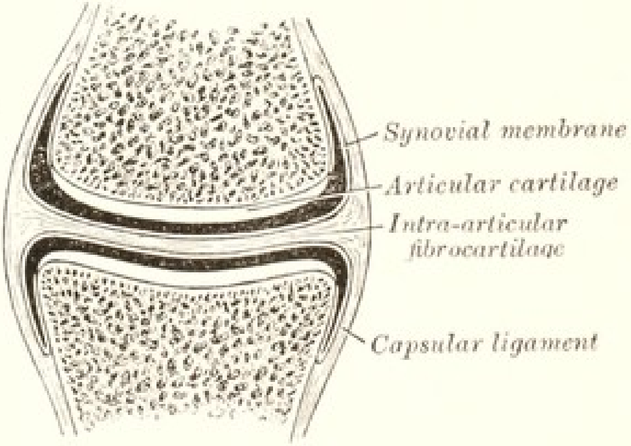


Fig. 10

Figs. 9 and 10.—A typical joint. (Gray.)

Before one can clearly understand descriptions of muscles and the location of their attachments it is necessary to become familiar with certain terms used in describing bones and joints. The upper end of a long bone is usually called its *head;* the cylindrical portion forming most of its length is called its *shaft.* A long and rather slender bony projection is called a *spine;* a shorter projection is called a *process,* and if pointed a *spinous process;* a rounded prominence is called a *tuberosity,* and if small a *tubercle.* A depression in a bone is called a *fossa,* and a hole into or through a bone is called a *foramen.*

The junction of two bones is called an *articulation*, of which there are several kinds. The bones of the skull and those of the pelvis are so joined as to permit no movement; articulations that permit movement are commonly called *joints*. The vertebræ of the spinal column are joined with a disk of cartilage between, the movement being due to the yielding of the disks; the name *amphiarthrosis* is applied to these joints. Many joints, like those of the wrist and foot, permit only a slight gliding of one bone upon another; these are called *arthrodial* joints. Others permit wide movement in one plane, like the elbow and ankle, and are called *hinge* joints. A few, like the wrist-joint, permit movement freely in two planes, but no rotation; such are called *condyloid* joints; finally we have the *ball-and-socket* joints, like the shoulder and hip, permitting free movement in all planes and rotation on an axis besides.

Articulating surfaces of bone are always lined by a *synovial membrane*, which is reflected across from one bone to the other to form a closed sac. The synovial membrane secretes a fluid, called the *synovial* fluid, which lubricates the joint and so prevents any considerable friction. In most joints there is at least one piece of cartilage to form a surface of contact, movement apparently taking place with less friction between bone and cartilage than between two bones. The bones forming a joint are kept in place by strong bands of connective tissue called *ligaments*. They are usually less elastic than tendons, and connect bone to bone as shown in Figs. 9 and 10. The several ligaments surround the joint and their edges are always joined to form a closed sac called a *capsule* which serves to protect the joint and to prevent rupture of the synovial membrane and escape of the fluid.

CHAPTER II.

THE BONES AS LEVERS.

A LEVER is a rigid bar revolving about a fixed point, which is called its *axis* or *fulcrum*. In the making of bodily movements it is the principal function of the bones to serve as levers, and the principal function of the muscles to move these levers. It is only by such action that the body is able to stand erect, move itself in the various forms of locomotion, and move objects outside of itself. The student of kinesiology must therefore be thoroughly familiar with the fundamental principles of leverage in order to get even an elementary conception of the bodily mechanism.

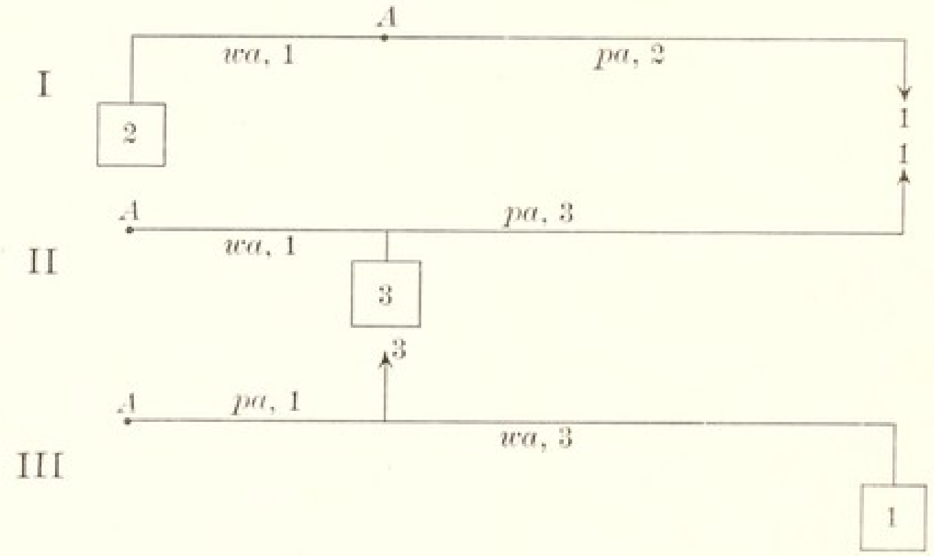


FIG. 11.—The three classes of levers. The long straight lines are the levers, *A* is the axis, the squares represent the weight or resistance and the arrows the power or pull of muscle; *pa*, power arm; *wa*, weight arm.

A rigid bar, such as one of the bones of the arm, may have various degrees of usefulness for a certain purpose, depending on the location of three points upon it: the point where the force is applied to it, the point where it is applied to the resistance we wish to overcome, and the axis on which it turns. Levers are divided into three classes according to the relative position of these three points, as illustrated in Fig. 11.

Levers of the first class have the axis between the other two points, and as a consequence the force and the resistance act in the same direction and the two arms of the lever move in opposite directions. This class of levers is illustrated by a crow-bar, a pump-handle, the walking-beam of a side-wheel steamer, a pair of scissors, or by muscle *I* in Fig. 12.

Levers of the second class have the resistance applied between the force and the axis; the force and the resistance act in opposite directions and the force required is always less than the resistance. This class is illustrated by the action of a wheelbarrow or a pair of nut-crackers. There are few if any levers of the second class in the body.

Levers of the third class have the force applied between the resistance and the axis; force and resistance work in opposite directions and the force must always be greater than the resistance. The action of a spring for closing a door is an example of third-class lever, also the pedal of a bicycle and the muscle marked *III* in Fig. 12.

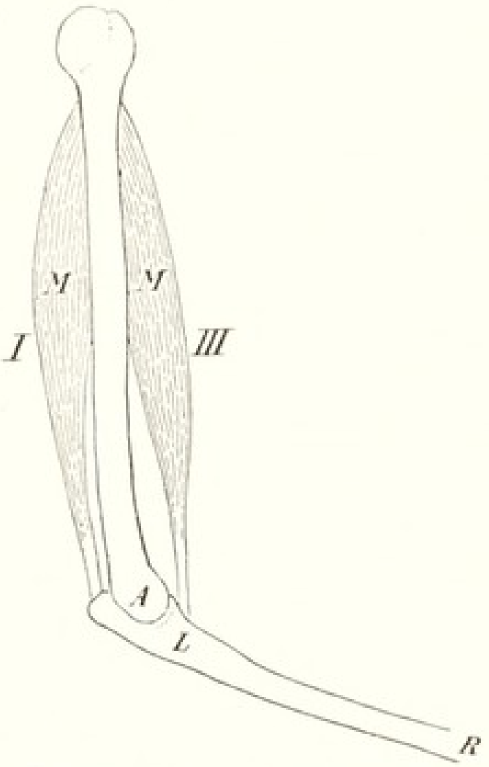


FIG. 12.—Illustration of first class and third class levers by muscles acting on the elbow-joint. The bone *AR* is the lever, with the axis at *A*, the weight or resistance at the hand, which is beyond *R*. *M*, *M* are the muscles and *L* is the insertion of the muscle *III*.

The distance from the axis to where the force is applied to the lever may be called the force-arm, power-arm, or muscle-arm of the lever, while the distance from the axis to the place where the resistance is applied may be called the resistance-arm or weight-arm. In Fig. 12 *AL* is the power arm and *AR* the weight arm for muscle *III*. The law of levers, which applies to levers of all classes alike, states that the force will exactly balance the resistance when the product of the force by its arm is equal to the product of the resistance by its arm; in other words, when the force and resistance are inversely proportional to their distances from the axis. Notice how the figures for weights and distances in Fig. 11 illustrate this. If the muscle-arm in case of muscle *III* in Fig. 12 is 2 inches and the weight-arm is 12 inches, a force of contraction of 48 pounds will hold a weight of 8 pounds in the hand ($2 \times 48 \div 12 = 8$). Any reader who is not familiar with the use of levers should study the effect of changing the length of the muscle-arm and the weight-arm on the force of muscle that will have to be used to lift the weight by making and solving problems similar to the above.

When a lever turns about its axis it is evident that all points upon it move in arcs of a circle and that the distances these points move is proportional to their distances from the axis. In the case of muscle *III*, for example, if the weight is six times as far from the axis as the muscle, it will move six times as far, so that when the muscle contracts through 1 inch the weight will be lifted through 6 inches. The relation of this fact to the law of levers given above is stated in the law of conservation of energy, which says that in the use of levers all that is lost in force is gained in distance, and *vice versa*. Since the time it takes a muscle to shorten is not affected by the length of the lever-arms, it follows that any gain in distance is a gain in speed as well.

In the common form of levers seen in familiar tools and machines, such as pumps, scissors, nut-crackers, and the like, the resistance is applied close to the axis and the force much farther away, since the lever is used to gain force at the expense of distance of movement. In the body, as illustrated by the two muscles in Fig. 12, the force is usually applied with a short muscle-arm to overcome a resistance much farther away; the penniform arrangement of muscle fibers gives a large amount of force and the leverage is such as to give great distance of movement and speed. This plan of construction not only gives the body all the power, speed, and extent of movement that is needed but also compactness of structure, the muscles lying much closer to the bones than would be possible with longer muscle-arms.

Besides the effect of relative length of lever-arms, the action of muscles is varied by the direction in which they pull upon the lever. In solving elementary problems of leverage it is usual to assume, as we have done in the examples above, that the force is applied at right angles to the lever, but in the action of muscles on the levers of the body this is the exception rather than the rule. Fig. 12 shows two muscles pulling at nearly a right angle, but it is plain that if the joint were in any other position they would not do so, and in the positions of extreme flexion and extension of this joint they will pull at a much smaller angle. Many muscles, as we will notice as we proceed, never pull an angle greater than 20 degrees.

Fig. 13 shows how the angle of pull changes as a muscle shortens. When the bony lever is in the position BC the angle of pull, DEB, is 12 degrees; in the position BC_1, it is 20 degrees, at BC_2, 25 degrees, etc. The angle of pull will never be as great as a right angle unless the origin D is farther from the axis than the insertion, E.

The smaller the angle of pull, the farther and faster will a certain amount of contraction move the bone, as may be seen by Fig. 13. The muscle *DE* is represented in this diagram as contracting four times, each time by the same amount (one-eighth of its full length). Starting from the position *BE*, where the angle of pull is only 12 degrees, the first shortening turns the bone *BE* through an angular distance of 32 degrees, but as the angle of pull increases the same amount of shortening only turns it 25, 21 and 19 degrees. Pulling at an angle of 10 to 12 degrees the point *E* moves more than three times as far as the muscle shortens; when the pull is at a right angle the contraction and the resulting movement are practically the same.

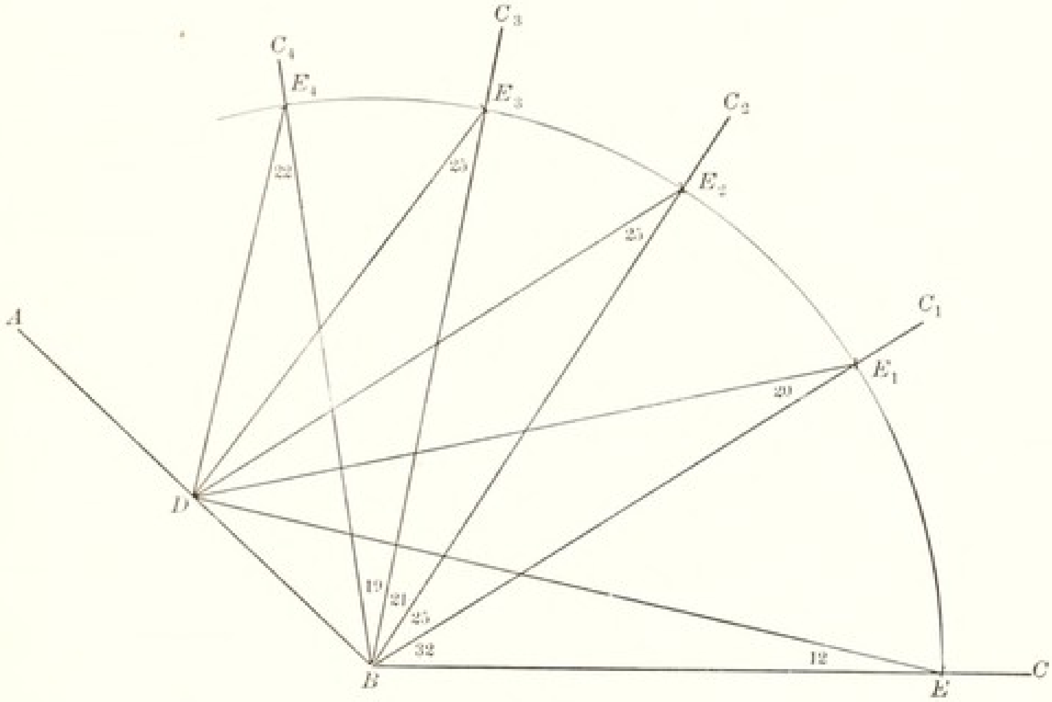


Fig. 13.—Diagram to show how angle of pull changes as the bony lever is moved by the muscle: *AB* is a stationary bone with axis at *B; DE* is the muscle and *BC* the moving bone, coming to positions BC_1. BC_2, etc., as the muscle shortens, the muscle coming to positions DE_1, DE_2, etc., *DEB* is the angle of pull.

The gain in speed and distance that a muscle secures when it pulls at a small angle is balanced by a loss of power that is illustrated in the diagram of Fig. 14, known as the "parallelogram of forces." As in the preceding Fig., *AB* is a stationary bone and *BC* a moving bone with the axis at *B; DE* is the muscle, pulling at the angle *DEB*. The muscle pulls on its insertion at *E* in the direction of *D*, but the rigid bone *BE* will not permit *E* to move that way, but rather resolves the pull of the muscle into two forces—one of which acts in the direction *EG* to move the bone on its axis and the other in the direction *EB* to move the bone lengthwise and only serves to increase the friction in the joint at *B*. Now it is found experimentally that if we choose any point on DE, as F, and construct the rectangle $HEGF$, with the two lines perpendicular to BC and the third line parallel to it, the length of the side EG will represent accurately the useful part of the muscle's force and HE the ineffective part, while the diagonal FE represents the entire force of pull. It is clearly seen by a look at the diagram that as the angle of pull, DEB, changes the length of the sides of the rectangle will change; with the larger angle of pull that exists when the point E is moved to E' it takes the form $H'E'G'F'$, with the relative length of sides reversed.

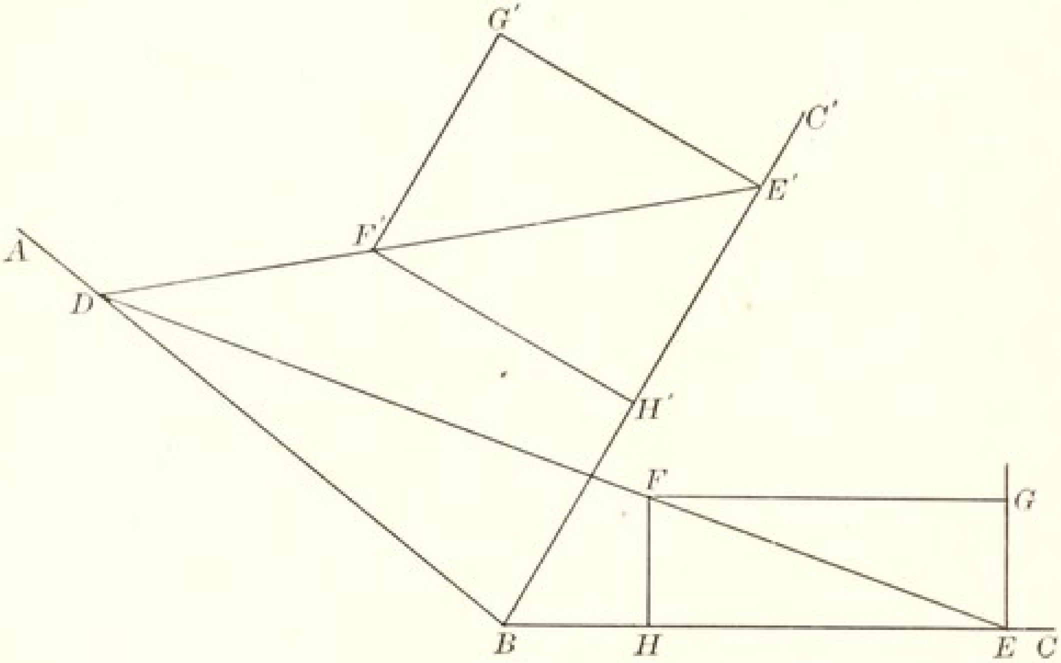


Fig. 14.—The parallelograms of forces: AB, stationary bone; BC, moving bone; B, axis; DE, muscle; BC', another position of BC, DE taking the position DE'. DEB and $DE'B$, angles of pull; $FGEH$ and $F'G'E'H'$, the parallelograms of forces. See text.

The relation of the side EG to the diagonal EF is constant for each size of the angle DEB, and the ratios for the different sizes of the angle have been computed and can be found in the table on p. 39. This ratio is called the *sine* of the angle, and the useful component for any angle can be found by multiplying the entire force of the muscle by the *sine* of the angle at which it pulls. The mathematical formula is $f = F \times s$, in which f is the effective force, F is the entire force, and s is the sine of the angle of pull.

To illustrate how this formula is applied to problems of muscular action, let us assume that the muscle DE, which is pulling on the lever at an angle of approximately 27 degrees, is contracting with a force of 100 pounds. In the table of sines we find the sine of 27 degrees to be 0.45399; placing these values in the formula it becomes $f = 100 \times 0.45399$, which gives 45.399 pounds as the effective force. To find the force acting lengthwise of the lever we find the angle HFE $(90 - 27 = 63)$ and proceed as before. $f = 100 \times 0.89101$, or 89.101 pounds. In this case, therefore, the diagonal represents 100 pounds and the two sides 45.3 and 89.1 pounds.

While we are considering angle of pull it is well to notice that the resistance as well as the muscle may act at various angles.

When the resistance is a weight it will always act vertically downward. In Fig. 15 the weight is shown pulling down on the bony lever at an angle of 45 degrees; when the lever is in a horizontal position this pull is at 90 degrees, but in other positions it acts at smaller and smaller angles, so that its force, like that of the muscle, is resolved into an effective component acting at right angles to the the lever and an ineffective component acting lengthwise of it.

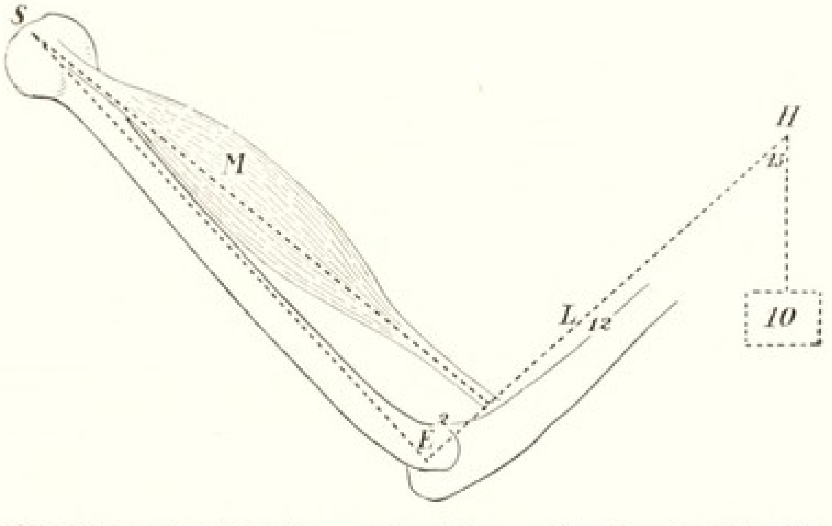


Fig. 15.—Conditions of action of a muscle acting on the elbow-joint to lift a weight in the hand: S, shoulder; E, elbow, M, muscle; H, hand; L, lever.

To illustrate fully how the muscular requirement is influenced by these elements of leverage and how to attack such problems, let us inquire with what force a muscle acting on the elbow-joint must pull to lift 10 pounds in the hand when the forearm is 45 degrees above the horizontal, the muscle-arm being 2 inches, the weight-arm 12 inches, and the angle of pull of the muscle 75 degrees.

The conditions of this problem are illustrated by Fig. 15. Evidently the weight will act upon the lever so as to resist the action of the muscle with a force equal to 10 pounds multiplied by the sine of 45 degrees, or 7.07 pounds. This multiplied by its lever-arm (7.07×12) gives 84.84 inch-pounds to be overcome by the action of the muscle. From the law of levers we have $f \times 2 = 84.84$, or

$f = 42.42$ pounds. This is the effective force that must be produced by the action of the muscle at an angle of 75 degrees (sine = 0.96593). We wish to find F, so in the formula $f = F \times s$ we substitute the known quantities, giving the formula, $42.43 = F \times 0.96593$, or $F = 42.42 \div 0.96593$, from which F or the whole force of contraction is 43.9 pounds.

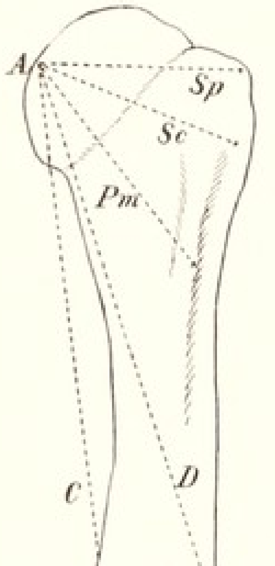


Fig. 16.—The humerus, to show the lever arms upon it: *A*, axis; *Sp*, lever-arm of supraspinatus; *Sc*, of suprascapularis; *Pm*, of pectoralis major; *D*, of deltoid; *C*, of coracobrachialis.

In applying the general principles of leverage to bones it is necessary to bear in mind that the two arms of a lever are two straight lines drawn from the two other points to the axis; in some cases these two may form one and the same straight line, but usually not. In case of the humerus, for example, the point of contact with the scapula that serves as the axis of the shoulder-joint is an inch or more to one side of the shaft of the bone; as a result the two lever arms meet at a rather large angle, as shown in Fig. 16. In most cases we have one principal resistance, and therefore one resistance-arm, with several muscles acting, each with its own muscle-arm, making a complex lever with several forces acting on it at once. The angle at the axis has no effect on the law of leverage, for as long as the lever is a rigid bar it acts in the same way whether it is straight or not. To solve cases of combined muscle action we may work each one out separately as if it acted on the resistance by itself, and then add the results, or we may multiply each force by its arm and add the products before applying the law of levers. To illustrate: suppose that two muscles pull on the humerus at Sp and D (Fig. 16) with a force of 100 pounds each, the muscle-arm at Sp being 1 inch and the angle of pull 60 degrees, the muscle-arm at D 5 inches and the angle 15 degrees; how much resistance will they overcome at a distance of 12 inches down the arm? The product for Sp will be $1 \times 100 \times 0.86603$, or 86.603; the product for D will be $5 \times 100 \times 0.25882$, or 129.41; the sum of the two is 216.013; by the law of levers r = 216.013 ÷ 12 or 18.001 pounds. This is the effective resistance; if the resistance acts at an angle less than 90 degrees, the total resistance overcome will be the number just given divided by the sine of the angle at which it acts.

Very often the resistance to muscular action is the weight of a part of the body, and when this is the case we must not only know the weight of the part but also its distance from the axis. In all cases of this kind the weight is assumed to be at the center of gravity of the part and the weight-arm of the lever measured from that point. These points have been worked out carefully. For example, the center of gravity of the whole arm is slightly below the elbow; for the lower limb just above the knee, etc.

TABLE OF SINES.

Degrees	Sines.	Degrees.	Sines.	Degrees.	Sines.	Degrees.	Sines.
0 or 180	.00000	23 or 157	.39073	46 or 134	.71934	69 or 111	.93858
1 or 179	.01745	24 or 156	.40674	47 or 133	.73135	70 or 110	.93969
2 or 178	.03490	25 or 155	.42262	48 or 132	.74314	71 or 109	.94552
3 or 177	.05234	26 or 154	.43837	49 or 131	.75471	72 or 108	.95106
4 or 176	.06976	27 or 153	.45399	50 or 130	.76604	73 or 107	.95630
5 or 175	.08716	28 or 152	.46947	51 or 129	.77715	74 or 106	.96126
6 or 174	.10453	29 or 151	.48481	52 or 128	.78801	75 or 105	.96593
7 or 173	.12187	30 or 150	.50000	53 or 127	.79864	76 or 104	.97030
8 or 172	.13917	31 or 149	.51504	54 or 126	.80902	77 or 103	.97437
9 or 171	.15643	32 or 148	.52992	55 or 125	.81915	78 or 102	.97815
10 or 170	.17365	33 or 147	.54464	56 or 124	.82904	79 or 101	.98163
11 or 169	.19081	34 or 146	.55919	57 or 123	.83867	80 or 100	.98481
12 or 168	.20791	35 or 145	.57358	58 or 122	.84805	81 or 99	.98769
13 or 167	.22495	36 or 144	.58779	59 or 121	.85717	82 or 98	.99027
14 or 166	.24192	37 or 143	.60182	60 or 120	.86603	83 or 97	.99255
15 to 165	.25882	38 or 142	.61566	61 or 119	.87462	84 or 96	.99452
16 or 164	.27564	39 or 141	.62932	62 or 118	.88295	85 or 95	.99619
17 or 163	.29237	40 or 140	.64279	63 or 117	.89101	86 or 94	.99756
18 or 162	.30902	41 or 139	.65606	64 or 116	.89879	87 or 93	.99863
19 or 161	.32557	42 or 138	.66913	65 or 115	.90631	88 or 92	.99939
20 or 160	.34202	43 or 137	.68200	66 or 114	.91355	89 or 91	.99985
21 or 159	.35837	44 or 136	.69466	67 or 113	.92050	90	1.00000
22 or 158	.37461	45 or 135	.70711	68 or 112	.92718		

CHAPTER III.

MUSCULAR CONTROL.

CIVILIZED man is inclined to show a certain amount of scorn for what he is in the habit of calling "mere muscle," but the fact remains that everything he does depends ultimately on the action of muscles. The muscle fiber is, in the last analysis, the sole instrument by which the human will can act upon the outside world. No matter how great the refinements of civilization, no matter how much machinery may be devised to do our work for us, man can never get away from the necessity for muscular work. The people of the "intellectual classes" do not escape muscular work; they only use small muscles instead of large ones.

Each muscle fiber is an independent unit, isolated from all its near neighbors by its sarcolemma as completely as if it were miles away. Normally a muscle fiber receives no communication during its whole life except from the nervous system. Although it can be made to act by an electric shock or a violent blow, these are rude departures from normal conditions. The muscle fiber is made to do just one thing: contract, and it is made to do this only when it receives the signal to do so through its nerve fiber. The nervous mechanism by which the million or more of muscle fibers in the body are controlled so as to perform powerful and graceful movements is one of the most interesting subjects of study. Surely no one can have greater interest in it than the student of kinesiology.

NEURONES.

The structural unit of the nervous system is the neurone. It consists of a nerve cell with all of its branches. The cell is a minute mass of protoplasm containing a nucleus; the branches are called nerve fibers. Neurones are so radically different in form from anything else in nature that for a long time they baffled comprehension. The feature that caused the trouble is the enormous length of the fibers in comparison with the size of the cell to which they belong. The cells are less than one-tenth of a millimeter in diameter, while the fibers are sometimes a meter long. Fig. 17 shows a neurone correctly in all details except this one; if the artist had drawn the main fiber of proportionate length to the size of the cell it would be more than 500 feet long; we need to bear in mind, therefore, that while the figure shows diameters magnified 25 to 30 times, the length of fibers is reduced to $\frac{1}{100}$ or $\frac{1}{1000}$ of the proportional extent.

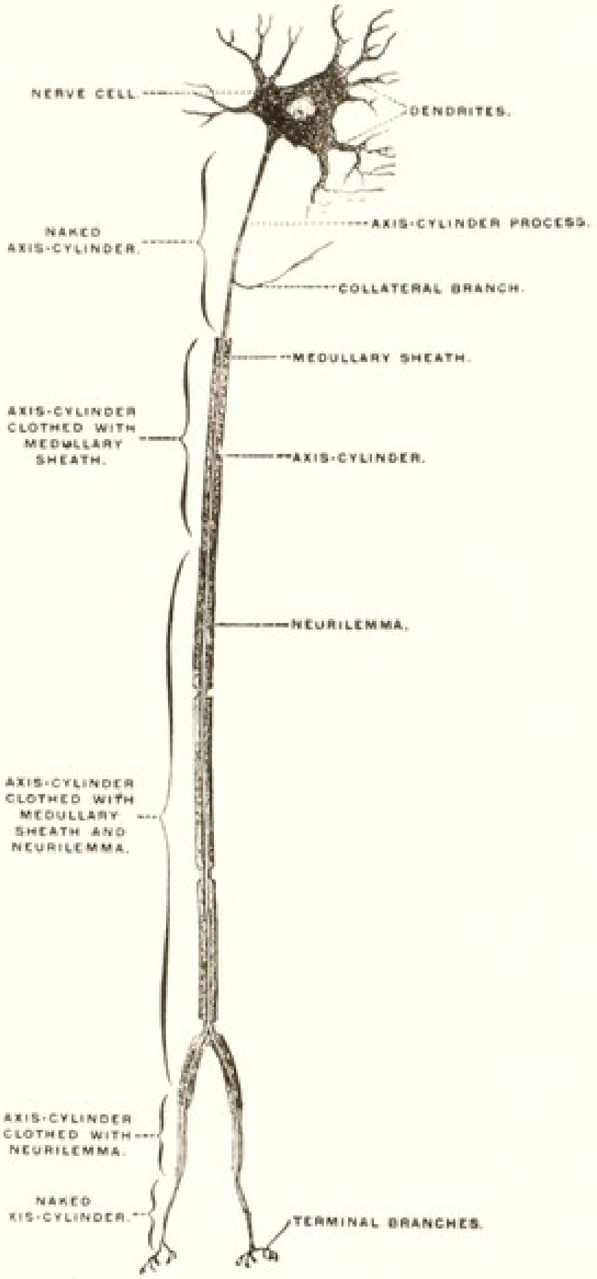


Fig. 17.—A motor neurone. (Stohr.)

The principle of division of labor is illustrated in the activities of a single neurone. The cell with its nucleus serves as a reservoir of food material and presides over the nutrition and growth of the entire neurone, even to the ends of its longest fibers. A fiber cut off from its cell dies, but the cell may send out another to replace it. The fibers carry messages. That which travels along the fiber is called a nerve impulse, and may be thought of as a wave of energy or excitement. Impulses travel on the nerve fibers of man at the rate of about 100 feet per second. The central thread of nerve substance in a fiber, on which the impulse travels, is called the axis-cylinder; it is protected through most of its length by a delicate membrane called the neurilemma, similar to the sarcolemma of a muscle fiber. Within the neurilemma is usually a white fatty sheath called a medullary sheath. The sheaths insulate the central thread and prevent the impulses from spreading to other fibers.

The endings of some fibers are developed into special organs for receiving messages; the endings of others into organs for transmitting messages to muscle, gland, or other neurones. This gives rise to a division of nerve fibers into *axones* and *dendrites*. The axone is the principal branch of a neurone and is the path by which impulses pass *from* the cell; most forms of the neurone have but one axone. Most neurones have several dendrites, which are the paths of impulses going *to* the cell.

The further study of neurones as a factor in muscular control requires an explanation of how they are distributed in the body, and this calls for a brief survey of the nervous system as a whole.

THE NERVOUS SYSTEM.

It is usual to distinguish two main divisions of the nervous system—the central portion, lying within the neural canal in the spinal column, and the peripheral portion, which includes the cranial and spinal nerves. The central portion includes the brain and the spinal cord. The nerves are bundles of nerve fibers that branch off from the central nervous system in 43 pairs. Another part, called the autonomic or sympathetic nervous system, is not concerned in voluntary movement.

The brain, lying within the skull, includes the cerebrum, the cerebellum, and several large groups of nerve cells called the "basal ganglia." The medulla oblongata connects the brain and the spinal cord. The central nervous system is separable into a gray and a white portion; the gray portion is on the outside in the cerebrum and cerebellum, forming a thin layer called the cortex. The area of the cortex is greatly enlarged by deep folds called convolutions. Within the cortex is the white portion of the brain, with the basal ganglia scattered through it.

The spinal cord is a cylindrical column about 18 inches long and about half an inch in diameter at an average; its diameter differs considerably in different places, two enlargements at the levels of the arm and leg being of most importance. The spinal cord consists of a vast number of neurones, along with the supporting tissues, called neuroglia, and the blood and lymph vessels. It is deeply cleft lengthwise by two fissures, the anterior and posterior median fissures, dividing it into its right and left halves. The fissures serve as a convenient guide to the study of the cord, since the anterior fissure is always an open one while the posterior fissure is always closed (Fig. 26), making it easy to distinguish directions. Cross-sections of the cord show the gray and white portions distinctly, the gray portion being within and entirely enclosed by the white portion. The gray portion is shaped much like a capital H; the four extremities of the H, as seen in Fig. 19, are cross-sections of four columns or ridges that extend up and down the whole length of the cord. The cross-bar of the H is called the commissure, and is the place where nerve fibers cross from one side of the cord to the other.

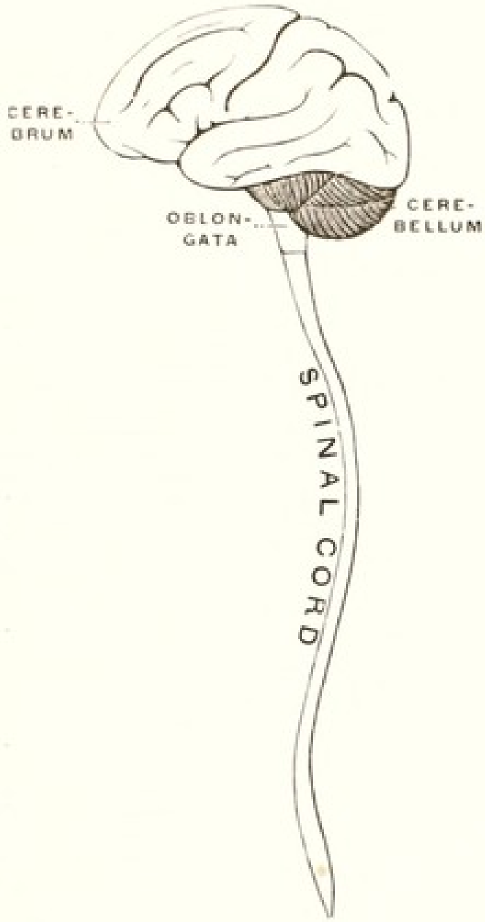


Fig. 18.—The central portion of the nervous system. (Gerrish.)

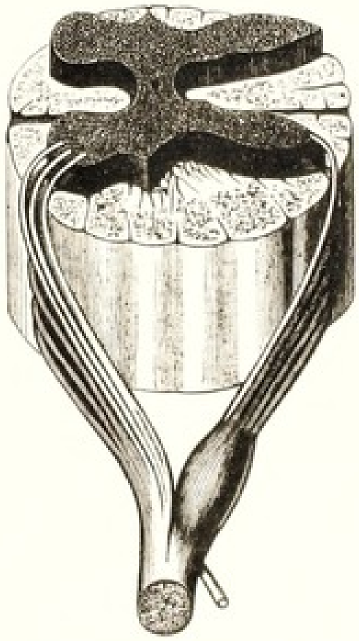


Fig. 19.—General structure of spinal cord and junction of a spinal nerve with it. (Gerrish.)

The spinal nerves leave the cord in pairs, one pair for each vertebra; one is on the right and its mate on the left side. Each nerve joins the cord by two roots; one opposite the tip of the anterior gray column is called the anterior root, and one opposite the posterior gray column is called the posterior root. The two roots join to form a nerve before they pass out of the neural canal; just before they join the posterior root has an enlargement upon it that is called a *spinal ganglion* (Fig. 19).

The four roots and the two fissures divide the outer or white part of the cord into six columns that extend its whole length: two anterior, two lateral, and two posterior. Microscopic study of the structure of these white columns shows them to be composed of medullated nerve fibers, each of which has the structure of the main fiber shown in Fig. 17. The medullary sheath is what gives this part of the cord its white appearance, leading the early anatomists to believe that there are two kinds of nerve substance, white and gray. Looking at a cross-section of the cord in a microscope we see cross-sections of these nerve fibers, each one appearing as a circle with a dot in the center (Fig. 20). The circle is the neurilemma and the dot is the axis-cylinder. The greater portion of fibers seen in any section pass in a vertical direction; a smaller number are usually seen passing across horizontally.

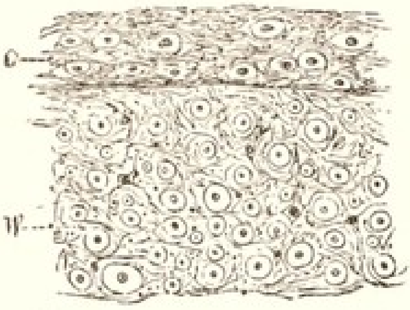


FIG. 20.—Cross-section of a white column of the spinal cord. (Klein.)

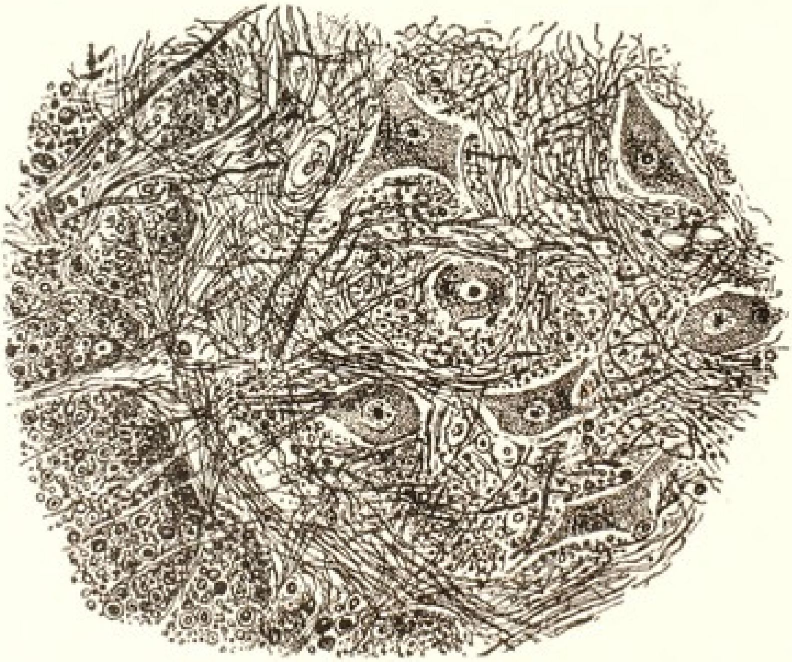


FIG. 21.—Cross-section of spinal cord on the border of gray and white portions. (Klein.)

Microscopic study of the gray part of the cord shows it to consist mainly of nerve cells and naked nerve fibers. The fibers form here a confusing jungle or network, having no uniformity of direction;

nerve cells of various sizes and shapes are seen scattered through it. Some of the fibers seen are the dendrites of the nerve cells that lie among them; some are the axones of these cells; some are the terminals of axones from nerve cells situated far away in distant parts of the nervous system. It is here, where cells and fibers have no insulating sheaths, that neurones are able to influence one another (Figs. 24, 25, 27).

The above description of the nervous system, dealing with its general form and appearance, is of value only as it leads to a knowledge of its internal structure and activities. From the latter viewpoint the central nervous system, so far as it concerns us here, consists of three systems of neurones: the motor, sensory, and association systems. The motor neurones constitute the only path by which impulses can be sent to the muscle fibers; the sensory neurones provide the only path by which stimuli can enter the nervous system from the outside world; the association neurones are the means of communication between the various parts of the nervous system and hence are the only possible means of muscular coördination.

The *sympathetic* or *autonomic* nervous system consists of a special set of motor neurones that control the action of involuntary muscles, heart muscle, and glands. Their axones are not medullated, so that they are not suited to finely coördinated action. Recent studies indicate that axones from the autonomic system are distributed also to the voluntary muscles, but their influence there is not clearly understood.

MOTOR NEURONES.

The cells of the motor neurones are situated in the anterior gray columns of the spinal cord, forming two long groups of cells extending the whole length of the cord. From each of the cells, which are like that shown in Fig. 17, arise several dendrites that may extend for varying distances through the gray part of the cord but never outside of it; they pass up, down, toward the posterior column, or through the commissure to the opposite half of the cord. It is through these dendrites that the motor neurones receive their stimuli.

Each motor neurone has a single axone (Fig. 17). From the cell in the anterior gray column the axone passes outward across the white part of the cord, traverses the anterior root of a spinal nerve and then follows the course of the nerve and one of its branches to a muscle.

Since each muscle fiber is so completely insulated from its fellows, each must have its own nerve fiber, and each nerve fiber must be so insulated that no message can jump across from one fiber to another in the nerve, where they lie side by side for long distances. The neurilemma and the medullary sheath serve this purpose. Many of the motor axones have several terminal branches, one neurone controlling several muscle fibers; evidently these must be fibers that will always need to act together. Four hundred thousand motor axones have been counted in the anterior nerve roots of a single individual. These axones enter the muscle along with sensory fibers, forming a mixed nerve; the nerve divides in the muscle and the fibers go to the various parts; each motor fiber finally terminates inside of a muscle fiber with an ending like that shown in Fig. 22. The office of this ending is to transmit to the protoplasm of the muscle fiber the message sent by the cell in the spinal cord. Under normal conditions it never conveys messages in the other direction.

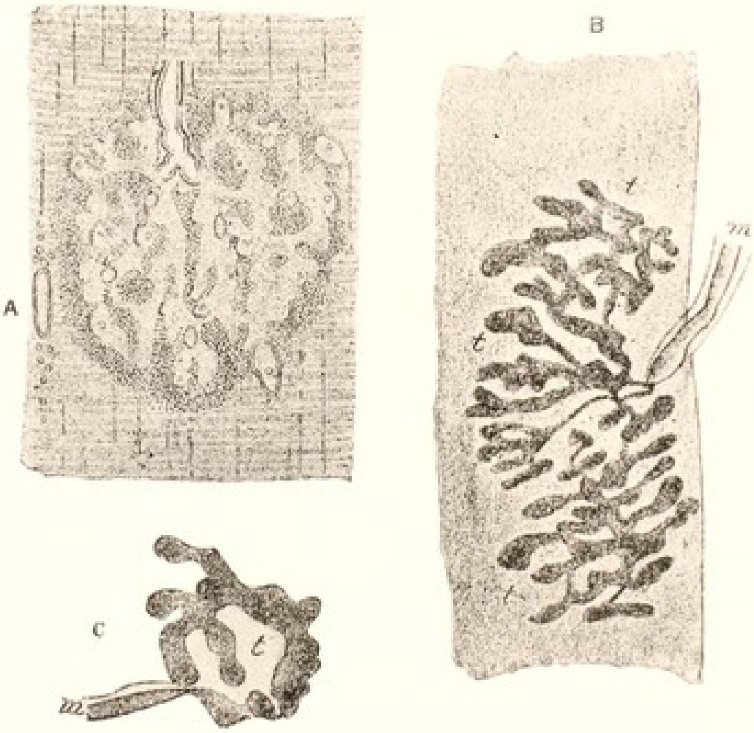


Fig. 22.—Motor nerve ending in a muscle fiber. (Klein.)

If one of the limbs of an animal is severed from its body the muscles in such limb may still be made to contract by stimulating the nerve. The motor fibers in the nerve, when stimulated, convey the message to the muscle fibers and they contract, just as if the message came from the animal's nervous system; with this difference: muscular actions arising in this way are not regulated and controlled so as to be useful. The machinery for muscular control lies within the brain and spinal cord.

SENSORY NEURONES.

The neurones of the sensory system have their cells situated in the so-called "spinal ganglia" on the posterior roots of the spinal nerves (see Figs. 19 and 24). These neurones are of a form utterly unlike the motor neurones. The cells are roughly spherical, without dendrites, and with one axone that shortly divides into two. One of these branches serves as a dendrite; it passes outward along the posterior root to the nerve and then along the nerve to terminate in the skin, muscle, bone, or other tissue, where it has an ending specially adapted to receive stimuli. There are in each individual somewhere from half a million to a million of these sensory neurones, each with an axone extending out to some part of the body. They are to be found everywhere but are most numerous in the skin. Endings near the surface give rise to sensations of taste, touch-temperature, etc., while others in muscles and tendons make us aware of the force of muscular contractions and the positions of the body (Figs. 2 and 23).

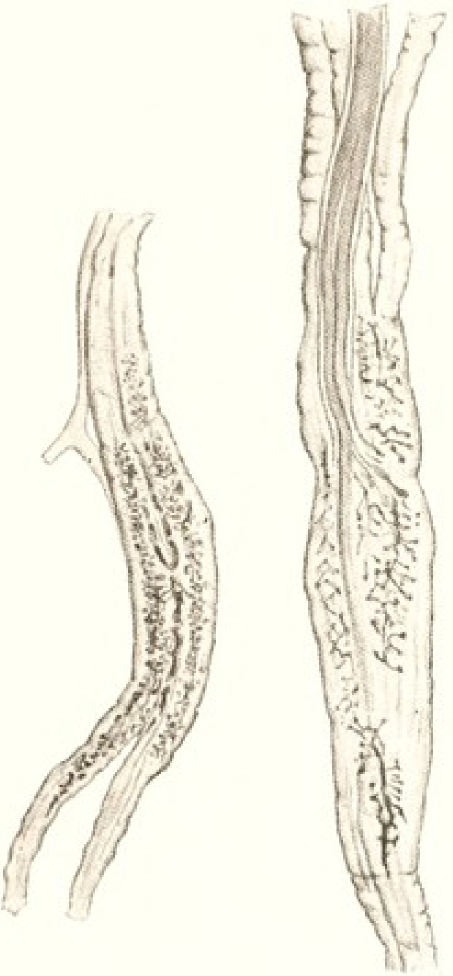


FIG. 23.—Sensory nerve ending in muscle. (Klein.)

The second branch of each sensory axone extends from the cell in the spinal ganglion along the posterior root into the spinal cord, where it penetrates the posterior white column for a short distance and then divides into an ascending and a descending branch. These two branches extend vertically in the posterior white column, giving off at intervals horizontal branches called *collaterals* which penetrate the gray portions of the cord and terminate among the cells and dendrites there (Fig. 24). The ends of these sensory fibers are often brush-like, and they often intertwine with similar brush-like endings of the dendrites of the motor neurones, thus forming what is called a *synapse,* or point of communication between one neurone and another.

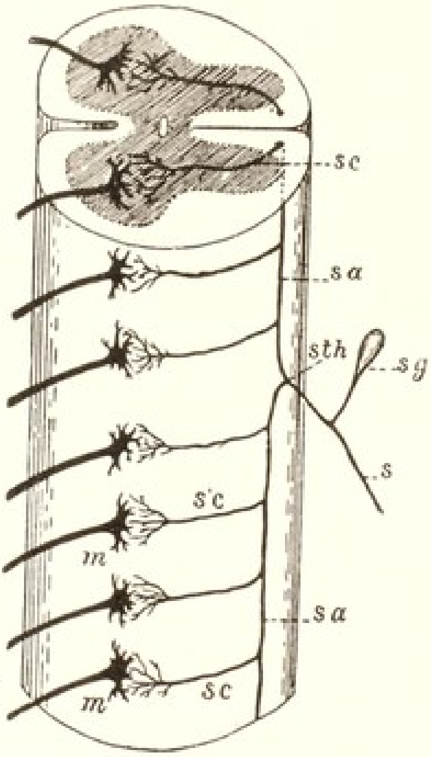


Fig. 24.—A sensory neurone and its branches in the cord. (Kolliker.)

Everyone knows how a light touch upon the hand of a person who is asleep may cause the hand to be moved without awaking the sleeper and without his being aware of it. Such movements, commonly called "reflexes" because the influence of the touch upon the skin seems to be "reflected" back from the central nervous system to the region from which it originated, can be explained only through a knowledge of the nervous mechanism we are just considering. The contact or pressure upon the skin stimulates one or more of the delicate sensory nerve endings in it and as a result a message or "impulse" passes up the corresponding nerve fibers to the spinal ganglion, thence to the spinal cord, up and down the vertical branches of the sensory axone, and along the horizontal branches to the synapses at their ends. The close intertwining of the sensory brush endings with the similar endings of the motor dendrites here makes it possible for the message to pass to the motor neurone, and once started upon the motor path it can only pass out to the muscles and give rise to a contraction. Such a nervous path, including a sensory neurone, a motor neurone, and the synapse that connects them is called a "reflex arc." Since the sensory neurone has two vertical branches and several horizontal branches it is evident that an impulse starting in the skin on a single sensory fiber may and naturally will spread to several motor neurones and thence to a considerable number of muscle fibers.

If instead of touching the sleeping person lightly you hit him a smart blow on the hand, his response is quite different. As everyone knows, he is apt to jump, gasp or cry out and contract practically every muscle in his body, all before he is fully awake or aware of what he is doing. To see how this can take place as a reflex resulting from a stimulus over so small an area, we need to notice how far the branches of the sensory axones extend into the central nervous system. By ingenious methods that we have not room to describe here, it has been shown that these minute nerve fibers, the branches of the sensory axones in the spinal cord, extend up and down the posterior white columns of the cord for various distances. Some of them, and in fact the most of them, extend no farther up or down than the width of one or two vertebræ. This makes the sensory neurones have most intimate connection with the motor neurones of the same district. Some of the vertical branches, comparatively few in number, pass up to the medulla and down to the lower extremity of the cord; others are of intermediate length. These make numerous contacts, by their synapses, with motor neurones controlling the muscle groups of distant parts, making it possible for the sleeping person's foot or his breathing muscles to respond directly to a stimulus given to the skin of the hand. It is an interesting point that no sensory fibers cross the cord from right to left nor from left to right, but, as we have noticed, some of the dendrites of the motor neurones cross the median line, enabling muscles of both sides to receive a stimulus given on only one side.

ASSOCIATION NEURONES.

Association neurones lie wholly within the central nervous system. Their cells are seen in the gray matter of all levels of the spinal cord and brain. They are by far the most numerous class of neurones in man, including a very large percentage of those in the spinal cord and practically all those in the brain. The superiority of man over other animals is due to the more extensive development of this class of neurones. They are best studied in separate groups, of which there are many, each with its peculiarities of form, location, and function.

We have just seen, in the preceding paragraphs and in Fig. 24, how the sensory axones branch in the spinal cord with the apparent purpose of spreading the effect of each sensory stimulus to a wide range of muscles. It is evident, however, that Nature does not consider the mechanism of the sensory branching sufficient for the purpose, for she has provided a group of association neurones to aid in the same way, making still more intimate connection possible between sensory and motor neurones and spreading the incoming messages still wider. These cells are smaller than either the sensory or motor cells; they are located in the gray part of the cord about midway between the anterior and posterior gray columns;

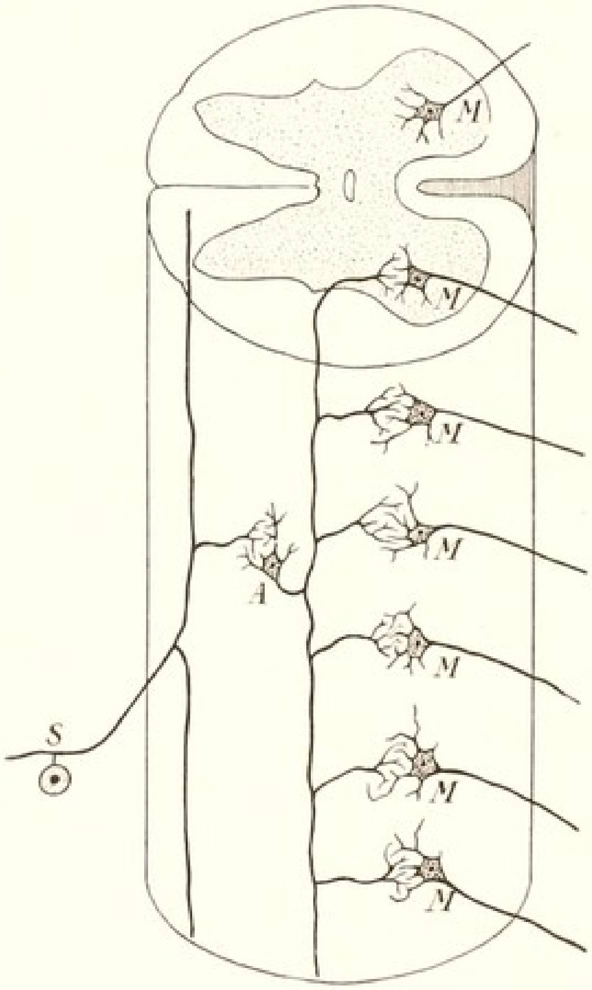


Fig. 25.—An association neurone of the spinal cord: *S*, sensory neurone; *A*, association neurone; *M*, *M*, *M*, motor neurones.

their axones pass out horizontally into the lateral white columns, where they divide into ascending and descending vertical branches like the sensory axones. These, like the sensory fibers, have horizontal branches that penetrate the gray part of the cord at all levels, with synapses connecting them with motor and other cells. About half of the axones of these cells cross to the opposite side of the cord, where they divide and end in like manner, making the most complete and intimate connection between each sensory area and practically all the muscle groups of the body.

Nothing is more familiar than the fact that we quickly become aware of any stimulation of sensory nerve endings in the skin, messages in some way going to the brain to cause our sensations. We have thus far seen a path reaching only up the spinal cord as far as the medulla upon which these sensory messages might go. A second group of association neurones, with cells situated in the medulla, performs the office of carrying the sensory impulses up to the seat of consciousness. They receive their stimuli from the long ascending branches of the sensory axones, with which they have synapses, and their own axones pass up and carry the messages to a higher level. It is likely that another similar "relay station" exists in the midbrain, most of the sensory impulses passing over three neurones in succession before reaching the cortex of the cerebrum, where consciousness resides.

These sensory pathways make possible not only a consciousness of stimuli applied to the skin but also a consciousness of the extent and force of muscular contractions and the positions of the parts of our bodies—the complex sensations commonly known as "muscular sense." The mechanism is the same, except that in place of the sensory endings in the skin we have those more complex and interesting ones found in muscles and tendons (Figs. 2 and 23). The reader can easily observe how fully he can with eyes shut tell the position of arms, legs or trunk or of almost any particular joint as he takes various poses, either standing, sitting, or lying flat.

Besides making us aware of the position of the body and the state of contraction or relaxation of muscles, the mechanism just described performs another and much more important office. When we walk, for example, what is it that controls the raising and replacing of the feet upon the ground in proper time? How does it happen that we repeatedly throw the weight on the forward foot just as it reaches the right place? It is easy to notice that we pay no attention to these things under ordinary conditions, although we do so when we first learn to walk and to a certain extent when the footing is uneven or insecure. The answer is that the sensory impulses that give rise to consciousness of position when we pay attention to it act as a guide to the muscular action when we think of something else. When the foot has been swung forward just far enough the nerve endings in muscles, tendons and joints send messages into the central nervous system that stimulate the muscles needed to perform the next act in the process.

Extended studies of the question lead us to believe that the cerebellum is the portion of the nervous system that serves as organ or center for the control of complex bodily movements. The cerebellum is closely connected by nerve fibers with the semicircular canals in the skull, which serve as the organ of equilibrium, and it also receives many nerve fibers from the body.

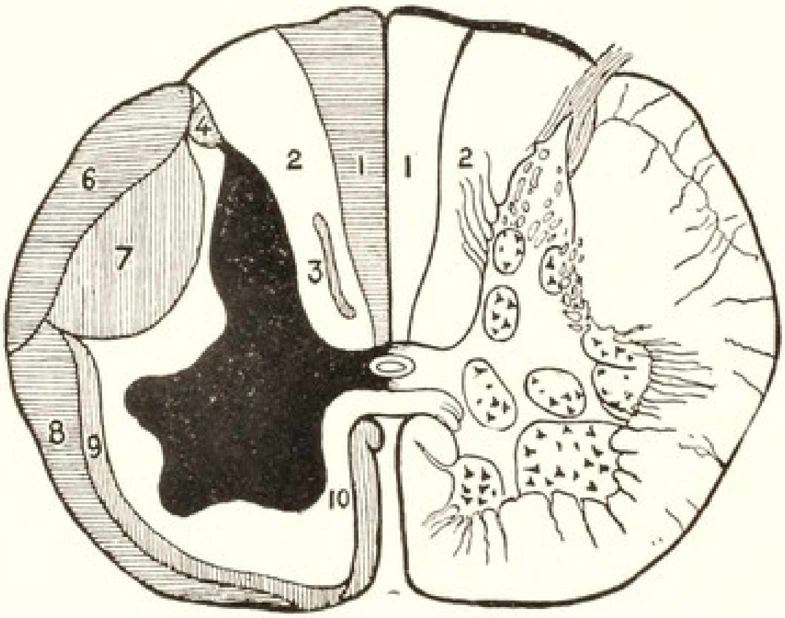


FIG. 26.—Cross-section of spinal cord to show the various columns of cells and fibers: *1*, column of Goll; *2*, column of Burdach; *3*, comma bundle; *6*, direct cerebellar tract; *7*, crossed pyramidal tract; *10*, direct pyramidal tract. (Sherrington.)

Nerve impulses from the body to the cerebellum pass mainly by means of a third group of association neurones whose cells lie in the spinal cord. Just posterior to the center of the gray matter of the cord is a column containing many nerve cells. The place is called "Clarke's column" and the axones of the cells in it form a bundle passing upward to the cerebellum and known as the "direct cerebellar tract." These neurones convey the impulses coming in from the muscular sense endings to the cerebellum, where they guide the activities of that organ in the control of all complete bodily exercises.

The cortex of the cerebrum contains a vast number of association cells whose fibers connect different parts of the cortex and also connect parts of the cortex with the sense organs and with the muscles. The latter group is of special interest to us here. We are all aware that we can move any part of the body at will or prevent any part from moving when we choose to do so. This connection between the will and the muscles is made by means of a group of association neurones known as the "pyramidal cells." They are situated in the cortex of the cerebrum at the top and sides along a prominent infolding or fissure known as the "fissure of Rolando." Their axones pass down through the brain and medulla, crossing from side to side as they pass down, and end at various levels where they make synapses with the dendrites of the motor cells of the cord. This bundle of axones is known in the cord as the "crossed pyramidal tract." A smaller bundle of the same group near the anterior fissure is called the "direct pyramidal tract." The reader should note that the pyramidal fibers do not go directly to the muscles but act upon the motor neurones of the cord, which in turn control the muscles.

STIMULATION AND INHIBITION.

We are accustomed to think of a nerve impulse as a form of energy that can cause a muscle to contract, but in order to secure muscular control and useful movement we must have nerve impulses that can prevent muscles from acting. The former influence is called stimulation and the latter inhibition. Careful observation has shown that whenever a group of muscles contracts normally, other muscles, the antagonists of the former, are made to relax at the same time; vigorous action of the flexors of the arm, for example, is usually accompanied by relaxation of the extensors; and this is not a passive failure to act, but an actual inhibition with less tone than is present in the normal resting state. Such a change is evidently necessary to the most economical use of the muscles, for if in making a movement one had always to overcome the tone of the opposing group, force would be wasted, and this is true especially during excitement, which greatly increases muscular tone. Inhibition is also necessary to the relaxation of rest, for the sensory nerve endings are constantly receiving thousands of stimuli from all kinds of sources, and, as we have seen, any one of these stimuli may spread to all the muscles; if there were no way to prevent reflex movements caused in this way, all the muscles would be stimulated to action all the time and either relaxation and rest or useful movement would be an impossibility.

Something like this happens when one is affected by a very violent stimulus, as when a bee stings him or a gun goes off unexpectedly close to him. He is apt to scream and jump in a spasmodic way, but the movement is not coördinated and accomplishes nothing useful. There is plenty of contraction but no inhibition of contractions that are more harmful than good. A muscular movement that is properly performed is, quite to the contrary, economical, graceful, and useful for a definite purpose.

Sherrington, the greatest authority on this topic, describes an experiment he has performed many times and which illustrates both the importance of inhibition in normal muscular action and the way it is brought about. He uses for the purpose a cat or dog whose brain has been removed and whose muscles are therefore under the influence of the spinal cord and the autonomic neurones. Such an animal exhibits an extraordinary amount of muscular tone, which in itself indicates that the general influence of the brain is to inhibit the tonic action of the muscles. The animal's limbs are quite rigid, requiring considerable external force to flex the joints, and when forcibly flexed they spring into the extended position again as soon as the force is removed. Taking such an animal, he cuts off all the insertions of the flexors of one knee, so that they are not able to exert any force to flex that joint, being careful not to injure the nerves going to the severed muscles. Then he places the animal on its back with its limbs pointing upward, and in this position stimulates by electric shocks the flexors that have had their tendons cut. The point of the experiment is the surprising thing that happens. Although the flexors are not able to flex the joint at all, being cut loose from their attachments, the joint does flex, just as if they were pulling upon it. The explanation is that the stimulation of the muscle and its contraction stimulates the sensory endings in it and a message goes into the spinal cord that causes an inhibition of the tone of the extensors, whose tonic action is holding the joint extended, and as soon as they relax the weight of the limb flexes the joint. As soon as the stimulation ceases the extensors have their tone return and the joint is extended again.

Another experiment performed by Sherrington and by others which indicates the same thing is the stimulation of the pyramidal cells of the cerebral cortex. When such stimulation is mild and applied to an area small enough it gives a coördinated movement involving the contraction of a certain group of muscles and the relaxation of their antagonists. Stimulation of a similar area nearby will reverse the action—relaxing the muscles that contracted before and contracting those that relaxed.

To make it appear how such control can be brought about it is supposed that there are in the formation of synapses two kinds of brush endings—one kind that has the power to stimulate the neighboring neurone to action and another kind that has the power of inhibition. A sensory axone in the cord may, for example, have some collateral branches with stimulating and some with inhibiting endings; in this way it gives rise to coördinated action by stimulating some muscles to action and inhibiting others. The association neurones, those of the cord and the pyramidal group, must, if the theory is correct, have both kinds of endings. The theory has been advanced that a single association neurone of the cord may have developed upon it just the combination of stimulating and inhibiting endings to give rise to a certain definite movement, and thus may constitute a "master neurone" for that movement.

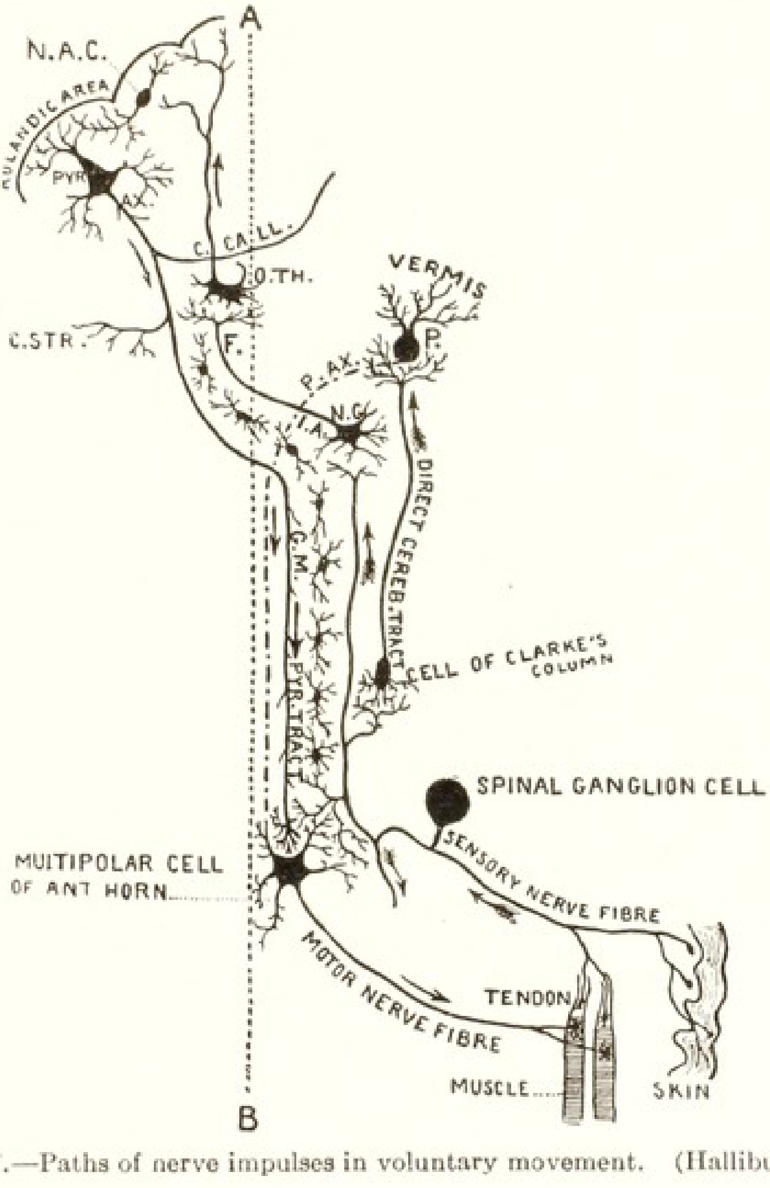


Fig. 27.—Paths of nerve impulses in voluntary movement. (Halliburton.)

NORMAL MUSCULAR CONTROL.

To see how closely all of these facts and theories apply to the most common activities of life, think of what happens when we raise a glass of water to the lips and drink it. No one considers this is a difficult or dangerous feat, yet it requires the use of many muscles, and every one of them must contract and relax with just enough force and at just the right time or a catastrophe will result. First there are the "moving muscles" that raise the arm; they must contract just enough to allow the water to be poured into the mouth rather than on top of the head or inside the collar, and must stop contracting just in time to prevent the glass from striking a smashing blow against the face. Then there are the "guiding muscles," which must contract with a force so related on the two sides as to bring the glass to the lips rather than to the ear or over the shoulder; the muscles that hold the glass at proper level must act so as to tip it at exactly the right time in order to spill no water where it is not wanted; finally, the muscles that control the glottis must close the windpipe at just the right moment and prevent the water from flooding the lungs. In common practice we do all these things without any attention to details. We simply will to drink and the nervous mechanism of coördination does the rest.

The mechanism that performs all these marvellous feats of muscular control is not so complex that we need to pass it by as something beyond our comprehension. It consists simply of motor, sensory and association neurones acting upon one another through their synapses. The muscles are all under the direct and perfect control of the motor neurones, but the latter never stimulate them to action excepting as they are influenced to do so by other neurones. When we will to take a drink of water the pyramidal neurones of the brain cortex, a group of association neurones subject to the influence of the will, send messages down the cord to the motor neurones that control the muscles of the hand and arm to initiate the movement. As the glass is grasped and raised, sensory endings in the skin of the hand and in the muscles and joints of the hand and arm are stimulated by the action. The stimuli thus produced give rise to sensory impulses that pass up the nerves of the arm to the spinal cord, where they influence the motor neurones that are acting to modify their action when the proper time comes and also influence the neurones controlling other muscles to begin to act when they are needed. At all stages of the movement these sensory impulses are acting to guide the muscular contractions of the next stage. Association neurones of the cord undoubtedly aid in spreading the effect of the sensory stimuli to the right motor districts. Just as the pyramidal neurones at the beginning of the act stimulate some motor groups and inhibit others, so the impulses coming in from joints, muscles, skin and eyes influence some muscles to contract and others to relax; each in its turn, and so perfectly guide the execution of the later phases of the movement.

Most of the bodily movements made by everybody in the course of every-day life, such as walking, talking, eating, dressing, and the like, consist of a continuous repetition of comparatively simple reflex acts, like the one we have been considering; the order and time of the different acts are, of course, quite as important as the form of the movements. The nervous mechanism we have just described is evidently just as capable of handling these series of movements as it is of controlling the separate acts. The incoming stimuli from the muscles, joints, and skin must be in evidence all the time to keep the muscles under full control, and stimuli from the eye frequently. Actions involving poise and balance will involve the activity of the cerebellum and the semicircular canals also. There is no apparent reason why the same nervous mechanism is not able to control the more complex activities of gymnasts, ball-players, musicians, and other skilled performers.

The question now arises, how do we acquire the ability to perform new movements? Up to a certain day a child has never tried to walk. A week later he walks everywhere. In a single period of practice one often acquires such an accomplishment as throwing a curved ball, swimming with the scissors kick, doing the twist service in tennis or executing the snake in club swinging. How can one learn in a day or in an hour to do what was impossible for him to do the day before?

Let us notice first just how we go at it to learn a new exercise. First, we watch someone do it and try to get a clear idea of how he does it; we then try to imitate, giving our entire attention to the performance. The first one or two trials are apt to be failures, but by comparing the imitation with the original and repeating the attempt we are apt to improve and soon be able to do the thing to our satisfaction. Right here is where a teacher is of use— to give the learner a clear idea of what is to be done in the first place and then to keep him posted regarding his mistakes as he proceeds. With persistent practice we soon reach the place where attention is no longer necessary, the movement gradually becoming reflex.

To execute a new movement for the first time the pyramidal cells of the brain must come into action. By their use we can move any part of the body at will. The first trial is apt to be a very crude imitation because our idea of the details of the movement is vague and incomplete and hence the attempt to do it, unless we can see a resemblance to some movement we have previously learned, is a step in the dark. We make a movement as nearly as we can like the pattern and then we try to see how it differs; in each voluntary trial it is the pyramidal cells that direct the movement by stimulating certain motor neurones and inhibiting others. By this method of "cut and try" we gradually eliminate the faults and approach the correct performance. The use of the pyramidal neurones to direct the movements is the special feature of this stage of the process.

The new movement gradually becomes reflex as practice continues, which means that the pyramidal cells or "higher level" nerve mechanism is replaced in control by "lower level" mechanisms, those of muscular sense in particular. When we perform an old and familiar movement we can recognize it by muscular sense; that is, we can tell what we are doing by the sensory impressions arising in the joints and muscles. In this way we can tell with our eyes shut whether we are walking or running, whether our arms are swinging alternately or together, and in general we could name any movement we had just made through the knowledge we have of it through the muscular sense. We have seen how these same sensory impulses that give us a sense of position and movement also guide the performance of reflex acts. But there can be no muscular sense of a movement we have never made. Such a sense has to be developed by repeated performance of the movement with the aid of the pyramidal neurones, and when the correct movement has been practised long enough to develop a muscular sense of it, then and not till then can it become a reflex. Much as the eye has to gradually acquire a knowledge of a wholly new scene or object, so the muscular sense gradually comes to recognize a new movement and to be able to control it. Like any other living thing, a nerve ending develops and its function, which in this case is response to stimuli, improves with use. This is why athletes, musicians, and members of some skilled trades and professions can be so marvellously accurate and sure in the muscular acts they practise so many thousands of times.

By guiding the new movement through dozens and perhaps hundreds of repetitions the pyramidal cells cause another important change in the nervous structure—development of the synapses that are most traversed by impulses in the performance of the movement. We can readily see how a more complete development of the fine fibrils of the brush-like endings forming each synapse and a more intimate intertwining of these fibrils together could make it easier for an impulse to be transmitted. By stimulating some synapses to greater activity while inhibiting others, the pyramidal cells promote the growth and development of those that are most active in the new movement, with the result that the path thus blazed is ever after easier for impulses to follow.

PART II.

THE UPPER LIMB.

CHAPTER IV.

MOVEMENTS OF THE SHOULDER GIRDLE.

The shoulder girdle in man consists of two bones, the *clavicle* and the *scapula*. The bones of the arm are joined to the scapula and the clavicle connects the scapula with the main part of the skeleton. The clavicle extends horizontally sidewise and slightly backward from its junction with the top of the sternum and joins the scapula at the tip of the shoulder. The scapula lies on the outer surface of the chest at the back, extending, in normal position, from the level of the second rib to that of the seventh, with its posterior border about 2 inches distant from the spinal column (Fig. 28).

The clavicle, which is about 6 inches long, appears straight when viewed from the front, but when seen from above it is curved like an italic *f*, with the inner end convex to the front and the outer end convex to the rear. The upper surface is smooth and the under surface rough; the inner end is the thicker and the outer end more flattened (Fig. 29).

The scapula is a flat triangular bone with two prominent projections upon it: the *spine* from the rear and the *coracoid* from the front. The spine has a flattened termination called the *acromion*. A deep impression above is named from its position the *supraspinous* fossa, while the shallower one below is called the *infraspinous* fossa. The humerus articulates with a shallow socket at the outer angle, just below the acromion, which is known as the *glenoid* fossa. The greatest length of the scapula in man is from above downward, in the adult about 6 inches; its greatest breadth is horizontal, about 4 inches. This is a marked exception to the general rule in vertebrate animals, most animals having the long axis of the scapula in line with its spine, so that the glenoid fossa is at the end of the scapula instead of at the side.

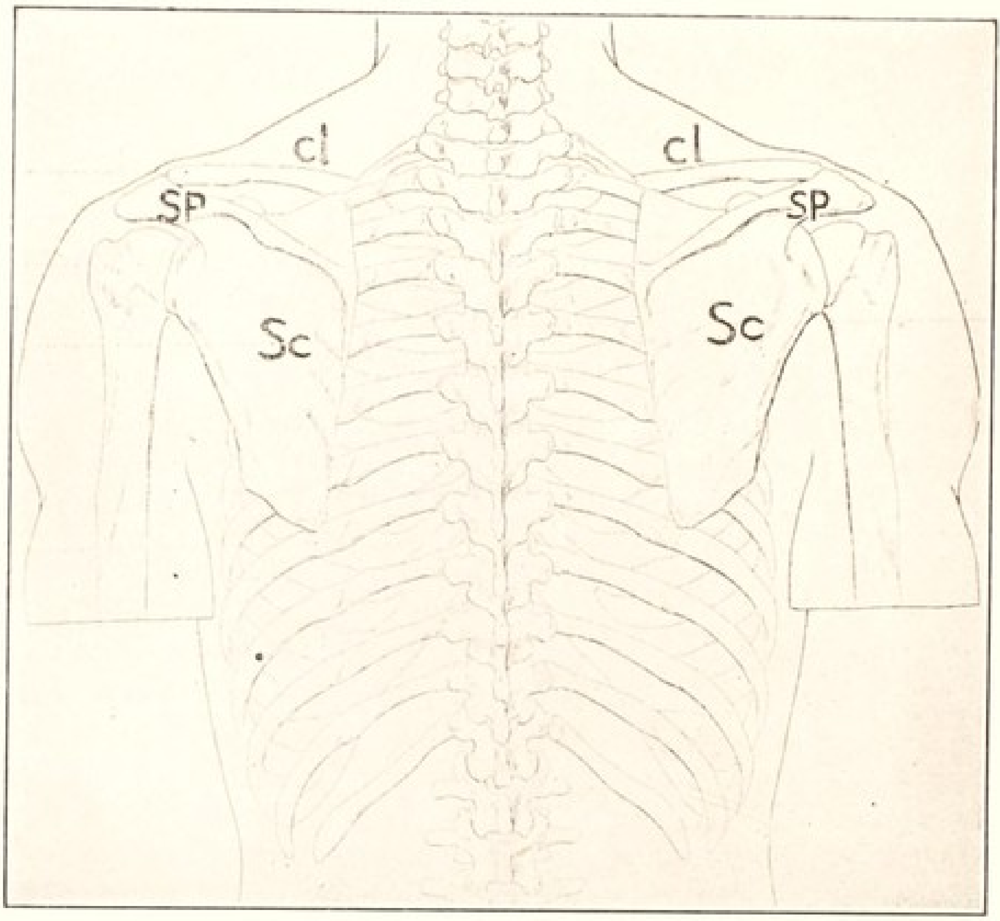


FIG. 28.—The shoulder girdle, rear view: *Sc*, scapula; *cl*, clavicle; *Sp*, spine of scapula. (Richer.)

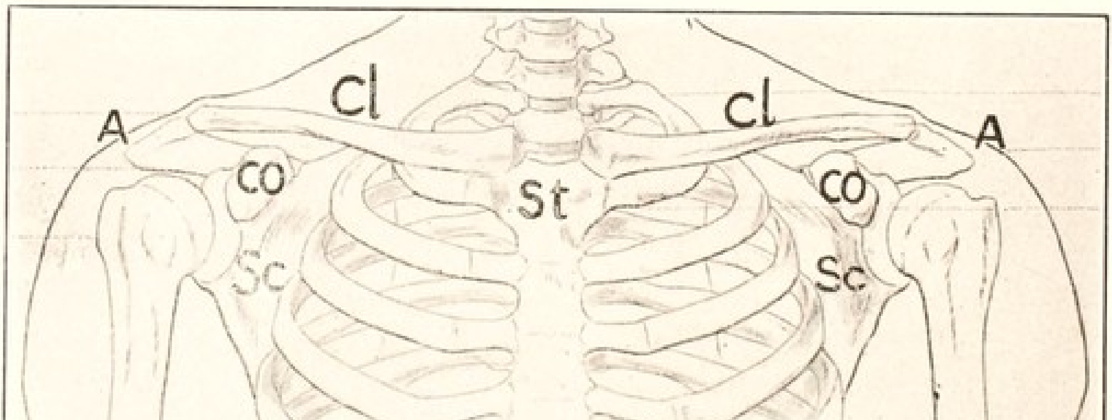


FIG. 29.—Shoulder girdle, front view: *Sc*, scapula; *cl*, clavicle; *co*, coracoid; *A*, acromion; *st*, sternum. (Richer.)

The clavicle is joined to the sternum by a double joint, the two bones being separated by a cartilage, with one articulation between the sternum and the cartilage and another between the cartilage and the clavicle. The cartilage serves as an elastic buffer in case of shocks received at the arm or shoulder, and the joint permits the outer end of the clavicle to be moved up and down, forward and backward, or any combination of these movements; it also permits slight rotation of the clavicle on its long axis. The capsular ligament of the joint is strengthened by thickened bands at the front and rear; injury of the joint is further prevented by a ligament, called *intraclavicular,* which joins the two clavicles, and by a ligament called the *costoclavicular,* which connects the under surface of each clavicle with the rib below it.

The outer end of the clavicle is joined to the anterior border of the acromion by a joint permitting considerable movement in various directions. The capsular ligament is strengthened on the upper side, but the main protection against injury to the joint is the *coracoclavicular* ligament, a strong band of fibers connecting the top of the coracoid with the under surface of the clavicle.

All movements of the shoulder girdle may be properly called movements of the scapula, since the position of the clavicle does not permit of its moving independently. These movements always involve both of the joints just described, the clavicle moving so as to allow the scapula to assume its proper relation to the chest wall.

The movements of the scapulamay be classified as follows:

1. Backward toward the spinal column (adduction) and sideward and forward away from it (abduction); this movement may extend through 6 inches or more, being limited posteriorly by contact of the two scapulæ at the median line and anteriorly by the resistance of the posterior muscles.

2. Upward movement of the entire scapula (elevation) and downward (depression); this may take place through four or five inches.

3. Rotation on a center so as to raise the acromion and turn the glenoid fossa upward (rotation up) and the reverse (rotation down), which may take place through an angle of 60 degrees or more. Rotation of the scapula is associated with all upward and downward movements of the arm.

Since the clavicle is attached to the sternum, which is comparatively stationary, it is evident that the acromion must always move in a curve with the clavicle as a radius. Since the clavicles are horizontal in normal position, any movement involving raising or lowering of the acromion will therefore narrow the distance between the two shoulders. Since the clavicles normally slant backward somewhat, evidently all adduction of the scapula will narrow the shoulders, and abduction will widen them until the two clavicles fall in one line, after which further abduction will narrow them again. The action of the clavicle will also cause the acromion to go toward the rear as the scapula is moved toward the spinal column.

The following six muscles connect the shoulder girdle with the main skeleton, hold it in normal position, and give rise to the movements just described. In preparation for the study of such movements as lifting, throwing, pushing, striking, etc., which involve both arm and shoulder girdle, it is well to make a careful study of the individual actions of these muscles.

TRAPEZIUS.

The trapezius muscle is a flat sheet of muscular fibers located on the upper part of the back and lying immediately beneath the skin.

Origin.—Base of the skull, ligament of the neck, and the row of spinous processes of the vertebræ from the seventh cervical to the twelfth dorsal inclusive (Fig. 30).

Insertion.—Along a curved line following the outer third of the posterior border of the clavicle, the top of the acromion, and the upper border of the spine of the scapula (Figs. 208 and 210).

Structure.—Best studied in four parts, passing from above downward.

Part one is a thin sheet of parallel fibers starting downward from the base of the skull and then curving somewhat sideward and forward around the neck to the insertion on the clavicle. It is so thin and elastic that when it is relaxed one or two finger-tips can be pushed down behind the outer third of the clavicle with ease, stretching the muscle before it and forming a small pocket; when it contracts the fingers are lifted out and the pocket disappears. This enables us to test the action of part one of the trapezius, which is too thin to be seen and felt in the usual way.

Part two, extending from the ligament of the neck to the acromion, is a much thicker and stronger sheet of fibers, tendinous at the origin and converging to the narrower insertion.

Part three is similar to part two and still stronger, and includes the fibers that arise from the seventh cervical and the upper three dorsal vertebræ; these converge somewhat to the insertion on the spine of the scapula.

Part four, the lowest, is not so strong as the two middle portions, but stronger than the first; the fibers converge from their origin on the lower dorsal vertebræ to join a short tendon attached to the small triangular space where the spine of the scapula ends, near the vertebral border.

Action.—A reader who has no anatomical material at hand can get an idea of some of the conditions under which the muscles work by study of Fig. 30 and others similar to it, but observation of a well-mounted skeleton and a living model are necessary to the best work.

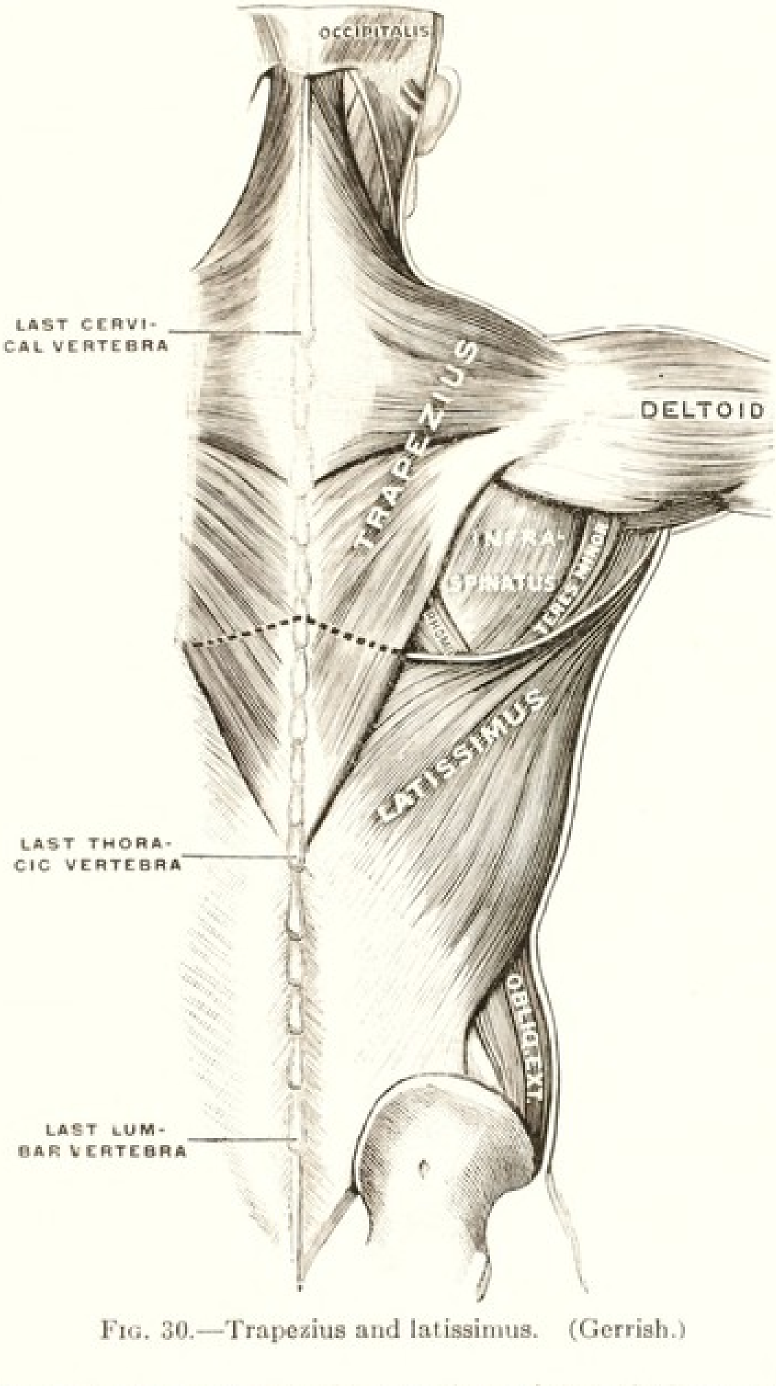


Fig. 30.—Trapezius and latissimus. (Gerrish.)

It can readily be seen by observation of the skeleton that when the head is free to move, contraction of part one of the trapezius will lower the back of the skull and turn it to the side; since the skull is poised freely on a pivot at its base, this will tilt the chin up and turn the face to the opposite side. When part one of right and left sides contract at once, evidently they will neutralize the tendency to rotate the head and will tilt the chin up with double force.

With the head held still and the shoulder girdle free to move, contraction of this portion will evidently lift the clavicle and scapula, but with little force, because the muscle is thin and weak.

Action of part two will pull upward and inward, swinging the acromion on the sternal end of the clavicle as a center, and drawing it slightly backward or forward, depending on the position of neck and shoulder at the start.

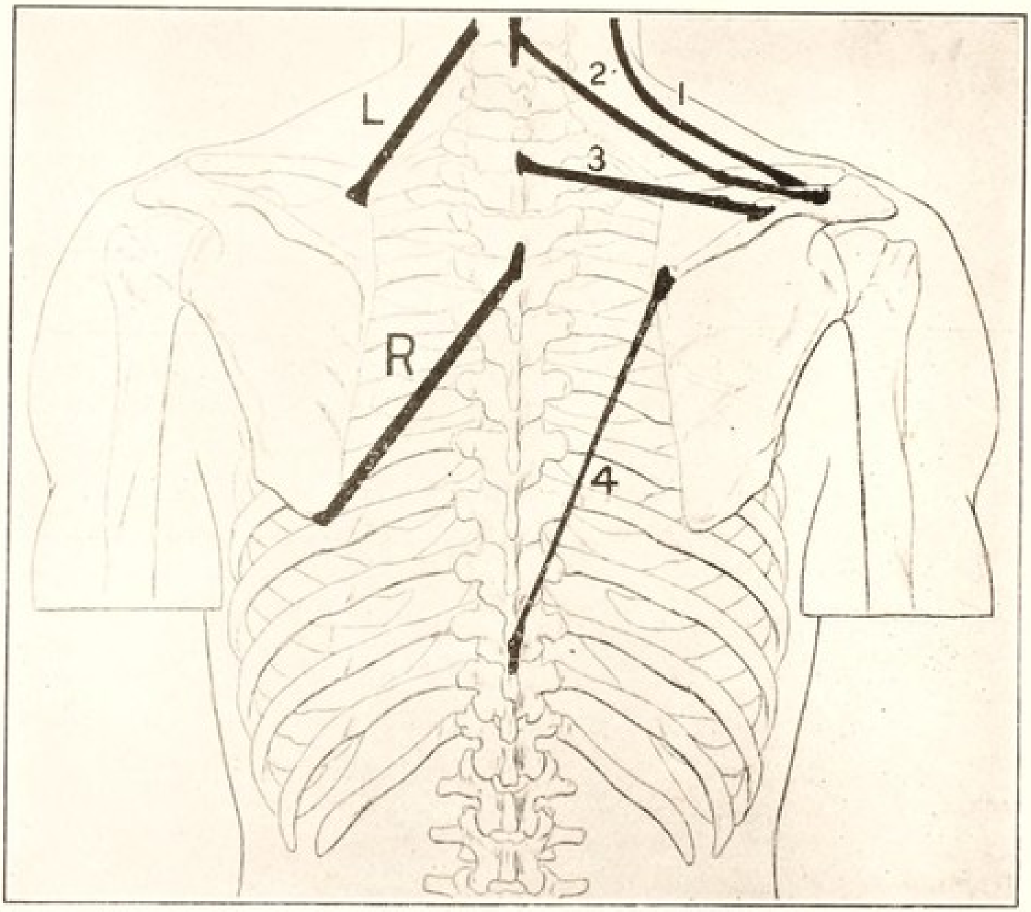


FIG. 31.—The direction of pull of the four parts of the trapezius on the right and of the levator and rhomboid on the left: *L*, levator; *R*, rhomboid.

Part three pulls in nearly a horizontal line upon the spine of the scapula, drawing it toward the spinal column; the posterior edge of the scapula will glide along the chest, while the swing of the clavicle will throw the acromion backward as the scapula is adducted.

Part four pulls so as to draw the vertebral border of the scapula downward and slightly inward, the lower fibers pulling more directly downward.

When all the parts of the trapezius contract at once it is important to notice that they act upon the upper rather than the lower portion of the scapula; since they at the same time lift the acromion, adduct the spine, and depress the vertebral border, they must by their combined action rotate the bone so as to turn the glenoid fossa upward rather than to move the whole bone any considerable distance in any direction.

The study of cases in which the use of the trapezius has been lost by paralysis or atrophy verifies the conclusions we have reached as to its action. Fig. 32 shows how the trapezius rotates the scapula, as can be observed by comparing its position on the two sides; the left side, where the muscle is sound, showing upward rotation while the right side shows the opposite. Fig. 33 shows how the trapezius influences the posture of the scapula when the muscles are only holding the body in habitual posture. Here the right trapezius is missing, and the reader will notice how far the scapula, especially the upper part of it, is out of normal position because of its absence; the left side, which is normal, shows correct position for comparison. Such studies, extended over hundreds of cases, have led to the conclusion that it is mainly the third and fourth parts of the trapezius that are responsible for holding the scapula back toward the spinal column and mainly the second part that keeps it up to normal height; this is especially true in unconscious habitual posture.

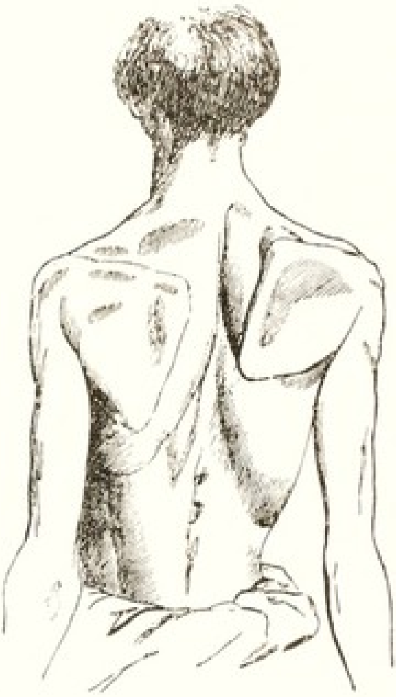


FIG. 32.—Subject lacking right trapezius, trying to hold shoulders well back. (Duchenne.)

The stimulation of the trapezius by electric current also verifies our conclusions as to its action. Stimulation of part one or part two gives lifting of the shoulder; stimulation of part three gives adduction with narrowing and carrying the acromion to the rear; stimulation of part four gives depression of the vertebral border with slight adduction; stimulation of all at once give slight elevation but especially rotation upward. The amount of upward rotation produced by the trapezius is small—not more than 15 to 20 degrees. The much greater rotation readily seen in raising the arm up by the head leads us to infer that other muscles can produce the same movement to a greater extent. The two middle parts of the trapezius, its thickest and strongest portion, are admirably fitted to anchor the upper end of the scapula firmly to the spinal column, so that if the lower angle were drawn forward, extensive upward rotation would be produced. The reader will be interested to watch this point as our study progresses.

Since the trapezius lies immediately beneath the skin it is comparatively easy to test its action in various movements by observing the thickening and hardening of its fibers during contraction. As shown in Fig. 34 the lower three parts show this effect plainly, the upper part indistinctly. The upper part of the trapezius illustrates well why it is necessary to study the muscles on the living model.

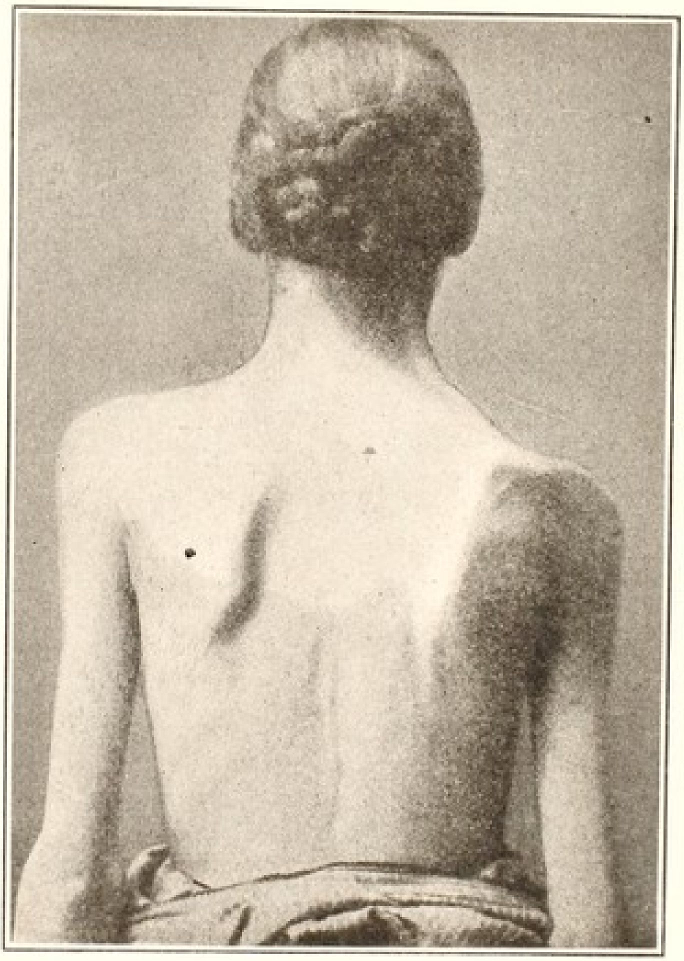


FIG. 33.—Abnormal posture of right scapula due to loss of the right trapezius. (Mollier.)

We have noticed that the first part of the trapezius is admirably situated for lifting the shoulders, and that when it is stimulated by electric current it does so promptly. When we shrug the shoulders, therefore, it is natural to infer that it aids in the movement, but observation of the kind we are considering now shows that it does nothing of the kind, remaining in complete relaxation while the movement is being performed.

To prove this we need only to press the tips of two fingers down behind the outer third of the clavicle and then, while they are there, to shrug the shoulders. The first part of the trapezius not only fails to lift the fingers out from behind the clavicle but we can remove the fingers, while the shoulders are lifted, and see the deep pocket remaining there. To notice how actual contraction of the muscle affects it, raise the arm sideward above the level of the shoulder and see how quickly the fingers are lifted out and the pocket obliterated. If the shrugging of the shoulders is done strongly, against a resistance, the first part of the trapezius acts in some subjects, but not in all; the same is true in taking the deepest possible breath.

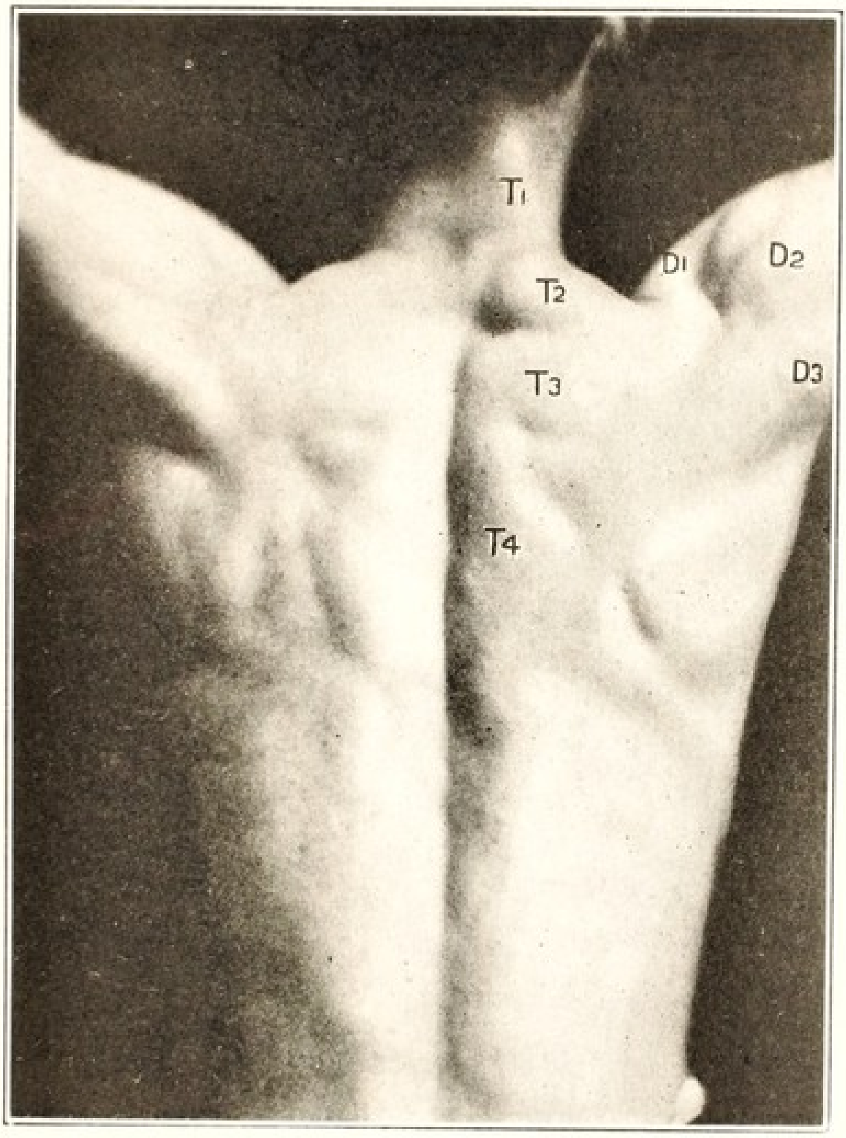


FIG. 34.—The trapezius in action. *T*, trapezius; *D*, deltoid.

The reader should not infer from this illustration that a study of what a muscle *can* do is no indication of what it *will* do, for in the great majority of cases all the muscles so situated as to be able to help in an exercise do so. There are, however, enough instances like this one to show that in the nervous control of the muscles in bodily exercise it is always necessary to supplement the study of what a muscle might do by noticing what it actually does. These exceptions to the principle of economy, which is plainly violated when a muscle that can help perform a movement is left idle while it is being made, suggest inquiry as to why such exceptions occur.

The nervous mechanism by which we coördinate bodily movements is, like the muscular system, inherited from ancestors, how far back we do not know. Possibly the first part of the trapezius is a group of fibers acquired more recently than others. If, as some scientists believe, man descended from a vertebrate that stood in the horizontal posture and only acquired the upright posture afterward, the present habitual posture of man may call for the use of some muscles not needed at the time the movement was developed in the nervous system; some cases will be noted as we progress that are possible to be explained in this way.

Another peculiarity in the action of the trapezius that should be noticed through this kind of study is the effect of the posture of the trunk on the action of parts two and three. When the shoulder is lifted as high as possible or when a weight is held on the shoulder, the subject standing erect, part two contracts strongly and part three slightly if at all; if he does the same thing in a stooping posture, as when one lifts a pail of water from the ground, parts two, three, and four all act at once, and the lower parts relax as the erect position is reached. Here the action meets the need exactly, and the person unconsciously brings into action the adducting and the elevating portions when they can do the most good.

All parts of the trapezius come into action at the same time in raising the arms sideward, and especially in raising them above the shoulder level, as shown in the above figure. No other bodily movements seem to employ the whole trapezius at once.

LEVATOR.

This is a small muscle on the back and side of the neck beneath the first part of the trapezius (Fig. 35).

Origin.—The transverse processes of the upper four or five cervical vertebræ.

Insertion.—The vertebral border of the scapula, from the spine to the superior angle. (Fig. 210).

Structure.—A thick band of parallel fibers, tendinous near the origin.

Action.—If the line (see Fig. 31) indicating the direction of pull of the levator is extended across the scapula it is seen to pass very nearly through the center of the bone, and therefore the levator appears to be so situated as to draw the scapula upward and inward as a whole rather than to rotate it. When, however, the levator is stimulated by electricity it lifts the vertebral edge of the scapula first and then moves the bone as a whole, giving a combination of elevation and downward rotation. This is explained by the fact

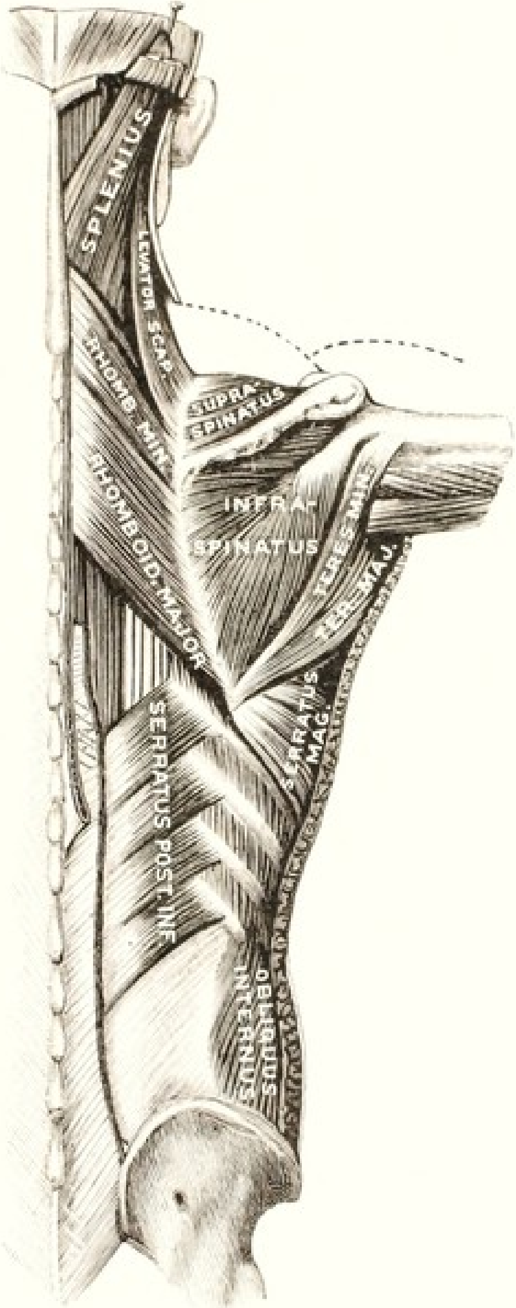


Fig. 35.—Muscles of second layer of the back and those on the back of the shoulder. (Gerrish.)

that the arm weighs down the acromial side of the scapula, and many muscles joining arm, scapula, and clavicle on that side add their resistance to any elevation, while the vertebral border is more free to move. Study of the living model shows that the levator and the second or acromial portion of the trapezius do the work in shrugging the shoulders and lifting or carrying weights in the hand or on the shoulder, as in case of a hod-carrier, postman, or ice man. The levator can be felt through the upper trapezius, and on a favorable subject one can observe that part two of the trapezius acts alone when a weight is held in the hand unless the shoulder is lifted; but as soon as the shoulder is raised by the slightest amount the levator springs instantly into action. This observation is made all the more interesting by beginning the movement in stooping posture and noting the shifting action of the muscles as the body is raised to the erect position.

The levator is an important support to the scapula in habitual posture, aiding the second part of the trapezius in holding it up to normal level. Subjects who have lost the use of the levator have the shoulder depressed, the deformity being most marked when both levator and second part of the trapezius are lacking. Loss of these two main supports gives rise to the type of thin neck and sloping shoulders that is known as "bottle neck."

RHOMBOID.

The rhomboid is named from its shape, that of an oblique parallelogram. It lies beneath the middle of the trapezius (Fig. 35).

Origin.—The row of spinous processes of the vertebræ, from the seventh cervical to the fifth dorsal inclusive.

Insertion.—The vertebral border of the scapula, from the spine to the inferior angle (Fig. 210).

Structure.—Parallel fibers extending diagonally downward and sideward from the origin. The upper part, usually separate from the lower and described separately as the "rhomboideus minor," is thin and weak, while the lower part is thick and strong. The attachment to the scapula is peculiar, the fibers joining a tendon of insertion that is scarcely attached to the scapula at all for its upper two-thirds; sometimes the middle half is entirely free from the edge of the scapula, bringing the pull to bear on the lower angle alone.

Action.—The structure of the rhomboid and its manner of insertion gives it a line of pull as shown in Fig. 31, considerably different from what is suggested by its general location and appearance. Figs. 32 and 36, from Duchenne, show how it adducts the lower angle of the scapula without adducting the upper angle at all, and so rotates the scapula strongly downward. Fig. 32, where the right trapezius is lacking, shows the combined action of the rhomboid and latissimus on the right side. The glenoid fossa is turned to face considerable downward, and Duchenne states that while the rhomboid is in contraction the subject cannot raise the arm above the level of the shoulder.

The part played by the rhomboid in maintaining normal posture, as shown by defective cases, consists in moderating the upward rotation of the scapula produced by the trapezius, so as to keep the acromion down and in holding the lower angle close to the ribs. Subjects who have lost the use of the rhomboid have this angle of the scapula projecting conspicuously from the back, with a deep gutter beneath its edge—a position due to the pull of muscles that attach to the upper part of the bone.

The rhomboid acts powerfully in all downward movements of the arms, such as chopping with an ax, striking with a hammer, pulling down on a rope, and rowing.

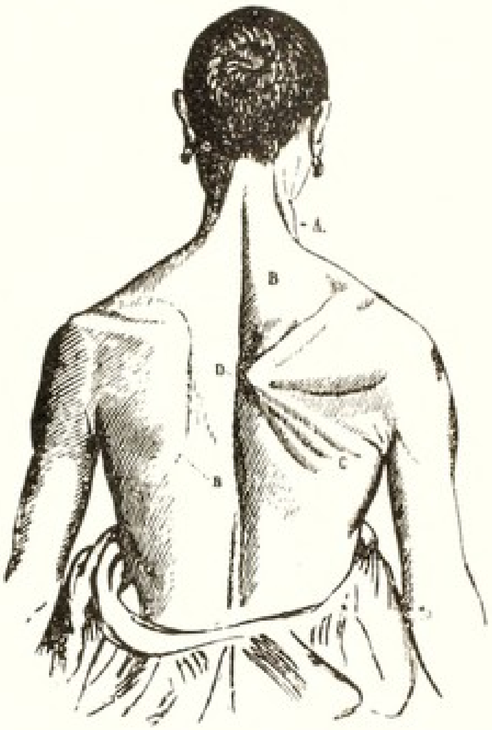


Fig. 36.—Isolated action of the rhomboid. The right rhomboid is contracted while the left is relaxed. (Duchenne.)

SERRATUS MAGNUS.

This muscle, named from its serrated or saw-toothed anterior edge, lies on the outer surface of the ribs at the side, covered by the scapula at the rear and the pectoralis major in front. It lies immediately beneath the skin for a space a little larger than the hand just below the axilla or armpit, its five lower sections showing plainly through the skin when the arm is raised against resistance, as in Fig, 39.

Origin.—The outer surfaces of the upper nine ribs at the side of the chest.

Insertion.—The vertebral border of the scapula, from the upper to the lower angle (Figs. 37 and 209).

Structure.—In two separate parts, the upper and lower. The upper part includes the fibers arising from the three upper ribs and diverging slightly to be inserted along the whole length of the scapula below the spine; the lower part is fan-shaped, the fibers arising from the lower six attachments on the ribs converging to be inserted together at the inferior angle. The lower part is thicker and stronger than the upper.

Action.—The fibers of the serratus extend too nearly lengthwise of the ribs to exert much pull to move them unless the scapula is raised. Its upper fibers are well situated for drawing the scapula forward as a whole, without rotation. As this motion takes place through the 5 or 6 inches of its extent, the swing of the clavicle on the sternum will evidently cause the acromion to move outward slightly and then inward, the two shoulders approaching each other

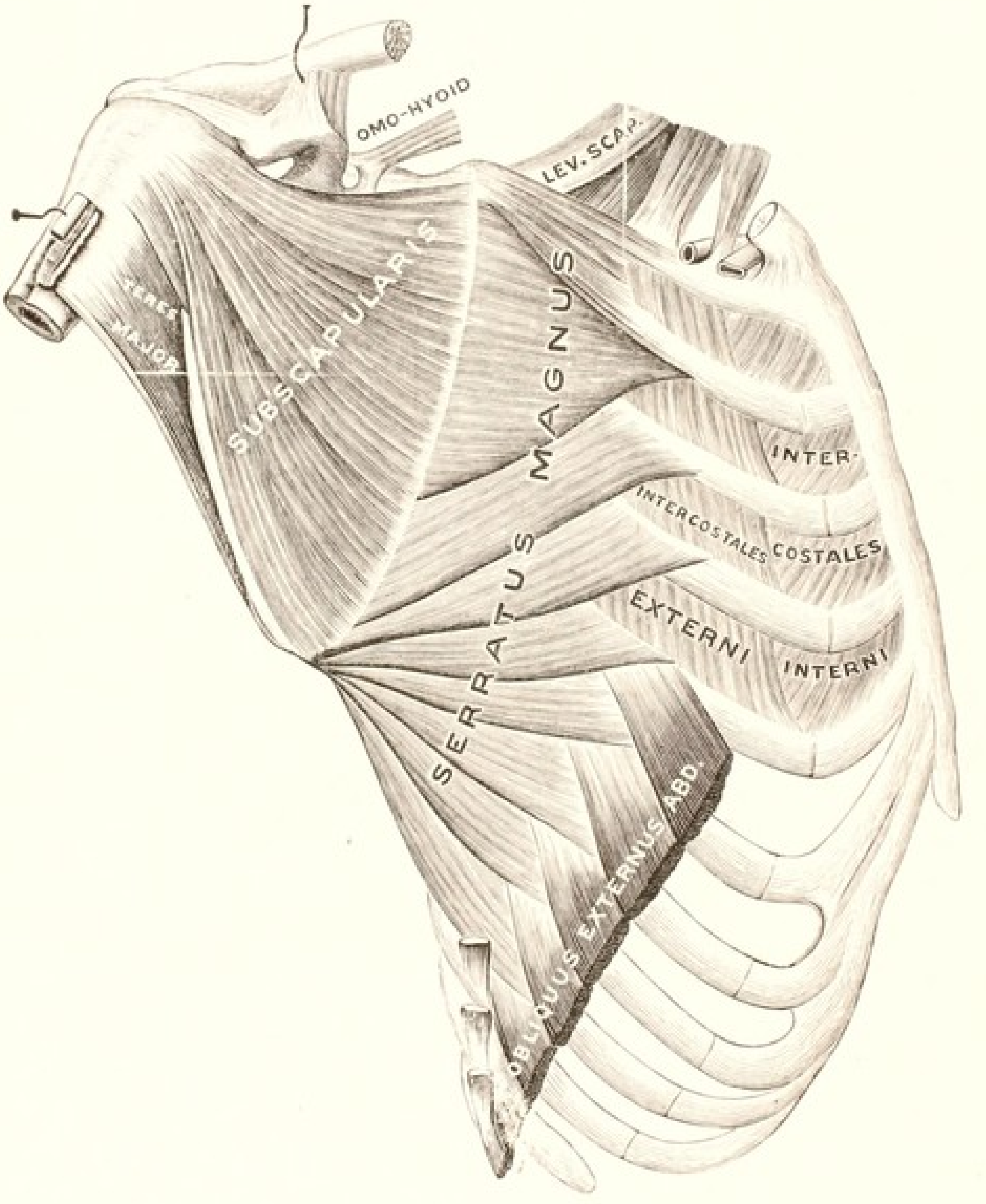


FIG. 37.—Serratus magnus, subscapularis and teres major. Notice that the clavicle is cut apart and the scapula turned back away from the chest wall. (Gerrish.)

rapidly as the clavicles come forward to the farthest possible point. The lower part of the muscle is in a position to produce vigorous rotation upward by drawing the inferior angle of the scapula forward. Notice how well these lower fibers are placed to associate with the trapezius in turning the glenoid fossa upward.

Stimulation of the serratus magnus verifies these conclusions, and study of defective cases also supports them. Loss of the serratus has little effect on habitual posture of the scapula, but it interferes seriously with forward movements of the shoulder and arm. Subjects lacking the serratus cannot lift the arm higher than the shoulder, and when they try to do so the vertebral border of the scapula projects backward instead of lying close to the chest wall, as it does when the serratus acts normally in the movement. Fig. 38 shows the deformity occurring in such cases, the normal left side contrasting with the right, where the serratus is lacking.

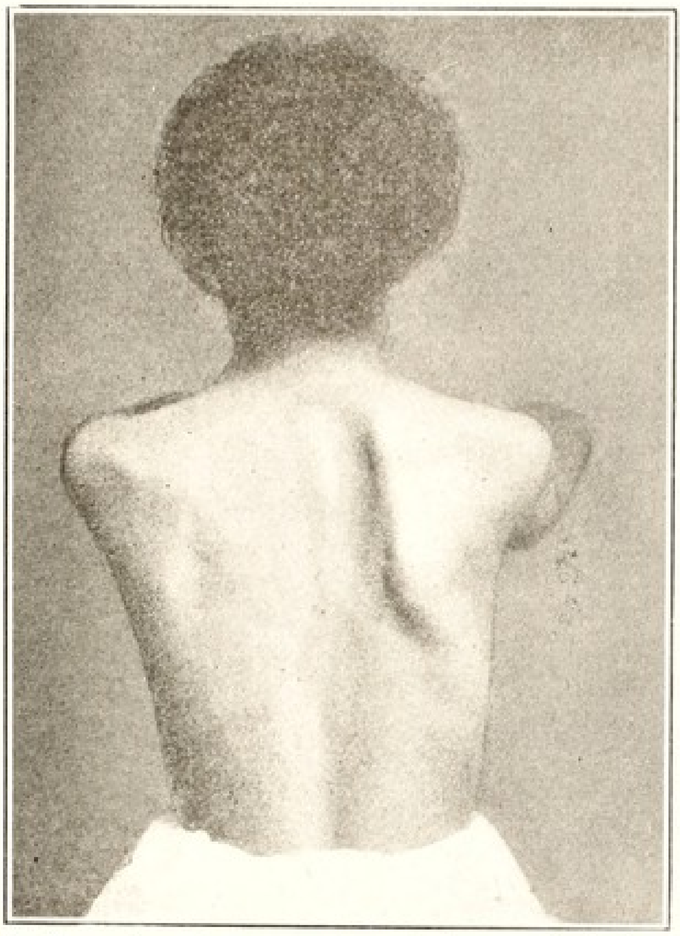


Fig. 38.—Effect of loss of serratus on posture of the scapula during elevation of the arms. Left side normal. (Mollier.)

Study of the serratus on the normal living body shows its action in a very clear and interesting way. Whenever the subject pushes or reaches forward the scapula can be seen and felt to glide forward over the surface of the chest, and the distance it moves is surprising to all who have not observed it before. (See Figs. 39 and 74.) When the arms are raised the trapezius can be felt to contract as soon as they begin to move, but one can also see that this contraction does not rotate the scapula; the lower serratus does not begin to contract until the arms have been raised through at least 20 degrees and sometimes through 45 degrees. This can be tested by placing the fingers on the lower angle of the scapula and noticing when it begins to move forward. Why the nervous system, in controlling the muscles in this movement, should leave the lower serratus idle at the beginning is a puzzling question, but it persists in doing

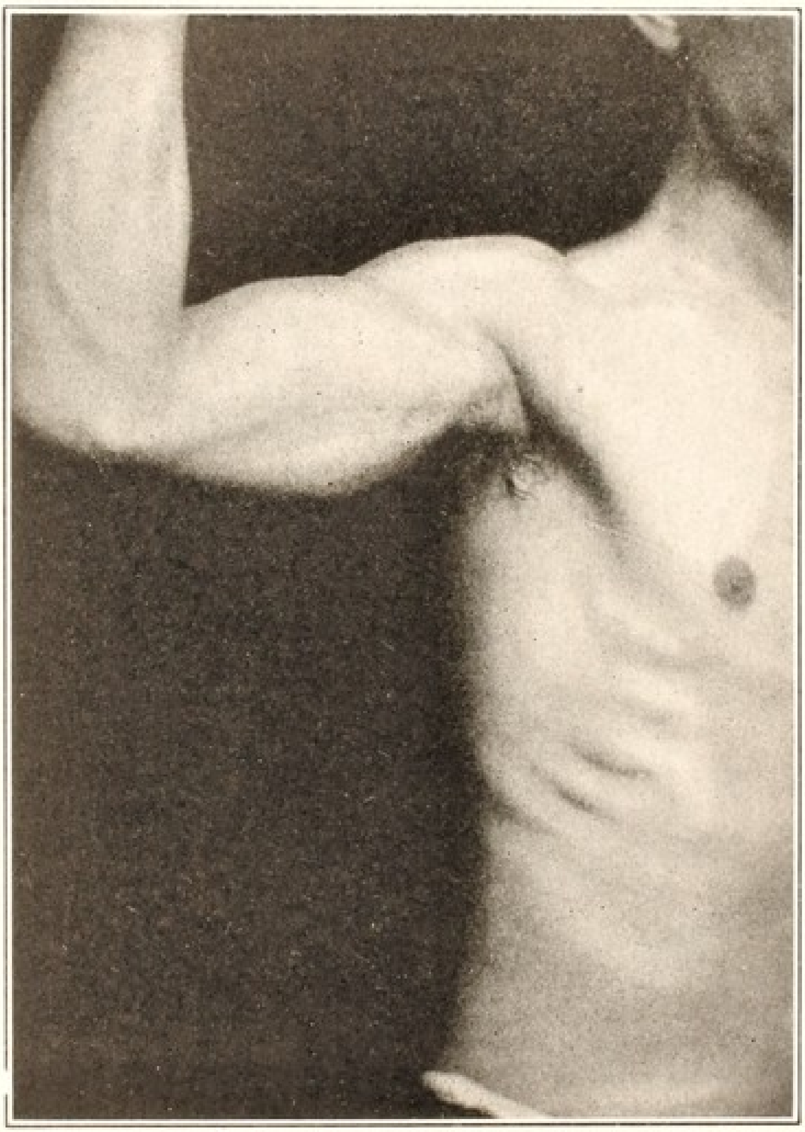


Fig. 39.—The lower part of the serratus magnus in action. The saw-toothed shape of its lower front margin is shown plainly where it attaches to the ribs. Only five saw teeth show, the upper ones lying beneath the pectoralis major.

so in all subjects, even when the rotation of the scapula is made especially difficult by loss of the trapezius.

Another interesting case in which the lower serratus fails to act when it would be of use is when a weight is lifted or carried on the shoulder. Although the lower serratus can lift the acromion with great force, as we have seen, it never acts in lifting with the shoulder or carrying a heavy weight on it, the work in this case being done by the middle trapezius and levator so long as the arm hangs at the side. As soon as the arm is raised 30 degrees or more from the side it at once springs into action. This shows a reason why one who carries a heavy weight on the shoulder finds it restful to hold the arm in various positions—sometimes down by the side and sometimes raised.

PECTORALIS MINOR.

A small muscle located on the front of the upper chest, covered by the pectoralis major.

Origin.—The outer surfaces of the third, fourth and fifth ribs at a point a little sideward from their junction with the costal cartilages (Fig. 40).

Insertion.—The end of the coracoid.

Structure.—Three groups of nearly parallel fibers that converge to join a single small tendon at the upper end.

Action.—The line of pull of the pectoralis minor may be represented on a mounted skeleton by a rubber band stretched from the coracoid to the fourth rib at a point about an inch from its junction with the costal cartilage. When the scapula is in normal position the direction of pull on the coracoid will be seen to be forward, downward and inward at nearly equal angles. The inward pull is prevented from acting on the scapula by the position of the clavicle, so that contraction of the muscle is calculated to produce a combination of abduction and downward rotation of the scapula. It can also be seen that the pull of the pectoralis minor, by prying across the chest, tends to lift the posterior edge and especially the lower angle of the scapula away from the ribs.

When the scapula is held still it is evident that action of this muscle will lift on the middle ribs, especially when the shoulder is raised in preparation for it, as one unconsciously does in taking a deep breath.

While normally the pectoralis minor is deeply covered, Duchenne reports cases in which, because of complete atrophy of the pectoralis major, it lay immediately under the skin and could be stimulated by electric current. The isolated action secured in this way is the same as that stated above. It is possible in favorable subjects to feel the contraction of the pectoralis minor through the muscle that covers it by proceeding as follows: have the subject hold the arms close to the sides and a little to the rear, which inhibits any action of the pectoralis major; then have him inhale deeply, first lifting the shoulders slightly. This puts the pectoralis minor into vigorous action and its lateral swelling may be felt and even seen as it lifts the relaxed tissue covering it.

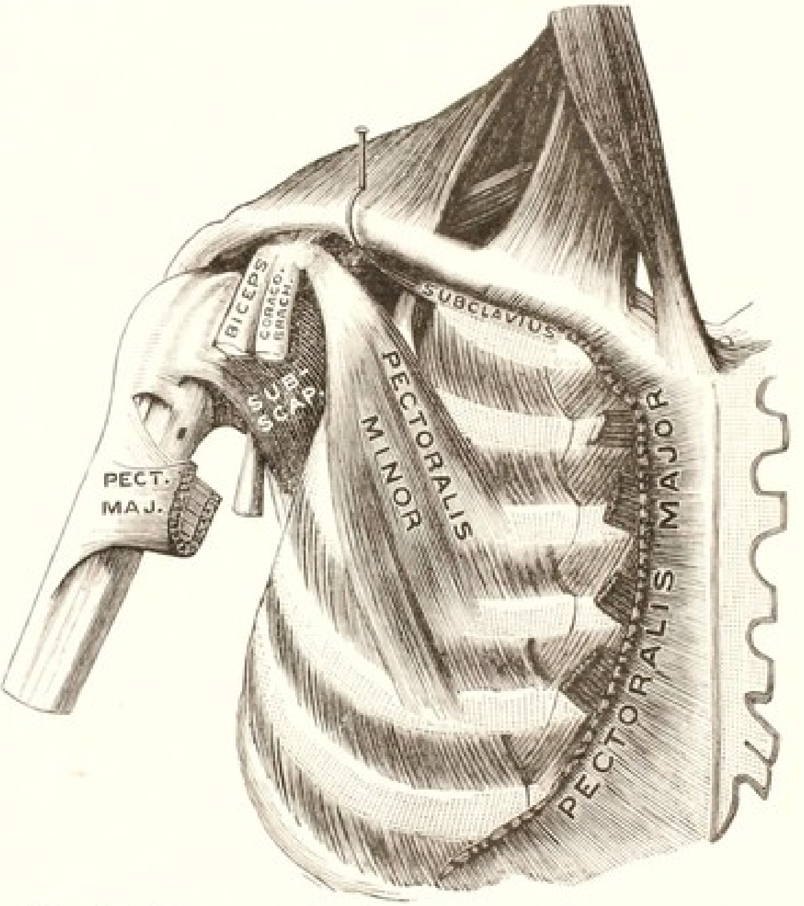


FIG. 40.—The pectoralis minor and subclavius. (Gerrish.)

To summarize, it may be said that the pectoralis minor acts in deep and forced breathing, but probably not in quiet breathing; it is placed in a position to help in all movements involving abduction and downward rotation of the scapula, which occurs in striking forward and downward as in chopping and also in supporting a part of the body weight on the arms. In most of these cases actual test of its action is rendered impossible because of the contraction of the large muscle covering it.

SUBCLAVIUS.

The smallest of this group of muscles; located, as its name indicates, beneath the clavicle.

Origin.—The upper surface of the first rib, just where it joins its cartilage.

Insertion.—A groove extending along the middle half of the under side of the clavicle.

Structure.—Fibers radiating fanwise from the small tendon of origin to the much wider insertion.

Action.—The action of the subclavius can only be inferred from its position, as it is not readily felt nor stimulated from without. It is in a position to depress the clavicle, and the long outward slant of its fibers makes it also draw inward, lengthwise of the clavicle—a pull that can serve to protect and strengthen its joint with the sternum in such movements as hanging by the hands, where the weight of the body tends to pull the shoulder girdle from the main part of the skeleton.

POSTURE OF THE SHOULDERS.

The shoulder girdle is so freely movable that its habitual position depends on the relative tension of the six muscles we have been studying, together with some influence produced by two others that act indirectly on it through the arm. Whenever some of these muscles are absent or inactive because of disease, when the clavicle or scapula is deformed by disease or accident, or when any of the muscles fail for any reason to exert the right amount of tension, abnormal posture of the shoulders is the result.

It is generally assumed by anatomists, as previously stated, that for normal posture of the shoulder girdle the clavicles should be approximately horizontal, which places the scapulæ at a height extending from the second to the seventh rib; that the scapulæ should be 4 inches apart, 2 inches on each side of the median line; and that they should lie flat against the chest wall on the back. Hygienists and artists have been inclined to accept this view, and it seems a reasonable ideal to hold.

The most common defect in the position of the shoulder girdle is abducted scapulæ. This is objectionable from a hygienic standpoint, partly because it weakens the support which the coracoid should give to the pectoralis minor and thus does away with the tension that muscle should exert on the ribs. The amount of assistance really given by the pectoralis minor in holding the chest up in an expanded position is not known, but it is commonly assumed that it helps. Another and perhaps greater objection to abducted scapulæ is that it is usually seen associated with drooping head and collapsed chest in the position known as "round shoulders." This fault of posture will naturally be studied when we take up the movements of the spinal column, but the part played by the shoulder girdle is of interest here. The weight of arm and scapula probably help to depress the chest.

Abduction of the scapula, as a fault of posture, most often results from continuous occupation with the arms held in front of the trunk. In writing, sewing, holding a book in position to read, and numberless other occupations, the arms and shoulders are held forward by continuous contraction of the serratus, pectoralis major and minor, while the trapezius, rhomboid and levator are relaxed to permit the scapulæ to move forward. This gradually tends to increase the bulk, strength, and tone of the muscles on the front and to modify their development so as to make them permanently shorter, while it has the opposite effect on the back group. After a time the scapulæ can be brought to normal position with difficulty, and this difficulty gradually becomes greater until the normal position is impossible. All this can be prevented by the regular practice of exercises that will develop, shorten and increase the tone of the trapezius, levator and rhomboid, and at the same time put on a stretch the muscles that are becoming shortened.

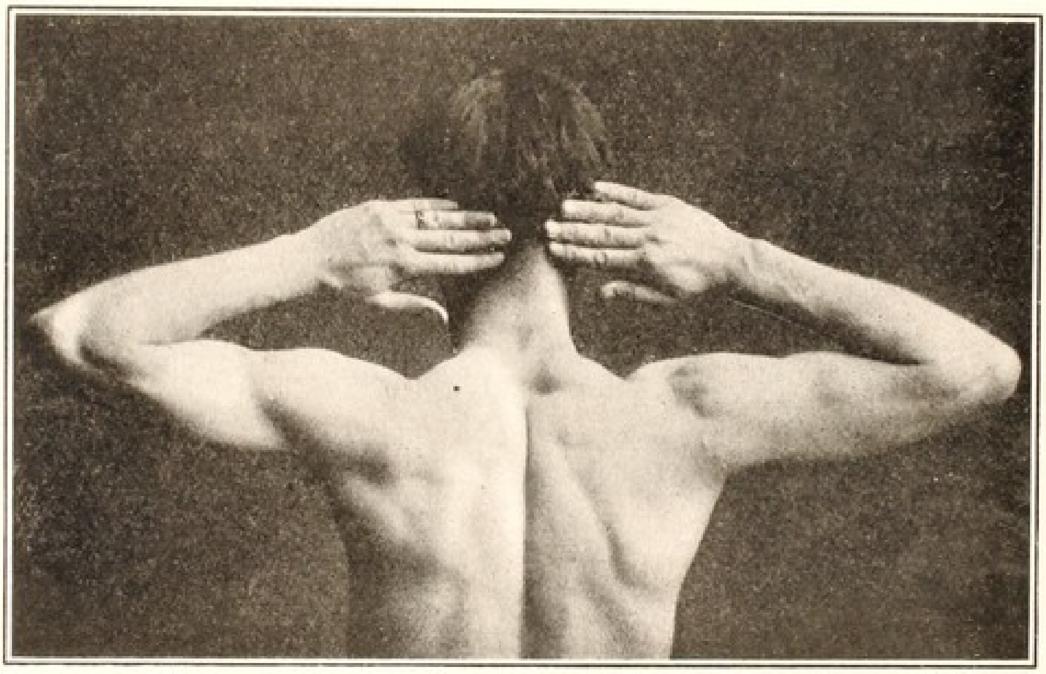


FIG. 41.—"Neck firm," an exercise used in Swedish gymnastics for correction of habitual abduction of the scapulæ.

It is considered one of the duties of a system of school gymnastics to give daily some good corrective to oppose the deforming tendency of school occupations. A very few of the most efficient exercises should be used frequently, and a greater variety of others that tend in the same direction should be taught as the time goes on, including as many as possible that are recreative as well as corrective. Among the best exercises for daily use may be mentioned "neck firm," shown in Fig. 41. The arms are raised sideward until slightly above the level of the shoulders and then the elbows are bent and the finger-tips placed against the back of the neck, which is held vigorously erect; the elbows are held back strongly. The position is held long enough to insure an accurate position and complete contraction of the muscles, then the arms are returned to the sides through the same path and the movement repeated several times. A second efficient corrective for abducted scapulæ is "chest firm," pictured in Fig. 42. The elbows are completely flexed, the entire arm is held horizontal, and the elbows are drawn strongly backward. Trapezius and deltoid hold up the arm and draw it back while the lower serratus rotates the scapula, tending to shorten and increase the tone of these muscles while stretching the pectorals. Raising the arms sideward and upward to the position of Fig. 62 is also good for correcting the posture of the shoulders, but in taking it there should be care not to thrust the chin forward by too vigorous action of the upper trapezius. Another good exercise consists in strong adduction of the scapulæ and outward rotation of the arms, taking a full breath at the same time; this movement, taken while the arms are at the sides, is called "West Point breathing."

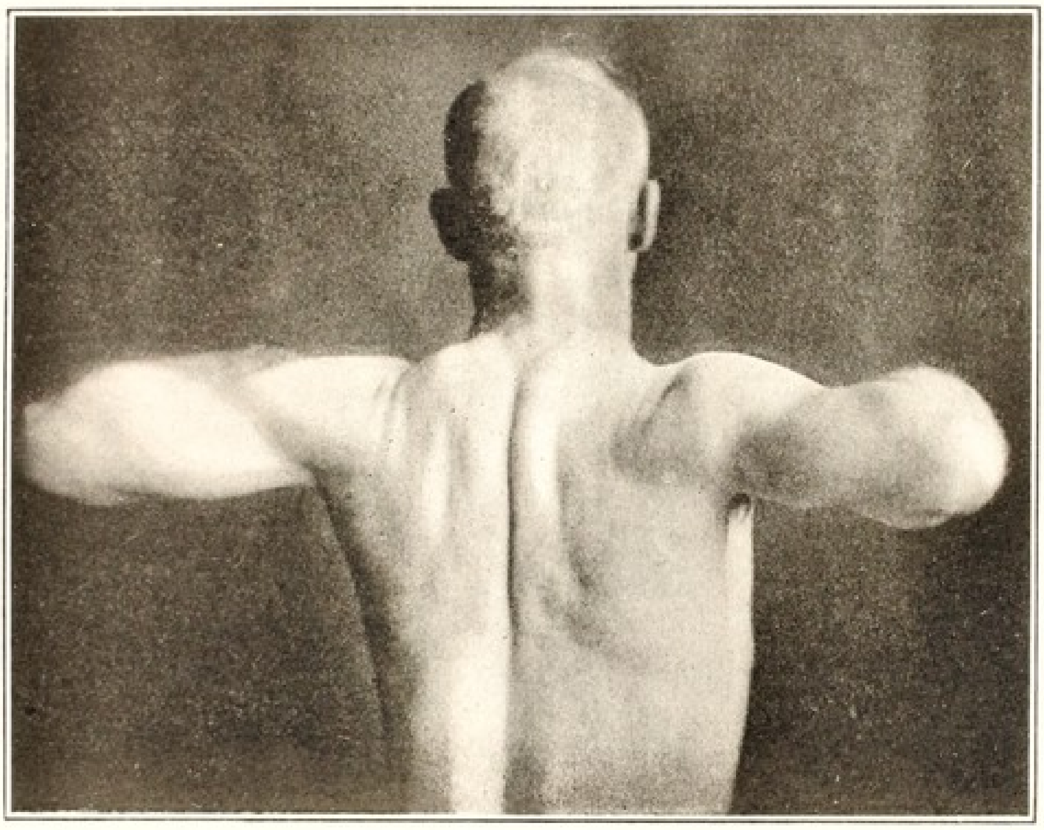


FIG. 42.—"Chest firm," a corrective exercise for abduction of the shoulders.

Shoulder braces, such as are often advertised and used to correct such faults, may be beneficial or highly injurious according to the manner of their use. The good they may do is to stretch the shortened muscles on the front of the chest and relieve the trapezius from extreme fatigue and prolonged stretching during an occupation conducive to the defect. The harm they are apt to do when used without intelligent direction is to leave the weak muscles that should maintain good posture without any necessity for vigorous action and thus weaken them still more. All such contrivances for the support and relief of overworked muscles should be used only under the direction of a competent specialist, and in practically all cases should be supplemented by exercises that will tone up and develop the weak muscles. In case of complete loss of the

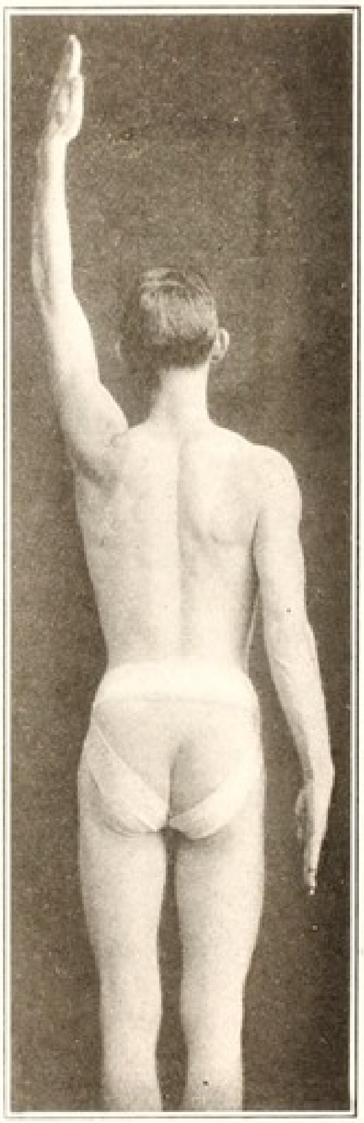


FIG. 43.—Upward stretching of one arm and downward stretching of the other arm, used for correcting uneven height of shoulders.

use of a group of muscles the brace may be needed permanently, but in any case expert advice should be secured.

A marked projection of the lower angle of the scapula, often known as "winged scapula," is usually due, as has been already observed, to a deficiency in the action of the rhomboid and shortening of the pectoralis minor. In mild cases the exercise of Fig. 75 is a good corrective, the effort to hold the elbows down giving vigorous but not straining work for the rhomboid while the effort to hold the hands back will stretch the pectoralis minor. As a general principle it is well to remember that exercises involving elevation of the humerus give work for the trapezius rather than the rhomboid, while the reverse is true of exercises involving depression of the humerus. A further study of this point will be made in the next chapter.

Uneven height of shoulders is a defect of posture often associated with lateral curvature of the spine. When the spinal column is straight and the fault is simply a lowering of one shoulder from lack of tone of the trapezius and levator, persistent shrugging of that shoulder is often sufficient to correct it. Another effective corrective for such a fault is upward extension of the arm on the low side combined with downward extension of the other arm, as shown in Fig. 43. This exercise is conveniently practised in alternation with the one shown in Fig. 41.

QUESTIONS AND EXERCISES.

1. Pick out a clavicle from the bones of a dismembered skeleton; point out and name its two ends, two surfaces, two borders, and two articular surfaces; tell whether it is a right or left clavicle.

2. Pick out a scapula from the bones of a dismembered skeleton; point out and name its two prominent projections, its two surfaces, three angles, three borders, three principal depressions, and two articular surfaces; tell whether it is a right or left scapula.

3. Demonstrate and name the six movements of the scapula, with the names of the muscles producing each.

4. Describe four different ways of studying the action of a muscle, and explain the advantages of each.

5. Explain how a weak trapezius may cause flattening of the front of the chest, and why the rhomboid cannot assist in correcting the defect.

6. If a man whose work is pushing a lawn mower wishes to take exercise to prevent its causing faulty posture of the scapulæ, should he be advised to box, put the shot, row, or drive a fast horse?

7. By means of a ruler or tape, measure the distance a subject can move the tip of the shoulder forward and back without moving the trunk; how far he can move it up and down; how much he can vary the width across the shoulders.

8. Mark on the skin with a flesh pencil the location of the subject's vertebral border of scapula while in habitual position; repeat when he is reaching forward as far as possible; when his scapulæ are adducted as completely as possible. Measure the extent of movement.

9. In similar manner mark and transfer to paper the angle of rotation of the scapula that takes place during elevation of the arms from the sides up to vertical position. Measure the angle with a protractor.

10. Demonstrate on a living model the failure of the first part of the trapezius and the lower serratus to help in lifting a weight on the shoulder, and the effect of elevation of the arm on their action.

CHAPTER V.

MOVEMENTS OF THE SHOULDER-JOINT.

The shoulder-joint, formed by the articulation of the humerus with the scapula, is the most freely movable of the ball-and-socket joints. The shallow glenoid fossa is deepened by a cup of cartilage, the glenoid cartilage, attached firmly to the inner surface of the fossa, and the head of the humerus fits into the cup. The joint is surrounded by the usual capsular ligament, which is reinforced on the front side by a strong band of fibers connecting the humerus with the coracoid and called the coracohumeral ligament. Several tendons of muscles have an intimate relation to the capsule and add materially to its strength. The capsule is so loose that it permits the head of the humerus to be drawn out of the socket about 2 inches, but the tendency of the weight of the arm to pull it far out is resisted normally by atmospheric pressure and by the tone of the muscles. The joint is protected by the acromion, which projects over it, by the coracoid in front, and by the coraco-acromial ligament, which connects these two processes.

Starting from the resting position at the side of the trunk and thigh, the arm can be raised (elevation or abduction) through movement in the shoulder-joint, in various directions and to various heights. The joint permits the greatest elevation toward the front, where it may swing forward and upward through 120 degrees; the possible extent of this movement diminishes as we pass sideward and backward, being about 90 degrees when it is directly sideward and 45 degrees directly to the rear. Further elevation toward the rear is prevented by tension of the coracohumeral ligament; toward the side or front, by contact of the greater tuberosity of the humerus and the tendon of the supraspinatus muscle with the top of the glenoid fossa. The way which the joint limits farther upward movement is shown in Fig. 44. The reader can observe, by the use of a free humerus and scapula, how this takes place and can also notice why the arm can be raised higher toward the front or when the humerus is rotated outward. First hold the humerus and scapula as they would be when the arm is at the side; then raise the humerus as in arm elevation sideward through 90 degrees and see how the tuberosity hits the top of the socket; now rotate the humerus 90 degrees to the rear, as in turning the palm up from this position, and see how the tuberosity is carried to the rear over the rounded edge of the socket to a place where it no longer prevents elevation of the humerus. Go back to starting-point and observe that elevation forward, with palms toward each other, does not cause the tuberosity to meet any solid obstruction.

Having been raised from the side, the arm can be swung forward until it strikes the front of the chest, swung backward to the lateral plane and 20 to 30 degrees back of the lateral plane. Movement of the arm downward toward the side from these positions is called adduction or depression. The shoulder-joint also permits the arm to describe a circle with the hand (circumduction), turn in or out on an axis passing lengthwise of the humerus (rotation), and with upward rotation of the scapula it can be carried up to a vertical position.

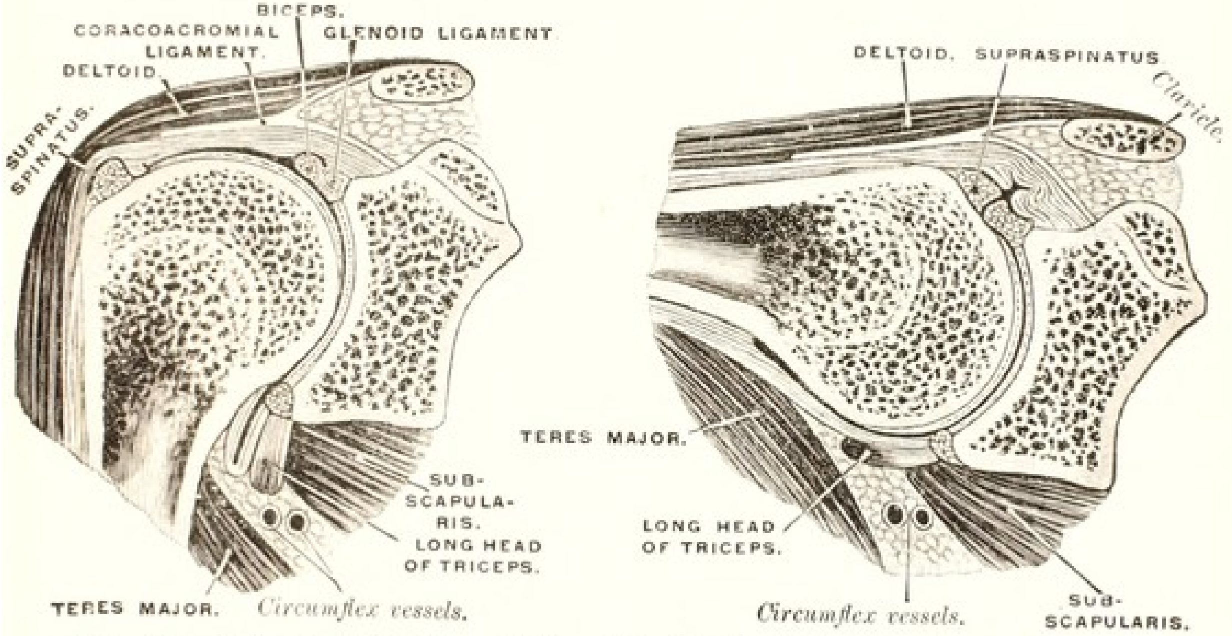


FIG. 44.—Vertical section through the right shoulder-joint, seen from the front, showing how sideward elevation of the arm is limited to 90 degrees. (Gray.)

Movements of the shoulder-joint are produced by nine muscles having that as their main function, along with one other (triceps) which acts on the shoulder-joint with one of its parts while its main action is upon the elbow-joint. The latter muscle will be described in the next chapter; the nine are conveniently placed in three groups of three muscles each. Three of the nine are large muscles, placed above, in front, and at the rear; with each of these goes a small associate and a rotator of the humerus, as follows:

	Large muscles.	Small associates.	Rotators of humerus.
Above . . .	Deltoid	Supraspinatus	Infraspinatus
Front . . .	Pectoralis major	Coracobrachialis	Subscapularis
Rear	Latissimus	Teres major	Teres minor

DELTOID.

A triangular muscle located on the shoulder, with one angle pointing down the arm and the other two bent around the shoulder to front and rear (Figs. 30, 46 and 48).

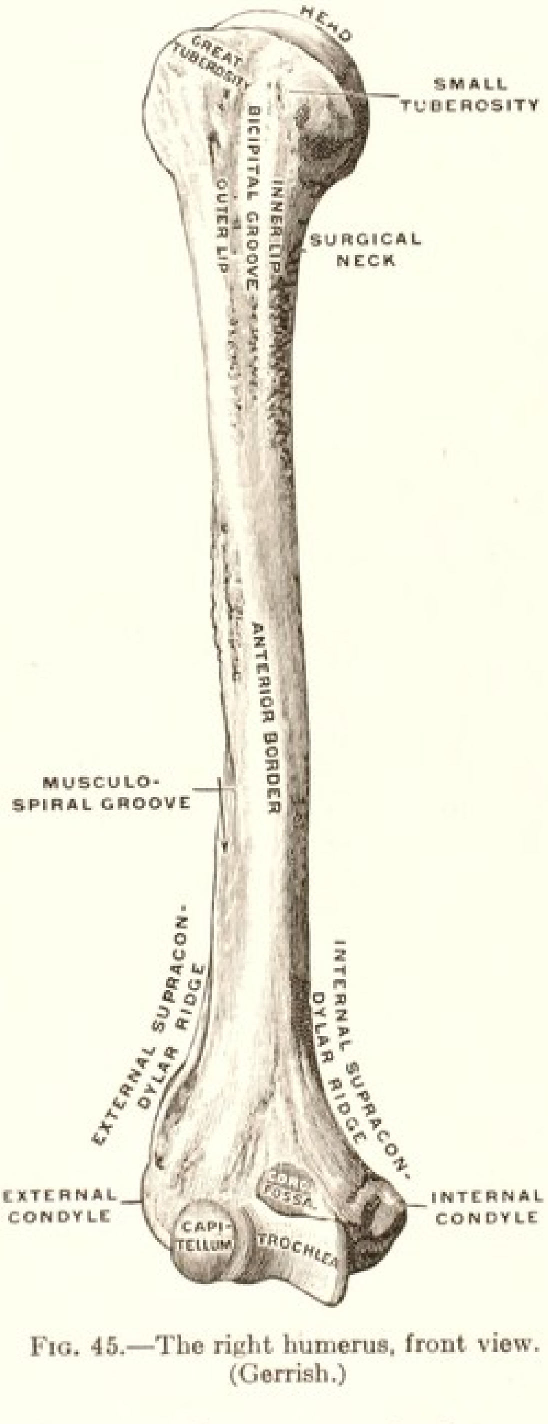


Fig. 45.—The right humerus, front view. (Gerrish.)

Origin.—Along a curved line following the outer third of the anterior border of the clavicle, the top of the acromion, and the posterior border of the scapular spine.

Insertion.—A rough spot on the outer surface of the humerus just above its middle.

Structure.—In three parts—front, middle, and rear. The front and rear portions are simple penniform while the middle is more complex. The tendon of insertion divides near the humerus into five strands; the outer two, placed front and rear, receive the fibers of the front and rear portions of the muscle, which arise directly from the bones above; the middle has four tendons of origin passing down from the acromion and the three tendons of insertion passing up from below alternate between them; the muscular fibers of the middle portion pass diagonally across between the seven tendons. The result of the arrangement is that the middle part has more power and less extent of contraction than the other two parts.

Action.—One can study the conditions under which the deltoid acts by attaching a rubber band to the humerus of a mounted skeleton and holding the free end of the band at the various points of origin in turn. Observe that its most anterior fibers pull upon the humerus at a fairly large angle (15 to 20 degrees) and that this angle of pull diminishes as we pass back to the acromion, where the pull is almost directly upward in line with the humerus; farther back the angle is greater again. This shows why the middle needs a more powerful structure than the other parts.

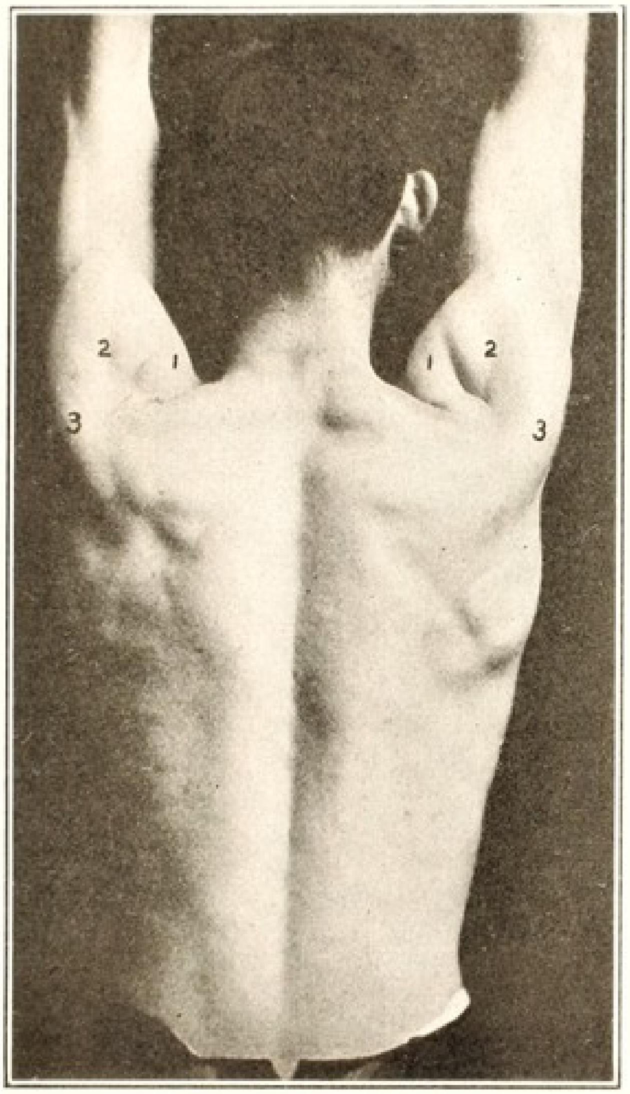


Fig. 46.—The deltoid in action.

Giving the rubber band a tension we can see in what direction any strands of fibers will move the arm; forward, then outward diagonally, then sideward, and finally backward, as we pass from front to rear as before. By using two rubber bands to represent two strands with origins separated at different distances we can see how the combined action of different parts raises the arm at every possible angle and also guides its motion in a definite direction; by holding the humerus up to the horizontal plane we can see how various parts pull forward or back upon it.

Using a non-elastic cord to represent a portion of the muscle, noting its length when the arm is at the side and again when it is raised to horizontal, we can see how far the muscle must contract to raise it as far as the joint permits. It is easy to demonstrate in this way that the middle part shortens less to lift the arm through 90 degrees than the others, the figures being approximately $1\frac{1}{2}$ and 2 inches, from which the fibers of the middle part would appear to be about 3 inches long and the front and rear fibers about 4 inches.

Fig. 47.—Identity of isolated action of deltoid (left side), with voluntary attempt to raise the arm when the trapezius and serratus magnus are lacking (right side). (Duchenne.)

Isolated action of the deltoid, as described by Duchenne, lifts the arm just as the above study of conditions would lead us to expect; it is raised to the greatest height by the most anterior fibers, and when the electric terminals are moved along the muscle from front to rear the arm swings to the rear and gradually lowers, the posterior fibers being able to lift it backward but 45 degrees. Anatomists who judged of the action of muscles solely by the conditions apparent on the skeleton or cadaver had for a long time doubted the ability of the middle deltoid to start the elevation of the arm without the aid of other muscles, because of its small angle of pull, but Duchenne's experiments on isolated action solved the problem definitely, showing that it can do so.

When the deltoid contracts from electric stimulus it does not lift the arm as high as the shoulder-joint would permit, because the scapula, being somewhat free to move, is rotated downward by the pull of the deltoid and the weight of the arm, bringing the lower angle back well toward the spinal column, depressing the acromion, and making the posterior edge of the scapula stand out from the chest wall as in Fig. 38. This downward rotation of the scapula gives the appearance of only a partial movement in the shoulder-joint, even when it has been performed to its full extent, precisely as in attempts to raise the arm by those whose trapezius and serratus are destroyed. Duchenne shows in Fig. 47 an experiment to make this plain. The subject has lost the trapezius and serratus through disease. When he tries to raise his arm he can bring into action only the deltoid, possibly aided by the supraspinatus. In the picture he is trying to raise his right arm and at the same time the left deltoid is being stimulated by electricity. The effect is the same on both sides: partial elevation of the arm, downward rotation of the scapula, and a deep trough between the posterior border of the scapula and the back. Notice how the arm and the axillary border of the scapula have moved away from each other, and recall that in normal elevation of the arm the axillary border moves forward because of the pull of the lower serratus, which contracts along with the deltoid and trapezius in all normal arm arising.

Loss of one or more of the three portions of the deltoid interferes so seriously with all movements involving elevation of the arm that subjects with this defect have much difficulty in feeding and dressing themselves. Loss of the posterior deltoid makes it impossible to put the hand behind the body at the waist line; if it is the front part the subject cannot bring his hand up to his face or put on his hat without bending the head far forward; if it is either the front or middle portion the arm cannot be lifted above the shoulder level in any direction. Few muscles are so important to the most common movements of the arm as the deltoid.

The deltoid is one of the easiest and most interesting muscles to study on the living body, and no student of kinesiology should fail to observe its action repeatedly, and upon several different subjects if possible. Since the deltoid raises the arm with such ease it is well to have the subject make the movements against a resistance great enough to bring it into strong contraction. Such a resistance can be furnished by a weight in the subject's hand, by the use of a pulley machine, common in most gymnasia, or by the hand of the observer.

The anterior deltoid hardens and swells out in all exercises in which the arm is raised or swung forward against a resistance; the middle deltoid does the same when the movement is sideward; the posterior part when it is backward. The position of "neck firm" (Fig. 41) brings all three portions into action, providing the subject holds his elbows well back. All positions above the horizontal bring both anterior and middle portions into action. It is easy to notice that a wider group of fibers contract in lifting a heavy weight than in lifting a light one; also that both front and middle portions come into action before the shoulder level is reached if the load is heavy. It is also easily seen that with quick arm elevation the deltoid contracts suddenly and then relaxes, leaving the momentum of the arm to finish the movement.

SUPRASPINATUS.

A small but relatively powerful muscle filling the supraspinous fossa and covered by the second part of the trapezius (Figs. 35 and 64).

Origin.—The inner two-thirds of the supraspinous fossa.

Insertion.—The top of the greater tuberosity of the humerus.

Structure.—Penniform, the fibers arising directly from the bone and joining the tendon of insertion obliquely as it passes through the center of the muscle, much as the seeds of a pine cone join their stem.

Action.—The supraspinatus pulls on the humerus with a short power arm and at a large angle; since it joins the humerus above the axis while the load is below it, it uses the humerus as a lever of the first class. Since the power arm is the line from the insertion to the axis it is plain that the power and weight arms are not in a straight line here, but the lever is bent sharply at the axis. This of course has no effect on the action of the muscle or its lever except to give it a favorable angle of pull.

Isolated action of the supraspinatus, which can be brought about by stimulating its nerve, raises the arm diagonally outward, but the direction is not fixed, and the arm may be moved forward or backward by the observer while the muscle is in contraction without hurting the subject. It is powerful enough to lift the arm to its full height, even when the deltoid is lost, but it is soon fatigued when so much work is put upon it. It pulls the head of the humerus directly into the socket and so prevents the upward displacement which the pull of the deltoid tends to produce. It is for this reason that persons who have lost the supraspinatus cannot do much work involving elevation of the arm, because of the friction of the head of the humerus against the under side of the acromion. Being covered by a muscle that usually contracts at the same time it is not easy to study the supraspinatus on the normal living body.

PECTORALIS MAJOR.

A large fan-shaped muscle lying immediately beneath the skin over the front of the chest.

Origin.—The inner two-thirds of the anterior border of the clavicle, the whole length of the sternum, and the cartilages of the first six ribs, near their junction with the sternum.

Insertion.—By a flat tendon about 3 inches wide into the ridge that forms the outer border of the bicipital groove of the humerus, extending from just below the tuberosities nearly down to the insertion of the deltoid (Fig. 211).

Structure.—The fibers arise directly from the bone and converge to join the tendon of insertion. Near its insertion it is twisted through 180 degrees, the lower part passing beneath to be inserted near the head of the humerus while the fibers from the clavicle pass across them on the outside and join the humerus lower down.

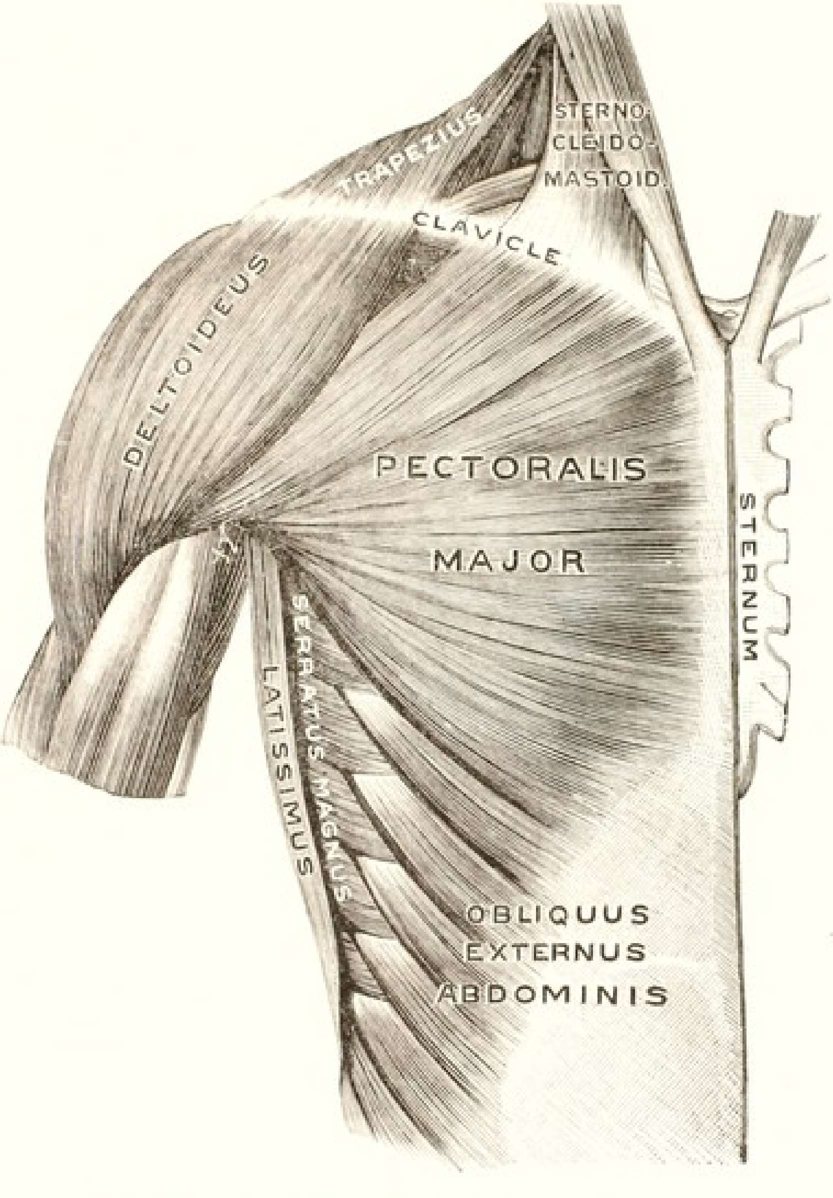


FIG. 48.—Deltoid and pectoralis major. (Gerrish.)

Action.—The pull of the uppermost fibers of the pectoralis major differs from that of the anterior deltoid only in having an origin a little farther to the front and an insertion a little higher. As we observe the pull of the different strands in turn passing downward it is plain that when the arm is at the side the whole muscle is in a position to pull it forward, the upper fibers tending to raise it and to pull at a better angle as the arm swings forward while the lower fibers pull at a small angle that grows smaller as the arm advances, the most of the force acting to pull the head of the humerus out of its socket. When the arm is first raised to horizontal the angle of pull is greater and a point can be found near the front horizontal where the pectoralis major pulls at a right angle, the upper part acting directly forward and the lower part forward and downward. With the arm overhead all parts pull forward and downward. The position of the insertion enables it to rotate the humerus inward; the twisting of the tendon gives the upper fibers the longer and the lower the shorter leverage.

Duchenne's study of isolated action cleared up several points about the action of the pectoralis major which had hitherto been topics of dispute and showed for the first time just what the muscle can do and what it cannot do. He shows that it acts like two muscles, just as the deltoid acts like three and the trapezius like four. He finds that the upper half of the pectoralis major swings the arm forward and inward and at the same time lifts the acromion so that it can help the levator and second trapezius in lifting and holding a weight on the shoulder; it presses the arm firmly against the side and front of the chest. When the arm is first raised to horizontal the action of the upper half swings it horizontally forward; when it is in vertical position upward the same fibers depress it forward to the horizontal. Isolated action of the lower half swings the arm forward and downward, depresses it if elevated, and pulls the head of the humerus strongly out of the glenoid cavity, at the same time lowering the acromion and pressing the arm forcibly against the front and side of the chest.

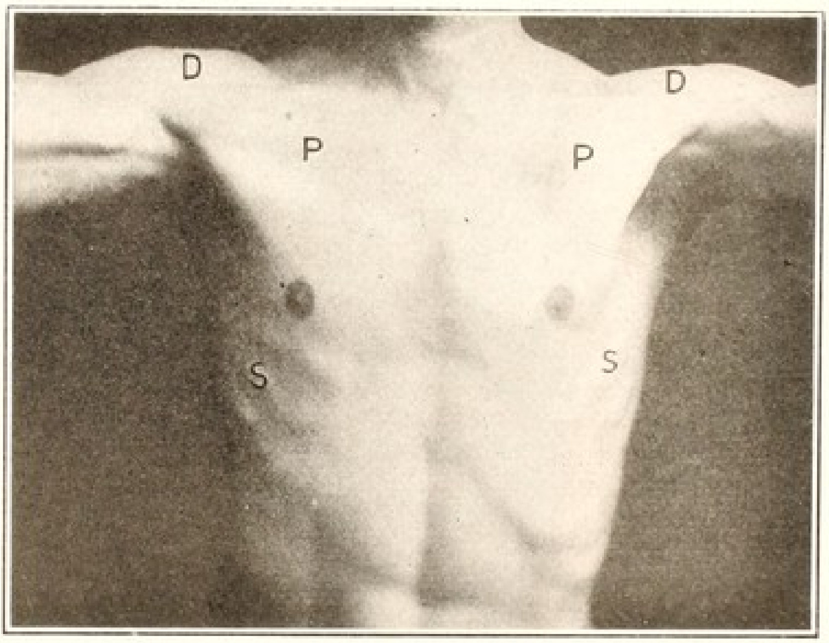


FIG. 49.—The pectoralis major in action. *P*, pectoral; *D*, deltoid; *S*, serratus magnus.

Loss of the pectoralis major disables one much less than loss of the anterior deltoid, excepting in movements where great force is required. When the deltoid is intact the subject can raise his hand to any position in front of the trunk, fold his arms, place the hand on the opposite shoulder, etc., even if the pectoralis major is lacking; the force of gravitation enables him also to lower the arm to or through any position with the aid of the deltoid; but the power in forward and downward movements of the arm is lacking unless the pectoralis can help.

Dr. Beevor, of London, has described an excellent way to begin the study of the pectoralis major on the living body. First have the subject hold his arms forward a little below the horizontal and with elbows extended press his palms strongly together; this brings the whole muscle into vigorous action and the two parts can be seen and felt plainly, the tendon standing out in strong relief near the arm. Now while the subject is doing this let the observer press down on the extended arms and have the subject resist the pressure; this instantly causes relaxation of the lower half while the upper half springs out in still stronger action; if the observer lifts against the arms and the subject resists, the upper half relaxes and the lower half acts. Let the observer try to move the subject's arms alternately up and down while the subject tries to keep them still, and notice the rapid change of action by watching the tendon near the arm. Observe that both parts of the muscle contract in all exercises where there is forward movement of the arms at a certain level, such as pushing a lawn mower; the upper part works alone when the movement is upward, as in putting the shot, throwing overhand, and the like; the lower part acts alone in such movements as sawing or shovelling. Notice how plainly the upper half shows action in lifting with arms forward, as when a waiter carries a heavy tray; notice also how it fails to act and the deltoid has it all to do if the arms are separated too widely; see if you can locate the width of arms at which the pectoralis ceases to aid the deltoid in lifting the arms. This is why the shot-putter finds it an advantage to extend the arm in a direction considerably inward rather than straight forward. He wants the deltoid to have the assistance of the pectoralis, and in the position of the arm where the latter works with the best leverage.

CORACOBRACHIALIS.

A small muscle named from its attachments and located deep beneath the deltoid and pectoralis major on the front and inner side of the arm (Fig. 50).

Origin.—The coracoid.

Insertion.—Inner surface of the humerus, opposite the deltoid.

Structure.—The fibers arise from a short tendon and are inserted directly into the humerus. Attachment to the tendon is penniform.

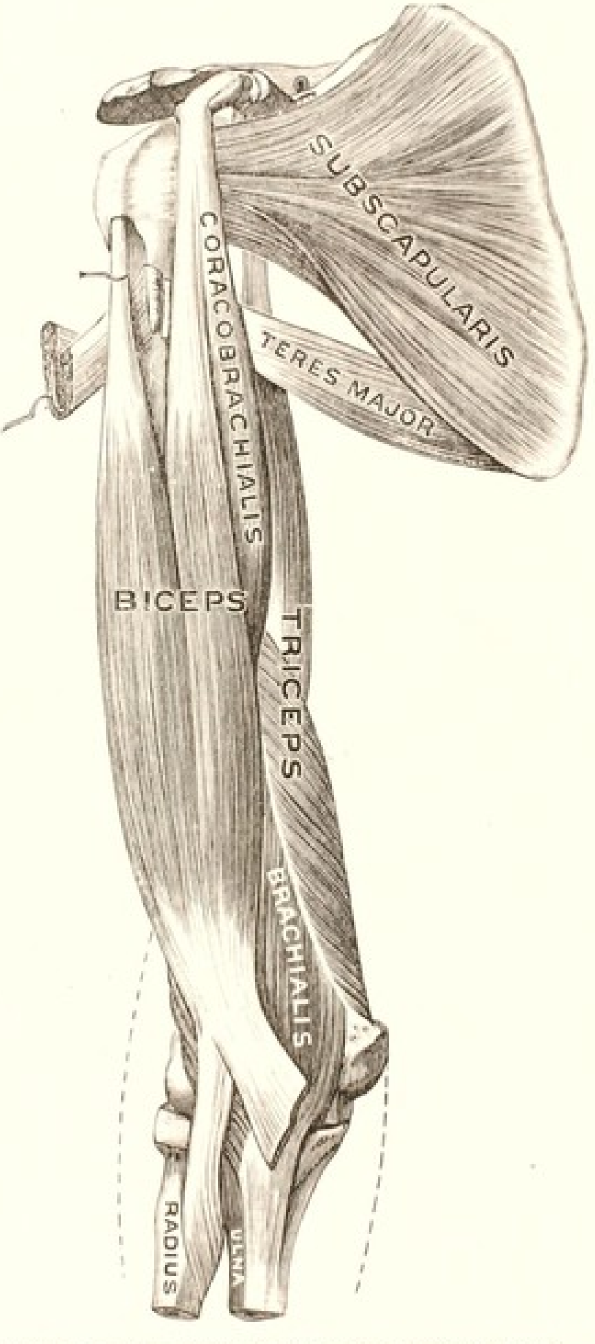


Fig. 50.—Muscles on the front of right shoulder and arm. (Gerrish.)

Action.—Observation of a cord placed to represent this muscle will convince the reader that it can pull upward and inward on the humerus, the angle being small and the force mostly used to lift the humerus lengthwise. Isolated action of the coracobrachialis holds the humerus strongly upward and swings it feebly inward.

It is too deeply placed to make a study of its normal action easily, but it is believed, because of the facts just stated, to work with the pectoralis major and the two muscles next following, all of which pull down on the humerus and thus tend to draw it out of its place in the glenoid cavity in vigorous downward movements of the arm.

LATISSIMUS.

A very broad muscle, as its name indicates, situated on the lower half of the back and lying immediately beneath the skin except for a small space, where it is covered by the lower trapezius (Fig. 30).

Origin.—The spinous processes of the six lower dorsal and all the lumbar vertebræ, the back of the sacrum, the crest of the ilium, and the lower three ribs.

Insertion.—The bottom of the bicipital groove of the humerus, by a flat tendon attached parallel to the upper three-fourths of the insertion of the pectoralis major (Fig. 211).

Structure.—The fibers converge from their wide origin much like the pectoralis major, and like the latter its flat tendon is twisted so that the upper fibers go to the lower insertion, and *vice versa*. The muscle is joined to the lower vertebræ and the sacrum by a sheet of fibrous tissue called the *lumbar fascia*, which also gives attachment to several other muscles.

Action.—The latissimus is situated so as to pull the arm down toward the side from any position of elevation. The lower fibers are in a position to act to best advantage when the arm is high, pulling at a right angle when it is near the horizontal, and in doing so they will tend to depress the acromion; the short lever arm makes them adapted for speed rather than power. When the arm has been lowered to within 45 degrees from the side the upper fibers pull at a better leverage than the lower, tending to adduct the arm and also the scapula, and having a longer lever arm than the lower fibers. The muscle working as a whole has its best leverage at about 45 degrees of elevation of the arm, when it pulls at a right angle; it pulls the arm to the rear of the lateral plane, in a certain degree of opposition to the lower pectoral, which pulls it forward. Its insertion on the front of the humerus makes it a rotator inward, and its position to the rear of the trunk enables it to turn it farther than the pectoralis major.

Isolated action of the latissimus produces exactly what we would expect. The upper fibers adduct the scapula so accurately and strongly that Duchenne is inclined to place it among the muscles maintaining normal posture of the shoulder girdle, and gives evidence from defective cases to support the opinion. He shows also that when the lower fibers contract with the arm at the side they draw the head of the humerus down from the socket as far as the capsule will permit.

Loss of the latissimus results in a forward displacement of the shoulder, due to the pull of the pectoral muscles, major and minor. It noticeably weakens all downward movements of the arm. When both the latissimus and pectoralis major are lost the shoulder is apt to be too high, because of the lifting action of the trapezius and rhomboid.

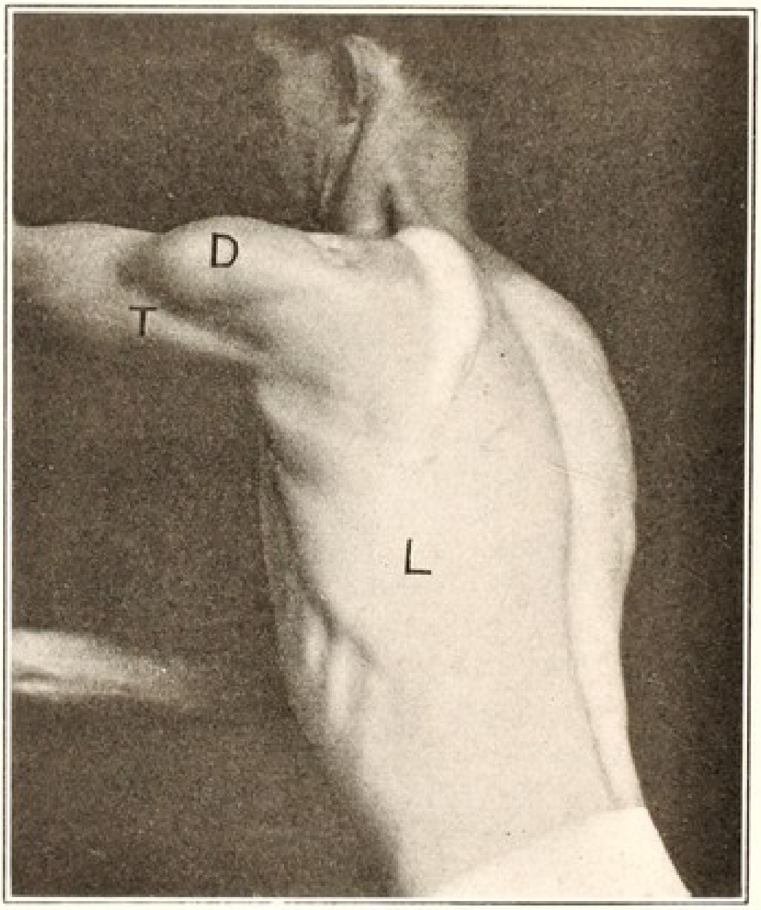


FIG. 51.—The latissimus in action. The subject is depressing his arms against resistance. Notice the narrow upper end of the latissimus just below the arm and trace its upper and lower margins as it widens out. *L* is near its center; *D*, deltoid; *T*, long head of the triceps.

The latissimus may be observed on the living body to act vigorously in all strong downward movements of the arms, such as chopping, striking with a hammer, and in supporting the weight of the body on the hands; the same is seen in movements more directly to the rear, such as rowing, paddling, and exercises on chest weights when the subject is facing the machine. It also acts in raising the trunk when it is inclined slightly forward up to the erect military position. The use of the latissimus in this movement is liable to give an excessive hollow in the back at the waist line unless other muscles are used to counteract it.

TERES MAJOR.

A small round muscle lying along the axillary border of the scapula, named "larger round" in comparison with the teres minor or "smaller round muscle" (Figs. 35, 37 and 50).

Origin.—The external surface of the scapula at the lower end of its axillary border.

Insertion.—The ridge that forms the inner border of the bicipital groove of the humerus, parallel to the middle half of the insertion of the pectoralis major (Fig. 211).

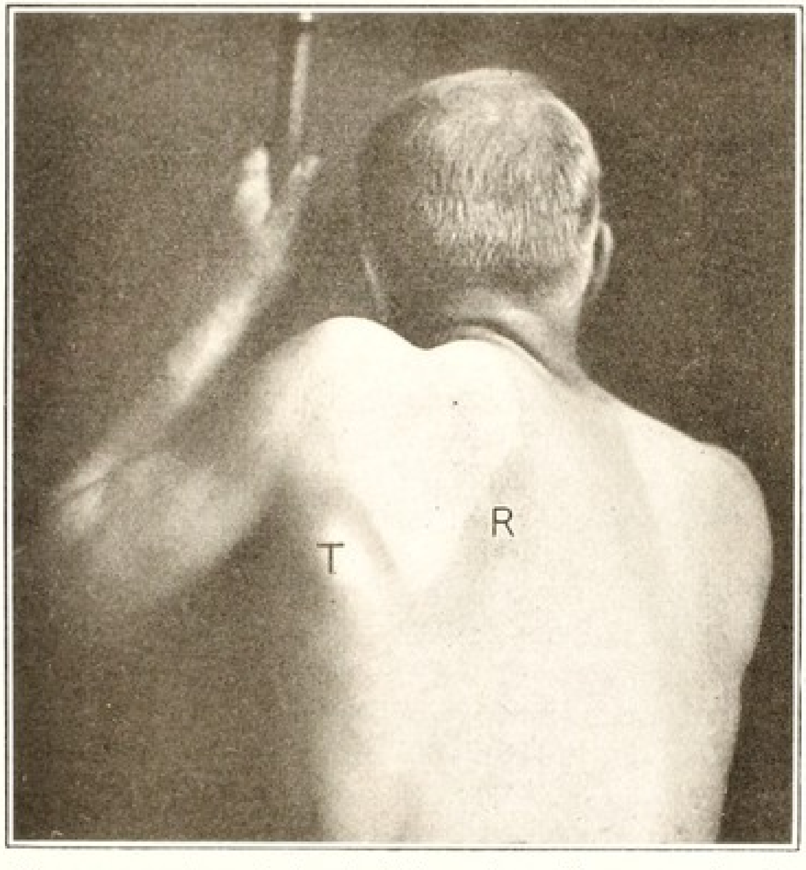


Fig. 52.—The teres major and rhomboid in action. *T*, teres major; *R*, rhomboid.

Structure.—Fibers arising directly from the scapula and inserted into the tendon in a penniform manner.

Action.—The teres major is in a position to pull the humerus and the axillary border together, and therefore is the most direct antagonist of the deltoid. It pulls at a right angle when the humerus has been moved from the side about 45 degrees. The position of its insertion enables it to rotate the arm inward. When there is a strong resistance to depression of the arm the action of the teres major tends to draw the lower end of the scapula forward—a movement that the rhomboid is in a position to prevent when it acts at the same time.

Isolated action of the teres major, in the words of Duchenne, "brings the inner side of the arm and the axillary border of the scapula toward each other, raises the tip of the shoulder, and carries the arm a little to the rear. The arm and scapula are drawn together with great force, but the arm is depressed but feebly; it requires but little strength to lift the arm to the horizontal in spite of its action." He goes on to say that in cases of loss of the trapezius he was able to apply electric stimulus to the rhomboid and teres major at the same time, and then the arm was depressed forcibly. He adds that the rhomboid and teres major may be considered as one muscle whose main function is to depress the arm, but he states that its force is less than either of the two larger depressors of the arm. Isolated action of the teres major, for some unexplained reason, does not rotate the humerus with any considerable force.

Loss of the teres major does not interfere with depression of the arm to nearly the same degree as loss of either the pectoralis major or latissimus.

It is easy to observe the action of the teres major on the living body in all movements involving forcible depression of the arm and also when the body is suspended by the arms, either with the hands grasping a fixed bar overhead or when the hands rest on two parallel bars or desks with the arms at the sides. Since the trapezius is relaxed in these movements the rhomboid can be felt. Notice also the complete relaxation of the deltoid in these exercises.

INFRASPINATUS AND TERES MINOR.

These two muscles, located on the back of the scapula, have identical action, and hence will be studied together (Fig. 35).

Origin.—The external surface of the scapula below the spine.

Insertion.—The posterior part of the greater tuberosity of the humerus (Fig. 212).

Structure.—Longitudinal converging fibers.

Action.—The point of insertion of these muscles being, as may be seen in Fig. 35, directly opposite the center of the joint where the articulating surfaces come in contact, it is evident that they can have no power to raise or depress the arm, but, pulling horizontally toward the median line of the back, will tend to rotate the humerus outward. When the arms are elevated to shoulder height, however, the line of pull is no longer at right angles to the humerus but more nearly in line with it, so that action of the infraspinatus and teres minor will in this position help to swing the arm backward, as well as rotate. The student should remember that when the arms are raised sideward the scapula rotates, so that the situation is not just the same as the mounted skeleton shows.

Isolated action of these muscles verifies the above conclusions so fully that Duchenne suggests that they be renamed "outward rotator of the humerus;" he states further that elevation of the arm does not prevent the rotating action, which can extend through 90 degrees.

Persons who have lost the use of these muscles cannot use a screw-driver efficiently and have great difficulty in writing, the movement of the forearm across the page in writing being produced by the outward rotation of the humerus while the elbow is flexed.

The outward rotators, while they are partly covered, can be felt in action just below the posterior edge of the posterior deltoid while the subject turns a screw-driver or a gimlet or twists the arm as in wringing a wet cloth.

SUBSCAPULARIS.

Named from its position on the inner surface of the scapula, next to the chest wall (Fig. 37 and Fig. 50).

Origin.—The whole interior surface of the scapula (next to the ribs) except a small space near the joint (Fig. 209).

Insertion.—The lesser tuberosity of the humerus (Fig. 211).

Structure.—Converging fibers.

Action.—The position of the subscapularis, just opposite the two muscles just studied, makes it appear to be an inward rotator of the humerus; with the arm raised sideward, to pull the arm forward. Experiments in electric stimulation, although not as conclusive as in most cases, seem to verify these conclusions.

Action of the subscapularis in association with the outward rotators would hold the head of the humerus firmly in the socket and thus serve to prevent injury to the joint in many violent movements of the arm; but the position of the subscapularis does not allow of its being felt or seen in contraction and therefore it is not certain that such action actually takes place.

THE FUNDAMENTAL MOVEMENTS OF THE ARM.

Having studied the muscles that move the arm on the trunk and gained a certain familiarity with the individual action of each and the conditions under which they act, we are now prepared to study the mechanism of the various movements of the arm. It seems best to take up first the fundamental movements—upward, downward, forward, and backward—and then to study certain gymnastic exercises which are but variations of the fundamental movements.

We have already noticed that certain movements of the arm involve motion not only in the shoulder-joint but also in the joints of the shoulder girdle, and it will develop as we proceed that this is true of practically all movements of the arm when they are made with any considerable vigor. We will find that whenever the arm is moved in either of its four cardinal directions or even when it is rotated on its long axis the shoulder-joint is itself moved to the position most favorable; the glenoid fossa, by a gliding of the scapula over the surface of the chest or a rotation upward or downward, is brought so as to face in the right direction; and the scapula is firmly anchored to the trunk so as to make the glenoid fossa a solid fulcrum on which the arm may swing as a lever, the force being applied just where and when it is needed to keep the axis in place during the movement.

Since the effect of gravitation is always directly downward it is desirable to test the participation of the muscles by having a subject perform the exercises in different positions, such as standing, lying with face downward and also with back downward, and inclined positions that will affect the action and effect of the exercise. Such a proceeding is helpful in deciding doubtful questions of muscular action and questions regarding the relative merits of exercises for special purposes.

ELEVATION OF THE ARM.

Normal elevation of the arm, starting from the position with the arm hanging at the side of the thigh, takes place through 180 degrees, terminating in a position vertically upward; the arm can be raised to this position in a plane directed forward or sideward or any plane between these two; some young and flexible subjects can carry the arm through an angle of a little more than 180 degrees and in planes somewhat crosswise in front and somewhat to the rear of the lateral plane, while other subjects are unable to raise it as far as the vertical position. The resistance to elevation of the arm is from two sources: gravitation and the tension of ligaments and antagonistic muscles. When weights are held in the hands or the movement is made against the resistance of a pulley machine, gravitation may prevent the subject from raising the arm to full height; but the weight of the arm alone is a comparatively small element in the case of those who are unable to put the arm straight up. In the first place it is not especially the weaker individuals who fail to make the complete movement; the weight of the arm acts most effectively at the horizontal position and has less effect above it, while the main difficulty these subjects experience in raising the arm does not begin until it is considerably higher than shoulder level; the difficulty is not removed by performing the movement while lying on either the face or the back, which eliminates the effect of weight of the arm. Continuous use of the arms in lower planes without even occasional upward movements to stretch ligaments and antagonistic muscles frequently modifies the tissues so that they no longer permit the normal elevation. The use of weights, such as dumb-bells and pulley machines, is frequently employed to increase the resistance and thus hasten the development of the muscles. The dumb-bells, acting only in the vertical direction, have little effect on other muscles than those required to raise the arms, while the pulley weights, with the three sets of

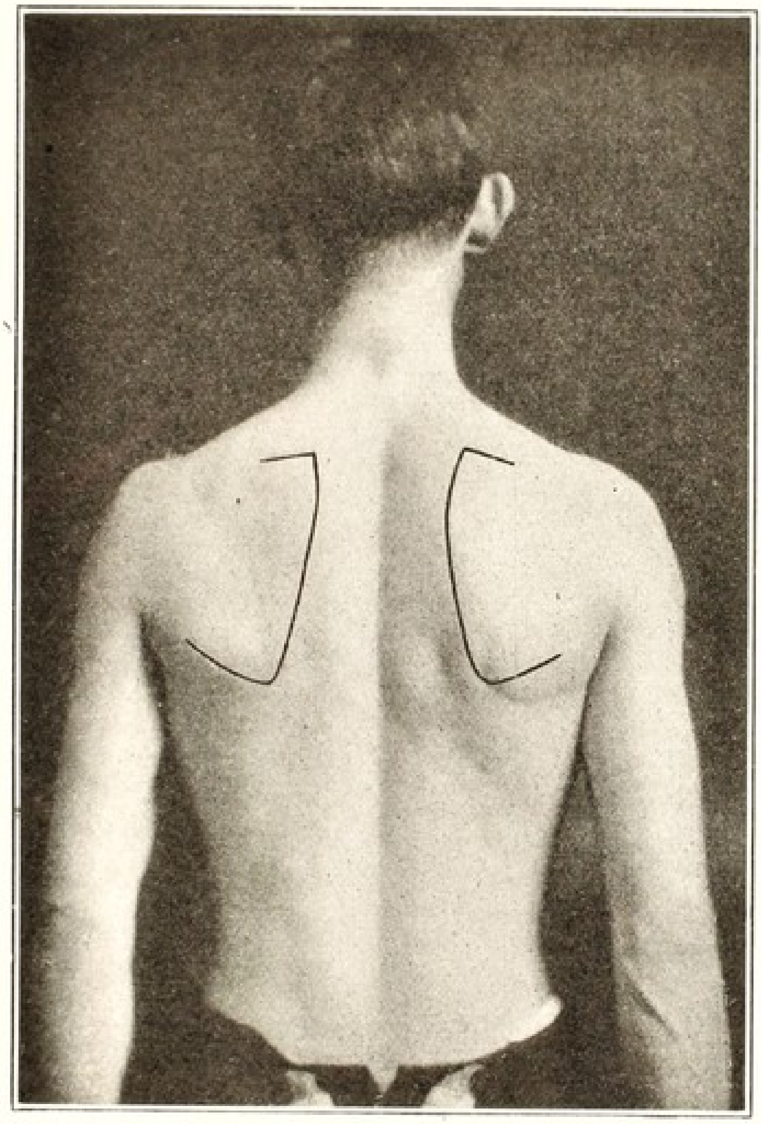


FIG. 53.—Position of scapulæ when arms are at sides.

pulleys placed chest high, overhead, and on the floor, permit the development of any muscle group of the body.

To raise the arm to vertical position requires movement in the shoulder-joint and upward rotation of the scapula. It was formerly taught that this is accomplished by first making all possible movement in the shoulder-joint and then rotating the scapula through 90 degrees, but as soon as students began observation of the living body as a source of information it became evident that it is not done in that way. While there is some variation in different subjects one can easily convince himself that in the average young subject the scapula does not rotate more than 60 degrees and that it does not rotate at all during the first part of the movement, nor

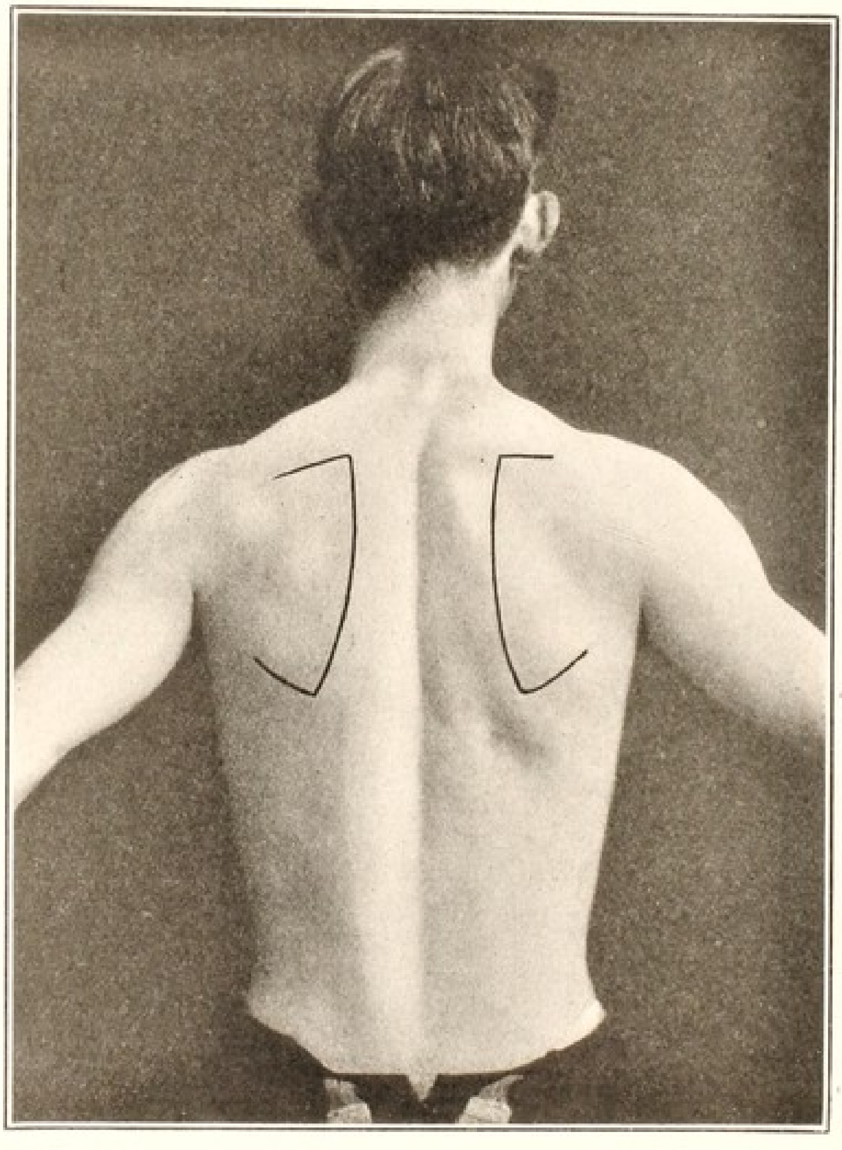


FIG. 54.—Position of scapulæ when arms have been raised through an angle of 45 degrees.

during the last part, but rather in the following manner, as the accompanying figures illustrate.

In raising the arm sideward the humerus is first moved in the shoulder-joint without any considerable movement of the scapula through 45 degrees by the action of the middle deltoid and the supraspinatus, while the entire trapezius, excepting the clavicular fibers, contracts to prevent the scapula from being rotated downward by the weight of the arm. During the next 90 degrees of elevation both the scapula and humerus are moving, the lower serratus acting to swing the lower angle of the scapula forward. At about the time the arm passes the horizontal the anterior fibers of the deltoid begin to act to aid the middle part, and the upper trapezius also contracts. The upper 45 degrees of elevation takes place

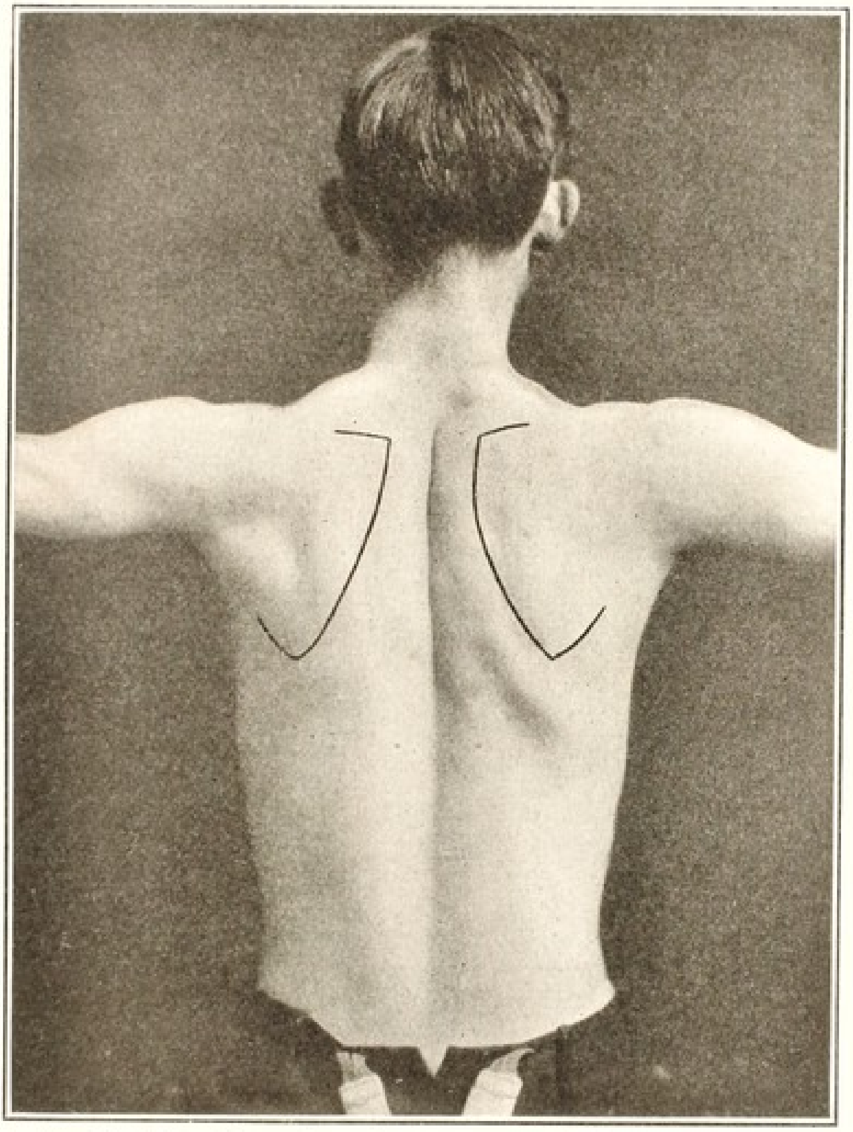


FIG. 55.—Position of scapulæ when arms are raised through 90 degrees.

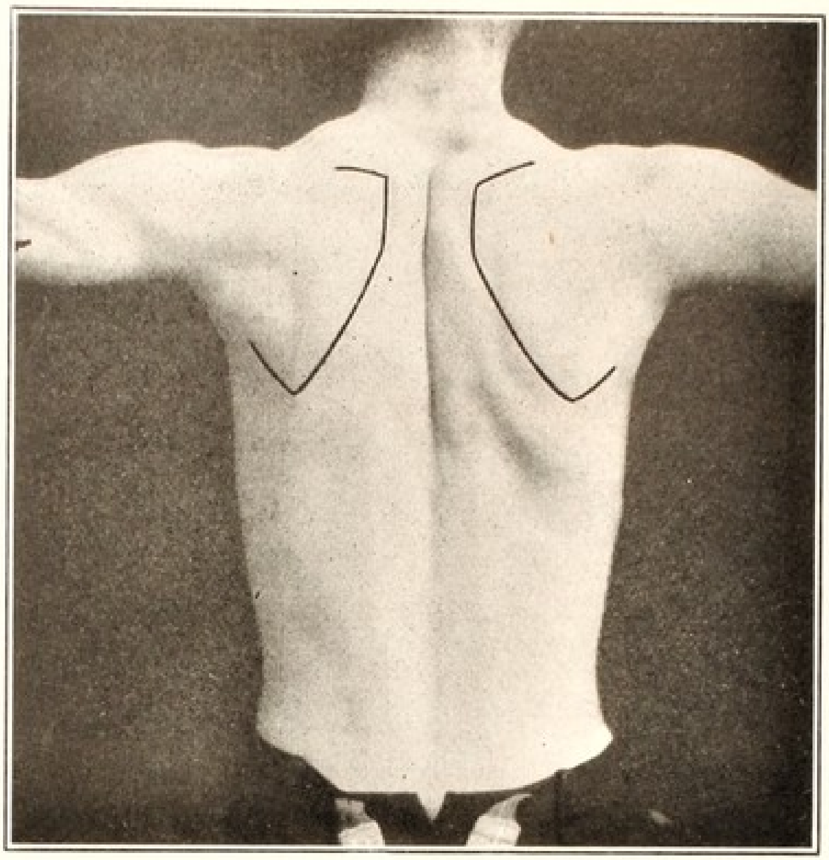


Fig. 56

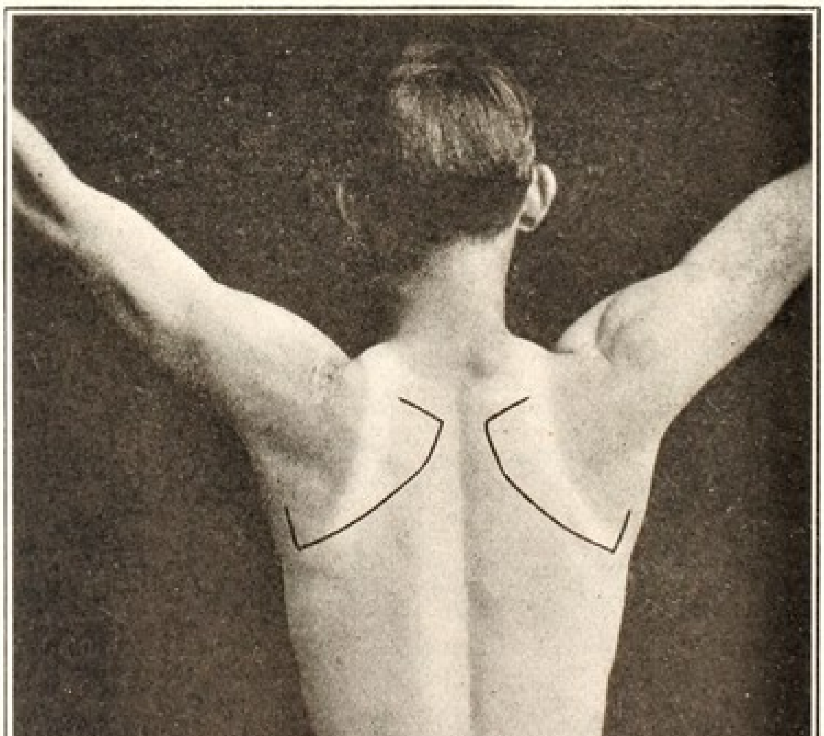


Fig. 57

in the shoulder-joint only. When the elevation is sideward the arm must be rotated outward, preferably when near shoulder level, to prevent the locking of the shoulder-joint by contact of the bones at the top of the joint. When the arms are carried well to the rear at the completion of the movement of elevation, and especially when it is taken when lying on the face, the posterior deltoid acts in some subjects.

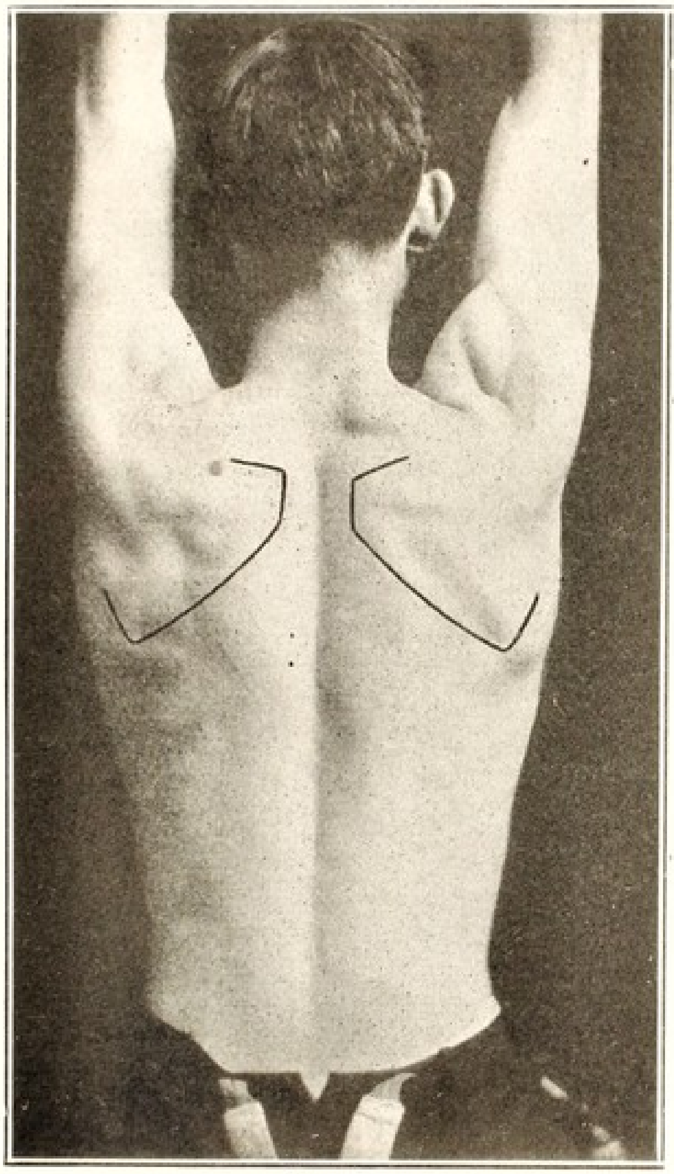


FIG. 58

FIGS. 56, 57 and 58.—Positions of scapulæ in arm elevation above the horizontal. Since the scapulæ turn forward along the chest wall the full amount of rotation cannot be shown in such a series of pictures.

When the arm is raised forward there is this difference in the mechanism of the movement: the middle deltoid is replaced during the first 90 degrees of elevation by the anterior deltoid and the upper half of the pectoralis major; above the horizontal there is no difference. Observation of elevation diagonally between forward and sideward shows that action of the deltoid is not necessarily divided into the three divisions usually named, for portions of the anterior and middle sections act in this case.

Many persons are unable to raise the arms above 135 degrees without moving the head forward and elevating the chin, showing strong action of the upper part of the trapezius and weakness or lack of control of the muscles that hold the head erect. Some writers say that the rhomboid acts in the later stages of arm elevation, but according to Sherrington's law of coördination it ought to be fully relaxed, so as to permit complete upward rotation of the scapula. In violent effort it may be brought into action through an uncontrolled spread of nerve impulses, but it is very poor gymnastic training that encourages the use of muscles that hinder in the work to be performed.

The pull of the deltoid, when the arm is down at the side, is so nearly lengthwise of the humerus that it tends to move the bone upward, lifting the head out of its socket and pressing it against the under side of the acromion. Contraction of the supraspinatus, which normally occurs along with the deltoid, acts to keep the head of the humerus down in its place; in this it is apt to be helped by the infraspinatus and the subscapularis.

The movement of the lower angle of the scapula away from the middle of the back as the arms are raised has been somewhat of a puzzle to students of this subject. Although it has been shown without question by Duchenne and others that the upper part of the scapula is anchored by the trapezius and the lower angle pulled forward in arm elevation by the serratus magnus, some recent writers speak of "the tendency of the lower angle to follow the arm, probably being pulled along after it by the teres major." To avoid this error one must bear in mind that the scapula is the origin of the pull that lifts the arm. The teres major is an antagonist of the deltoid and must be relaxed to allow complete arm elevation. If it should by any means be brought into action it would pull the arm down with just as much force as it would pull the lower angle forward. It may serve to move the lower angle forward when the arm is raised up beside the head by another person, but that is not normal arm elevation. When you raise your own arm up beside the head the teres major is normally resting. Instead of the upward rotation of the scapula being a *result* of the elevation of the humerus it is really a *cause* of that elevation; the trapezius and serratus rotate the scapula and rotate the whole upper limb along with it.

One question of interest remains, the location of the resistance that necessitates the exertion required to raise the arms to vertical position and that stops many persons before they arrive. There is probably some resistance to the last stages of the movement in the clavicular joints, and when the humerus strikes the acromion, if it does, that and the pull of the supraspinatus will resist further movement in the shoulder-joint; among the muscles, the rhomboid and pectoralis minor passively resist the extreme upward rotation of the scapula, while the pectoralis major and latissimus resist the elevation of the humerus. Since the difficulty of holding the arm far enough back is so evident it would seem that the pectoral is the greatest single factor in the resistance.

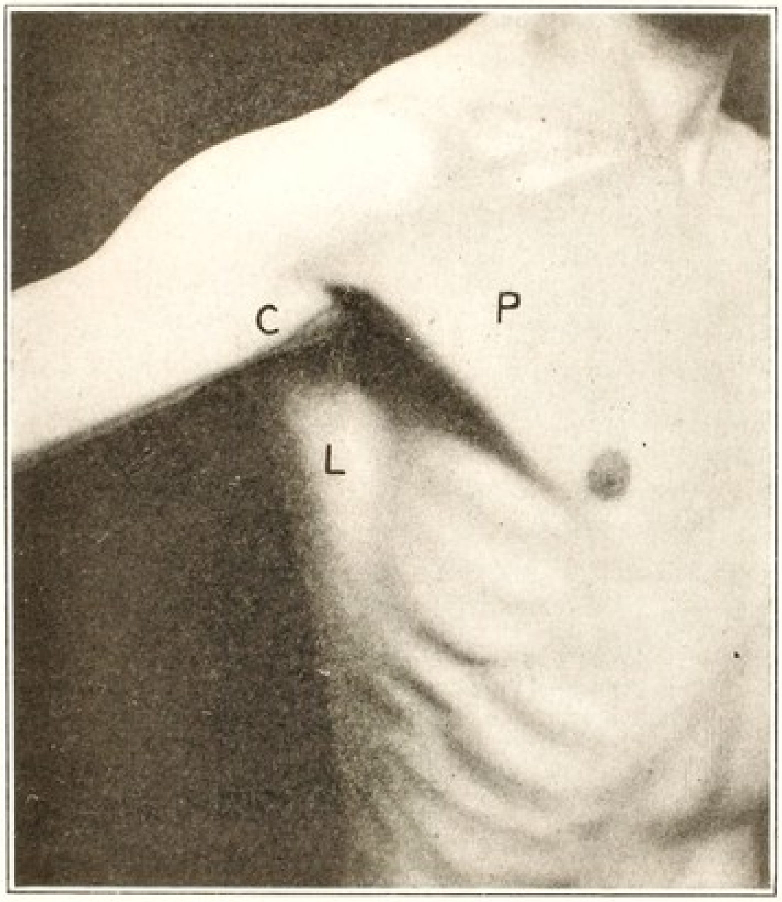


FIG. 59.—Depressors of the arm in action. *P*, pectoral; *C*, coracobrachialis; *L*, latissimus.

DEPRESSION OF THE ARM.

Normal depression of the arm, when there is no external resistance, offers no such difficulties as elevation. Not only does gravitation, when the trunk is erect, help instead of resist the movement, but the arm is brought down against the side with no joints, ligaments, or muscles impeding its way. It is the exact reverse of elevation and all the planes possible in elevation are also possible in depression.

The movements in the joints—depression of the humerus and rotation downward of the scapula—appear to take place in the reverse order of elevation, the movement of the scapula occupying the middle half of the arm movement.

A convenient way to study the action of muscles in this movement is to have the subject depress the arms while he holds the handles of an overhead pulley machine. The movement can be taken any desired speed and can be stopped at any level to notice changes.

When the arm is depressed in the sideward plane against the resistance of the pulley machine the pectoralis major, latissimus, and teres major can be felt in action through the entire extent of the movement; by placing the fingers on the ridges to front and rear of the arm-pit these actions are easily detected. The scapula does not rotate downward until the arm has lowered 45 degrees or more, showing delayed action of the rhomboid and pectoralis minor similar to what we have noticed of the lower serratus in elevation of the arm. The pectoralis minor can be felt in contraction in the middle phase of the movement. The rotation of the scapula, although it starts late, is completed when the arm is about 45 degrees from the side, and the last stage of depression, like the last stage of elevation, takes place in the shoulder-joint only. The relative force of the pectoralis major and latissimus varies noticeably as the depression is made at different angles to the front and rear of the lateral plane, the pectoral showing most tension when the arm is forward and the latissimus when it is back. When the movement is made in a plane as far to the rear as possible, the posterior deltoid acts with the latissimus and teres major and the pectoral is idle; the deltoid, however, stops acting when within about 45 degrees of the side of the thigh. When it is in the forward plane or internal to it the pectoral acts alone.

An interesting relation between the use of pulley weights and some forms of stationary apparatus appears when we consider what happens if the weight is increased. If the weight attached to an overhead pulley is increased indefinitely the point is eventually reached, if the subject is strong enough to do the work, when this weight is greater than that of his body; when this time arrives, in place of the weight going up he will go up as the result of the action of his depressor muscles, changing the apparatus at once to the stationary type, like the parallel bars or the suspended rings. In a similar way, if we increase the weights of the chest pulley while the subject is swinging arms down past the thighs, when the weight equals his own we may replace the pulley machine by a pair of suspended rings or a horizontal bar and he will, with the same movement of the arms, lift his body and swing his feet above his head.

This points to the fact that work on stationary apparatus, such as bars, rings, and the like, is apt to be in the main for the depressors of the arm, just as work with dumb-bells is for the elevators.

We have referred to a tendency in both elevation and depression of the arm for the head of the humerus to leave the socket, because of the looseness of the ligaments and the direction of pull of the muscles. There is a type of movements in this group where this tendency is especially strong for another reason. In chopping with an ax or striking with a heavy sledge, for example, the arm and the tool is made to describe an arc so swiftly that centrifugal force tends to pull the arm from the body, and when the tool strikes to do its work the swing of the arm abruptly ceases and the vigorous pull of the depressor muscles is brought to bear on the joint in an oblique direction. To protect the joint from injury the coracobrachialis and the long head of the triceps are useful here, since they help somewhat in depressing the arm but exert most of their force lengthwise of the humerus, holding it firmly up in place.

HORIZONTAL SWING FORWARD.

After the arm has been raised to a horizontal position, as shown in Figs. 55, 56 and 60, it can be swung forward and backward in the horizontal plane. The forward movement involves a forward swing of the humerus in the shoulder-joint and an abduction of the scapula. The movement can continue forward and across until the upper arm comes in contact with the chest.

During this movement the arm is held up to its horizontal position by the supraspinatus and various sections of the deltoid, and moved forward by the anterior deltoid, pectoralis major and coracobrachialis. The scapula is held in the position of partial rotation upward by the lower serratus and abducted by the upper serratus. Variations in the height of the arm are brought about by different degrees of contraction of the upper and lower parts of the pectoralis major, associated with variations in the degree of rotation of the scapula.

HORIZONTAL SWING BACKWARD.

Starting with the arm horizontally forward, it can be swung backward horizontally until the two arms form one straight line, and then 20 or 30 degrees farther back, the movement being finally limited by tension of the pectoral muscles and the coracohumeral ligament. The swing of the humerus backward is due to contraction of the posterior deltoid and the infraspinatus and teres minor, with adduction of the scapula by the trapezius. The rhomboid cannot help without depressing the arm below the horizontal; the latissimus can help pull the arm back, but it will also pull it down, requiring more work of the middle deltoid to keep it up. When the arm is below the level of the shoulder, the latissimus, teres major and rhomboid can help move it backward.

When the arms are carried horizontally forward against an external resistance, such as that of a pulley weight, the scapulæ can be seen moving forward, by action of the serratus and pectoralis minor, while the anterior deltoid and both parts of the pectoralis major pull the humerus forward. Notice how the clavicles keep the plane of the scapula well in line with the humerus through the movement, so that the glenoid fossa is at each stage turned in the best direction to support the humerus; notice how the scapula rotates to keep this relation when the flexion is made a little above or below the horizontal plane, controlled by action of the lower serratus and rhomboid.

Fundamental movements of the arm	Elevation	Humerus	Forward	Deltoid 1. Supraspinatus. Pectoralis major 1. Coracobrachialis.
			Sideward	Deltoid 2. Supraspinatus.
			Upward	Deltoid 1. Deltoid 2. Supraspinatus.
		Scapula, rotation upward		Trapezius 1, 2, 3, 4. Serratus 2.
	Depression	Humerus, depression		Latissimus. Teres major. Pectoralis major 2. Coracobrachialis.
		Scapula, rotation down		Rhomboid. Levator. Pectoralis minor.
	Forward swing	Humerus, forward		Deltoid 1. Pectoralis major. Coracobrachialis.
		Scapula, abduction, rotation upward		Serratus 1. Serratus 2.
	Backward swing	Humerus, backward		Deltoid 3. Deltoid 2. Infraspinatus. Teres minor.
		Scapula, adduction, rotation upward.		Trapezius 2, 3, 4.

The uniform manner in which all subjects perform the four fundamental movements of the arm—elevation, depression, forward swing and backward swing, gives us reason to believe they are inherited coördinations, like walking, running, etc., developed by nature as the race has developed, so as to get the work done in the most economical and efficient way. Such coördinations are not easily changed, even if they could be improved, and it would seem wise for teachers of gymnastics to use exercises that bring in these normal movements rather than to try to invent new ones on a different plan.

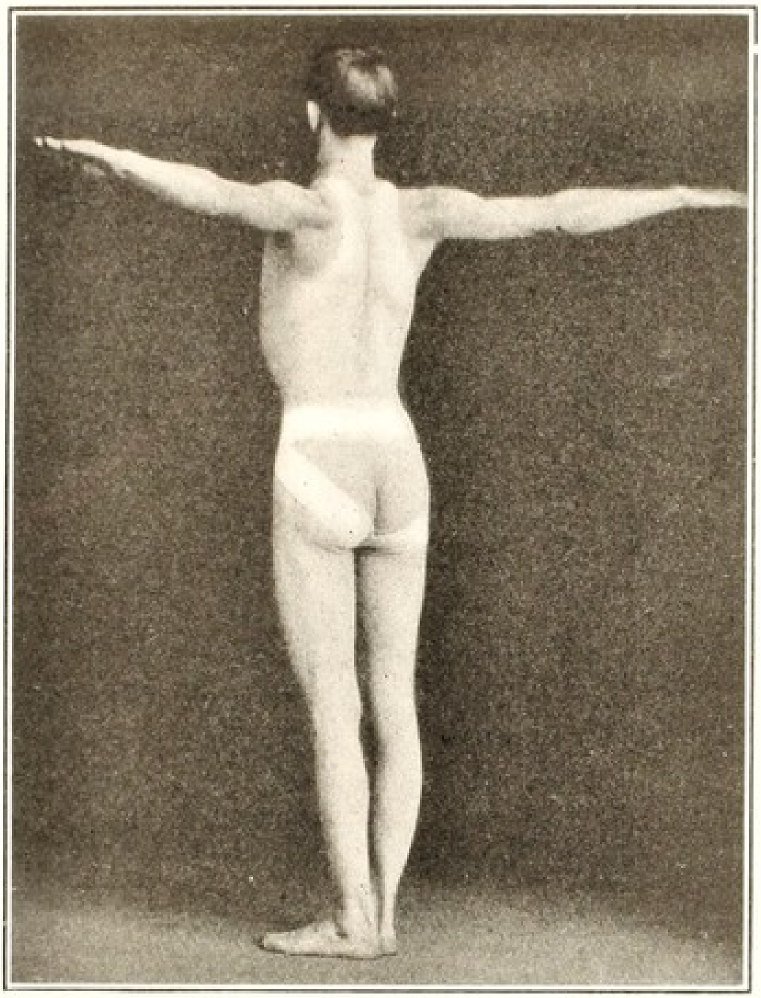


FIG. 60.—Arms sideward, as taken in Swedish gymnastics.

GYMNASTIC MOVEMENTS.

A gymnastic movement, as the term is now understood, is a movement taken in imitation of a pattern or model shown or described, and therefore is always predetermined and defined, as to its starting position, its course, its speed, and its terminal position. Gymnastic movements are devised to accomplish some purpose in the mind of the inventor, which purpose may be to develop or improve the tone of some muscle group, stretch some muscle or ligament, influence the circulation of lymph or blood, acquire skill or "form" in some exercise to be used in competition, form certain habits of movement or posture, etc.

Raising Arms Sideward (Fig. 60).—This is taken with palms down and the arms held a little behind the lateral plane, terminating at the horizontal with the arms carried as far to the rear as possible. The object here is improved posture of the chest, gained through adduction of the scapulæ and some elevation of the ribs. The scapula is drawn back by the trapezius and the arm held up and drawn back by the supraspinatus, middle and posterior deltoid, assisted somewhat by the infraspinatus and teres minor; this puts a tension on the two pectorals and thus lifts somewhat on the ribs on the front of the chest. Taken in this way this is a perfectly normal extension of the shoulder-joint, but writers on the theory of Swedish gymnastics are inclined to urge the use of the rhomboid and latissimus, "to flatten the back and help adduct the scapulæ." They infer that the vertebral border of the scapula should be paralell to the median line, apparently forgetting that normal elevation of the arm to horizontal requires upward rotation of the scapula and contraction of the lower serratus; action of the rhomboid and

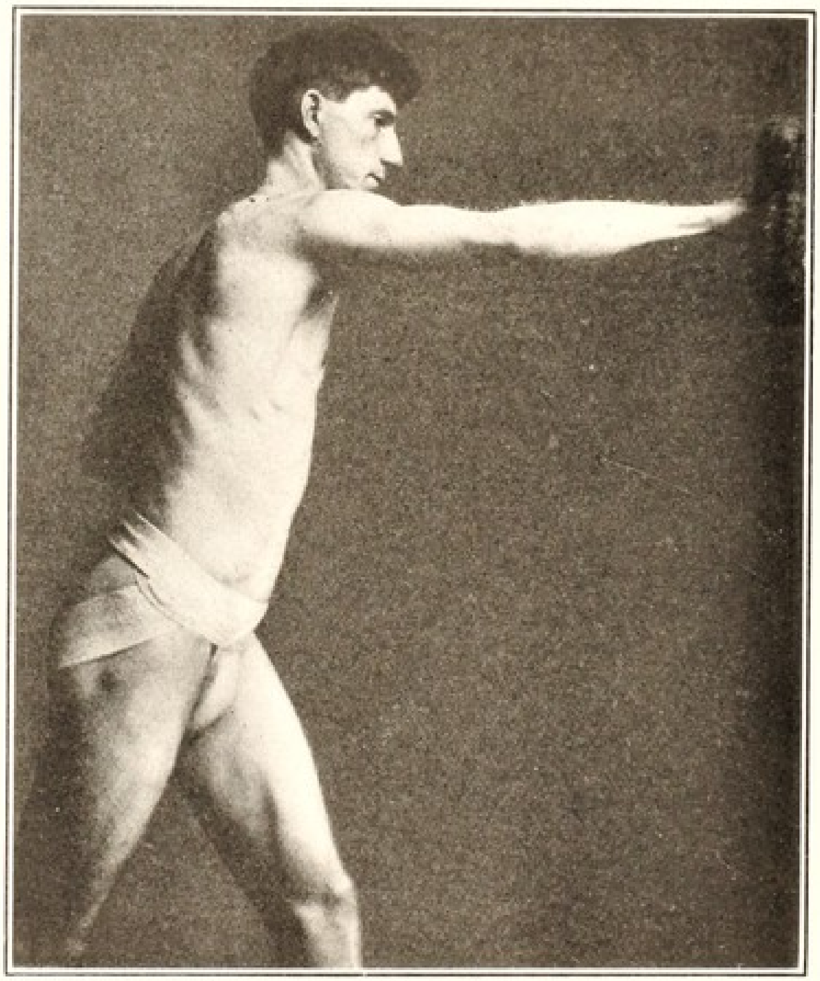


Fig. 61.—The normal forward position of the arm as used in pushing and striking, the scapula being considerably abducted.

serratus together will do nothing but lift the scapula vertically—something they want the latissimus brought in to prevent. The normal rotation of the scapula is also needed to give the tension on the pectoralis minor that is specially desired, while the action of the latissimus and rhomboid would prevent it. For these reasons the normal movement of shoulder extension seems best adapted to secure the results desired; the added action of the rhomboid and latissimus occurs in the awkward and less effective attempt of a beginner who tries with all his might and thus by uncontrolled spread of nerve impulses stimulates muscles that do more harm than good.

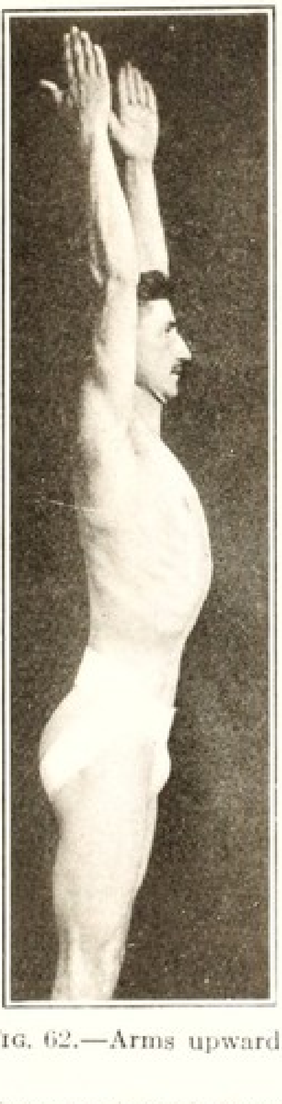


Fig. 62.—Arms upward.

Raising Arms Sideward-upward and Forward-upward.—These are normal elevations of the arms to vertical position, taken for muscular development and to aid in chest expansion. The upward rotation of the scapula lifts on the pectoralis minor and through it lifts on the ribs, while the elevation of the humerus acts in the same way on the pectoralis major and those fibers of the latissimus that arise from the ribs, so that the movement may well aid in chest expansion. Many writers mention the serratus as an elevator of the ribs, but it is difficult to see how it can do so directly, since it pulls down on quite as many ribs as it pulls up; it seems more likely that it acts only indirectly by rotating the scapula and thus works through the pectorals. Exponents of the Swedish system insist here, as in most arm movements, on the use of the rhomboid and the latissimus "to aid the trapezius," failing to consider that these muscles are direct antagonists of arm elevation and therefore antagonists of the trapezius whenever arm elevation is involved.

When we recall that the utmost traction on the ribs requires complete elevation of the arm, and that this is impossible without complete upward rotation of the scapula, which action of the rhomboid prevents, it is hard to see how the introduction of this antagonist can improve the result. The argument for use of the latissimus is nearly as weak; it pulls down on the arm much more than it pulls back, when the arm is up to vertical, so how can its action put more tension on the pectorals to lift the ribs? If the muscles used in normal elevation of the arm are weak or the opposing muscles are short, it will be hard enough to put the arms up to vertical without action of antagonists; if it is so easy for anyone to put the arm up to vertical that he needs more work, it would seem wiser to add to the resistance by a dumb-bell or a pulley weight rather than to upset the normal coördination by the use of muscles that do not normally take part.

QUESTIONS AND EXERCISES.

1. Pick out a humerus from the bones of a dismembered skeleton; point out and name its two extremities, its two tuberosities, its two condyles, its bicipital groove; tell whether it is a right or a left humerus.
2. Write in a column the names of the six movements of the shoulder-joint; in a parallel column 4 inches away write the names of the nine muscles acting on this joint; by lines connecting movement with muscle indicate the actions of each muscle.
3. Explain why those who cannot raise arms up to vertical usually complete the exercise with arms in front of the vertical; explain why the action of the rhomboid will add to the difficulty.
4. Demonstrate with a pulley machine exercises for developing each of the nine muscles acting on the shoulder-joint.
5. Explain why dumb-bell exercises develop the trapezius more than the rhomboid; the anterior more than the posterior deltoid.
6. Explain why exercises on bars and rings develop the latissimus and the rhomboid so much more than the deltoid and trapezius.
7. By use of a ruler or tape find the length of the power arms in case of each of the nine shoulder muscles.
8. With a loose scapula and humerus demonstrate how elevation of the humerus is limited in the shoulder-joint; how the rotation of the humerus permits further movement; how elevation can be greater at the front than at the rear.
9. By means of an inelastic cord attached to the mounted skeleton, find the extent of contraction of each of the nine muscles and thus find the length of their muscular fibers.
10. If the deltoid pulls with a force of 400 pounds and the supraspinatus with a force of 200 pounds, how much will they together lift at the hand when the arm is horizontal? Find distances and angles of pull by reference to the skeleton.

CHAPTER VI.

MOVEMENTS OF ELBOW AND FOREARM.

The arm has a hinge joint at the elbow and a rotary union of radius and ulna in the forearm.

The elbow is a typical hinge joint, the humerus articulating closely with the ulna and slightly with the radius. The movements are flexion and extension, taking place through an angle varying in different subjects from 120 to 150 degrees. Extension is limited by contact of the olecranon process of the ulna against the posterior side of the humerus; flexion is limited by contact of the muscles on the front of the arm. Some individuals can overextend the arm at the elbow while others cannot fully extend it, the difference being due mainly to occupation, habitual position of the joint and variation in the laxness of ligaments. The capsule of the joint is reinforced by strong bands of connective tissue on the outer and inner sides.

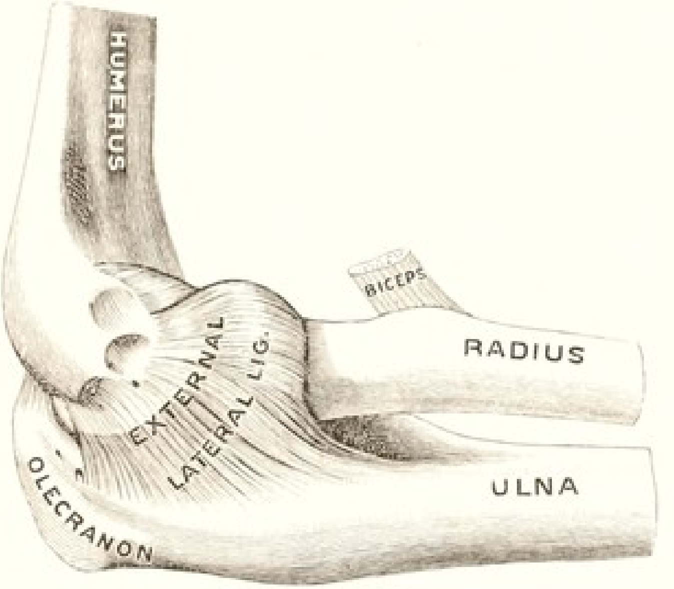


Fig. 63.—The elbow-joint, outer side. (Gerrish.)

The radio-ulnar union is a double pivot joint, the radius rotating in a ligamentous ring at the elbow and the lower ends of the two bones describing semicircles around each other at the wrist. The ulna cannot rotate at the elbow and the radius cannot rotate at the wrist, yet by means of the peculiar manner of union between the two the hand can turn through nearly 180 degrees. This, together with the 90 degrees of rotation possible in the shoulder-joint, makes it possible to turn the hand through almost 270 degrees when the elbow is extended. The position with palm upward is called the supine position, and the rotation of the forearm inward and upward to this position is called supination; the position with palm downward is called the prone position of the arm, and the rotary movement to this position is called pronation.

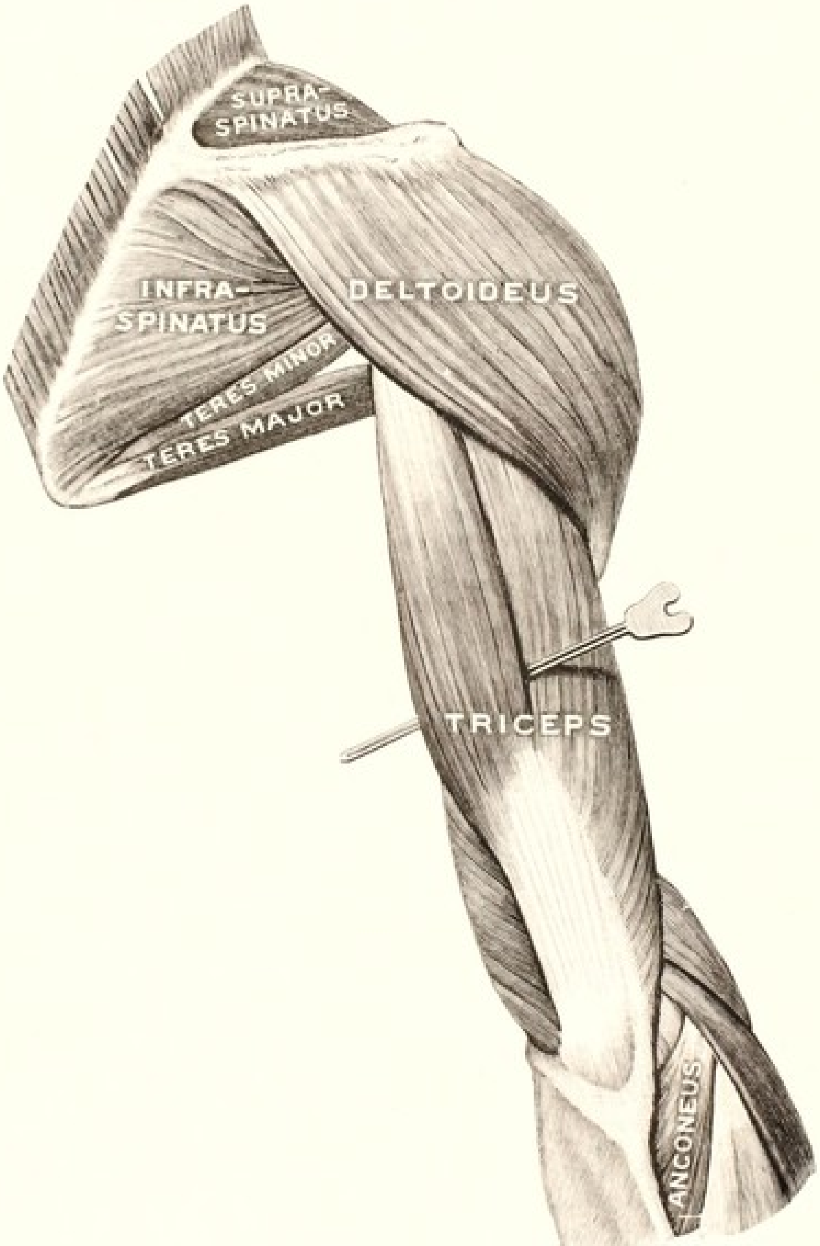
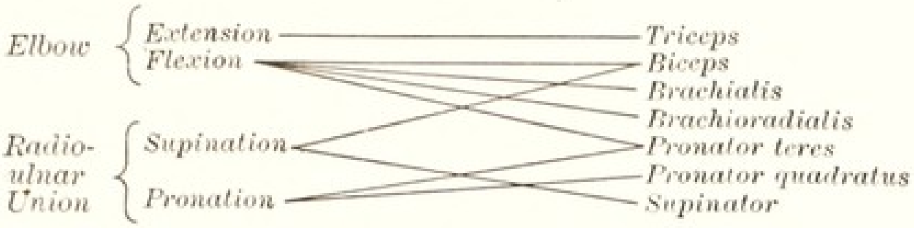


FIG. 64.—Muscles on the back of shoulder and arm. (Gerrish.)

There are five muscles acting on the elbow-joint; two of these also have some action on the shoulder-joint and two act also on the radio-ulnar union. Two muscles act on the radio-ulnar union only, giving the following list:



TRICEPS.

The triceps is on the posterior side of the upper arm, and, as its name implies, has three separate places of origin (Figs. 64, 209, 210, 212).

Origin.—(1) The middle or long head, from the scapula, just below the shoulder-joint; (2) the external head, from a space half an inch wide on the back of the humerus, extending from the middle of the shaft up to the greater tuberosity; (3) the internal head, from the lower part of the back of the humerus, over a wide space extending nearly two-thirds of the length of the bone.

Insertion.—The end of the olecranon process of the ulna.

Structure.—The long head has a short tendon of origin; the fibers of the other two parts arise directly from the humerus. The tendon of insertion is flat, and as it leaves the ulna it broadens into a thin sheet that extends far up the external surface of the muscle and the muscular fibers attach obliquely to its deeper surface. The long head passes up between the teres major, lying in front, and the teres minor, behind it.

Action.—The olecranon process of the ulna extends past the elbow-joint and the triceps is inserted into the end of it, making of the ulna a lever of the first class. Since the triceps pulls up on the olecranon it will evidently move the main part of the lever down and thus extend the elbow-joint. The leverage is short, favoring speed rather than power; the angle of pull is nearly 90 degrees through a large part of its movement, the tendon passing over the lower end of the humerus as a pulley; the great number of short fibers in its structure, together with its large angle of pull, gives the muscle great power as well as speed. The origin of the middle head on the scapula enables that part to act on the shoulder-joint as well as the elbow; a rubber band looped around the olecranon and held at the point of origin shows plainly that its pull is chiefly lengthwise of the humerus, lifting its head up into the glenoid cavity. If the humerus is lifted the tension on the rubber band is increased, showing that it is able to aid in depressing the arm, but its angle of pull is here very small.

Loss of the triceps destroys a person's ability to extend the elbow forcibly, but does not disable him for light tasks, since the weight of the forearm will extend the elbow when there is no resistance, making it possible to use the hands in any position when the movement requires little force.

Stimulation of the different parts of the triceps causes extension of the elbow with great speed and power. Duchenne states that the long head has much less power to extend the elbow than the other two parts, but this is no doubt due largely to the fact that he used electric stimulus when the subject was standing at ease, the scapula and humerus not being held in place firmly as they are in normal coördinated action. The action of the long head to depress the humerus and lift the humerus lengthwise is plainly shown in Duchenne's experiments.

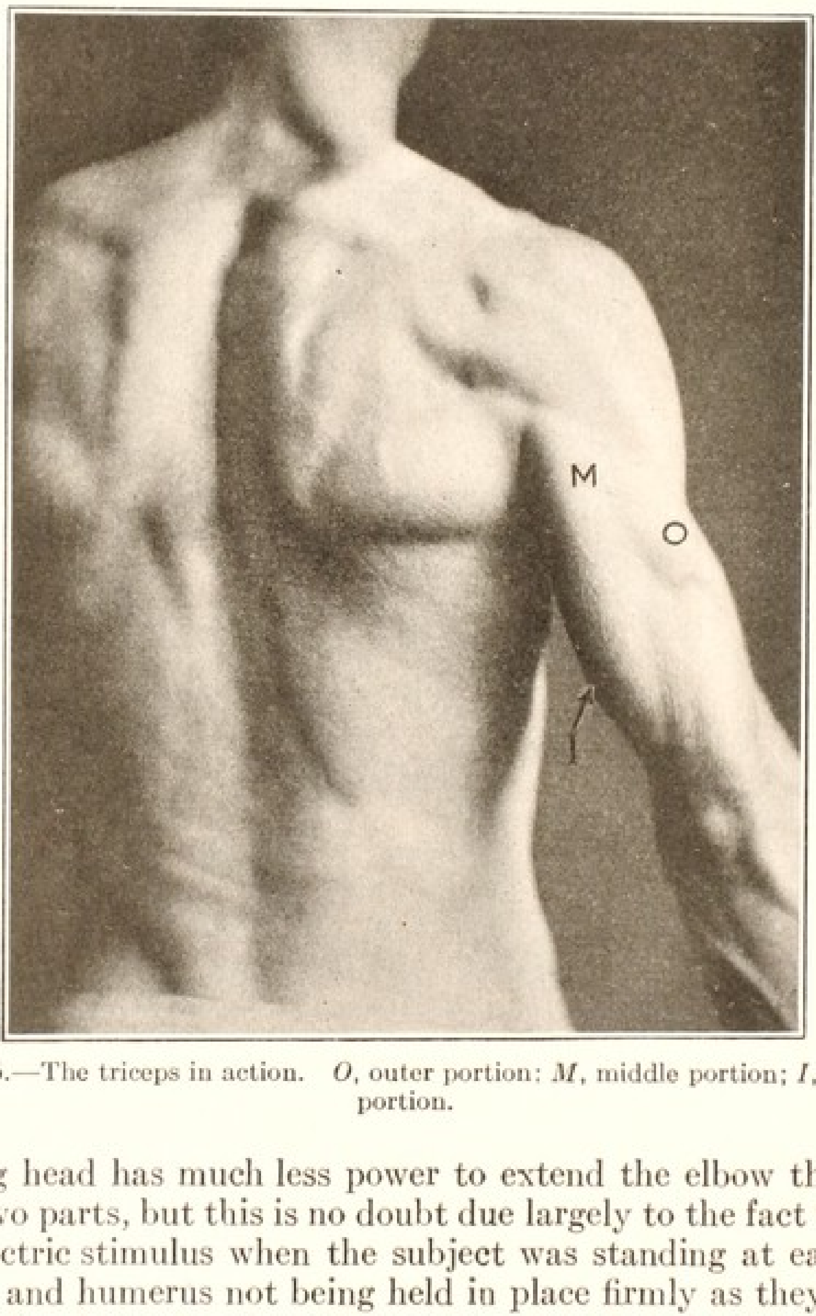


Fig. 65.—The triceps in action. *O*, outer portion; *M*, middle portion; *I*, inner portion.

The triceps can be seen and felt in vigorous action in all movements involving forcible extension of the elbow; its action is prominent in such exercises as boxing, putting the shot, driving nails, thrusting dumb-bells, pushing a lawn mower, chopping with an axe, shovelling, etc.

BICEPS.

A prominent muscle on the front side of the upper arm with two separate places of origin (Fig. 50).

Origin.—(1) The outer or long head, from the scapula at the top of the glenoid fossa, the tendon passing over the head of the humerus and blending with the capsular ligament of the shoulder-joint; (2) the inner or short head from the coracoid.

Insertion.—The bicipital tuberosity of the radius.

Structure.—The tendon of the long head is long and slender and lies in the bicipital groove of the humerus, becoming muscular at the lower end of the groove. The tendon of the inner head is shorter, the muscular fibers of the two parts being of equal length. The tendon of insertion is flattened as it joins the muscle and passes up as a septum between the two parts and receives the fibers in a penniform manner from both sides.

Action.—The biceps is in a position to act on three joints: shoulder, elbow, and forearm. Tension on the long head will surely help to hold the head of the humerus in the socket and the inner head will act with it to lift the humerus lengthwise. Both parts act to flex the elbow, the power arm being somewhat over an inch in length and the angle variable from 15 to 20 degrees in the position of complete extension up to 90 degrees when the elbow is flexed to about a right angle and diminishing again as flexion continues. When the hand is placed in extreme pronation the bicipital tuberosity of the radius is turned inward and downward, wrapping the tendon of the biceps more than half-way around the bone; contraction of the muscle will evidently tend to unwrap it and thus supinate the hand. Both the flexing and supinating actions of the biceps will take place to best mechanical advantage when the arm is half flexed.

Isolated action of the biceps flexes the elbow, supinates the hand and lifts the humerus up into the shoulder-joint, without raising the arm.

Loss of the biceps does not make one unable to flex the elbow, since there are other muscles able to perform this movement; those who have the use of the other flexors but lack the biceps can do light work readily, but when they try to lift heavy objects the weight pulls the head of the humerus down out of its socket, causing pain and quick fatigue. When all the flexors are lost the use of the arm is practically abolished, as the subject cannot lift the hand to the face nor touch the body with the hand above the middle of the thigh; this makes it impossible for him to dress or feed himself.

The biceps can be observed in action in all movements involving forcible flexion of the elbow, such as lifting, rowing, climbing, and the like; in all forcible supination, as in turning a screw-driver to turn a screw in with right hand or out with left; when the arm is raised sideward it seems to contract during a horizontal swing of the arm forward, but this may be done to protect the elbow against injury from overextension, which the movement tends to produce.

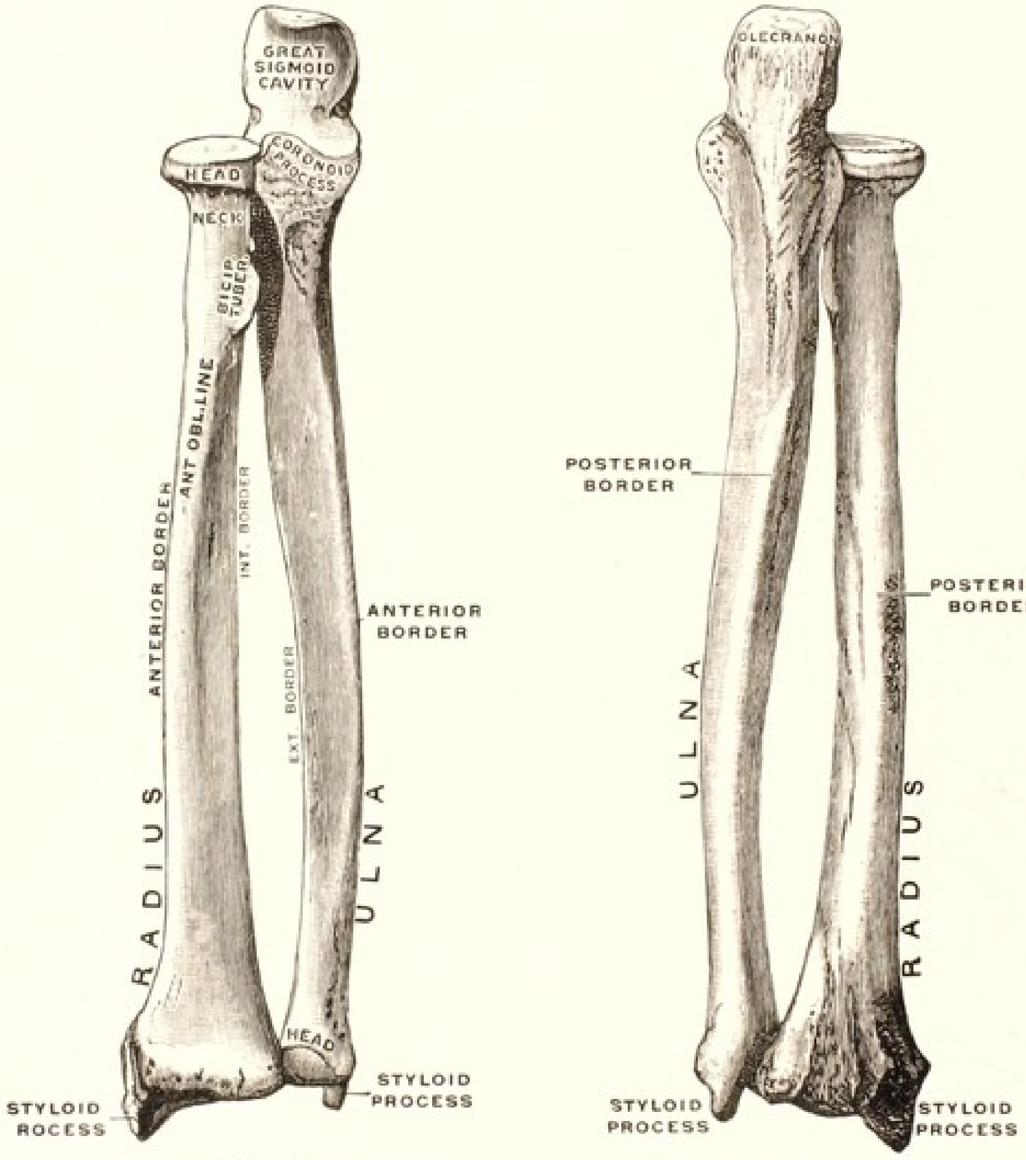


Fig. 66 Fig. 67

Figs. 66 and 67.—The radius and ulna. (Gerrish.)

When the biceps is stimulated by electricity it flexes the elbow and supinates the forearm at the same time, and the question arises, How does one perform these two movements separately and use the biceps in both? Anyone can easily demonstrate on his own arm that he can flex the elbow without difficulty with the forearm in any position from extreme pronation to extreme supination, and can supinate the forearm while the elbow is in any position between complete flexion and complete extension, the biceps acting in all cases. Evidently the will can do nothing directly to cause one of the two movements separately, for it can do no more than stimulate the muscle to action.

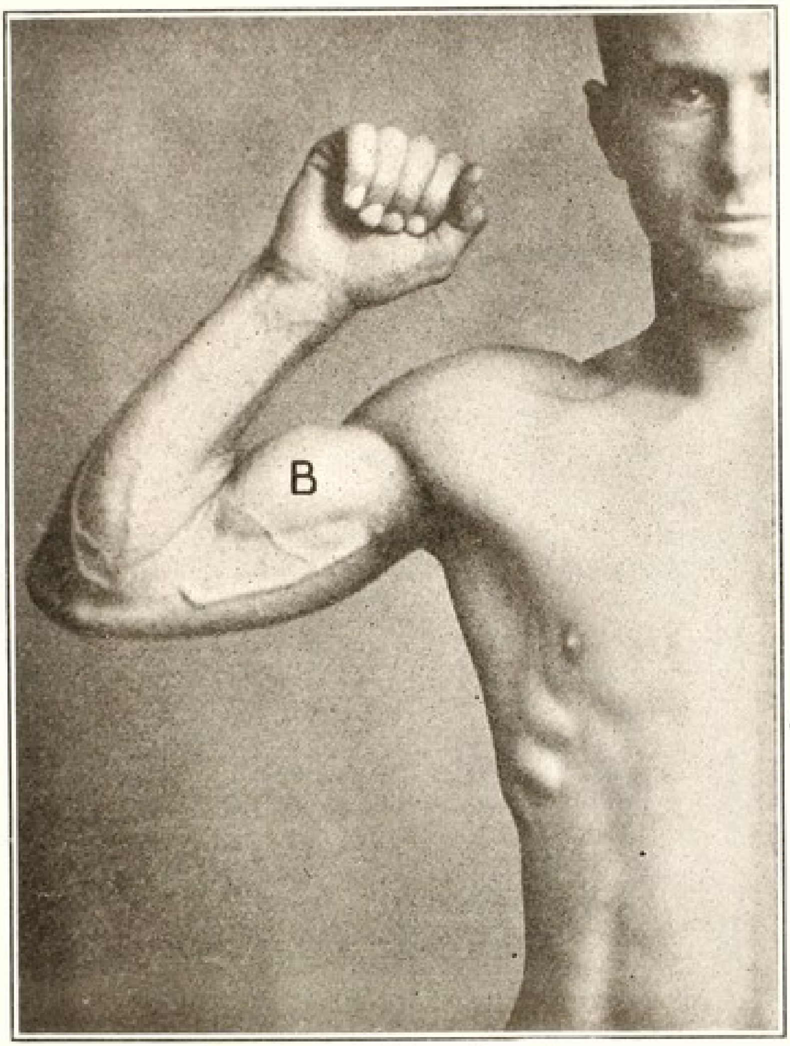


FIG. 68.—The biceps in action.

The reader can find a clue to the problem by making the following easy test: stand in front of the person who acts as subject and facing him, with your left hand grasping his upper arm loosely with the finger-tips resting on the triceps and the thumb on the biceps, so as to be able to detect any contraction of either; now have him supinate the forearm strongly while with your right hand you grasp his hand to resist the movement he makes, and notice how both his biceps and triceps contract at the same time. Evidently the biceps is acting to supinate the forearm, but why is the triceps working? Beevor, who first explained the matter, says that the triceps acts to prevent the elbow from being flexed by the action of the biceps, and that this is the way such actions are separated in all cases of this kind. For example, when the latissimus, pectoralis major and teres major act to depress the arm they also tend to rotate it inward, for they all attach to the humerus in a way to produce this combined action; to prevent this rotation, which is not wanted in driving nails with a hammer, the infraspinatus and teres minor contract—not to help directly in depressing the arm, as some observers have concluded, but to prevent the rotary action produced by the depressors.

All this has a bearing on the interesting problem of the use of a screw-driver. When any considerable force is needed to turn the screw it is also necessary, as all know who have used this tool, to push hard to keep the tool in the slot in the top of the screw. How can we turn the screw, which requires action of the biceps, and at the same time push, which requires action of the triceps? Examination of the arm while the work is being done will convince anyone that both muscles are in action at the same time. Every pound of pull of the biceps acts on the elbow-joint to neutralize the pull of the triceps, and the biceps has much the better leverage. How can the triceps extend the elbow with any force under these conditions? The only explanation seems to be that the triceps, because of its structure, is stronger than the biceps, or that the biceps is inhibited from its full contraction when we try to push with greatest force. The force of the push must be the amount by which the action of the triceps exceeds that of the biceps, and the stronger we push the less force can be used to turn the screw. It is also interesting to notice that when this tool is used with the elbow bent to a right angle only the muscles we have just mentioned take part in turning it; but when the elbow is fully or almost extended the infraspinatus and teres minor act too, since in this position supination and outward rotation are combined.

BRACHIORADIALIS.

This muscle was named "the long supinator" by the ancient anatomists, but its action has been found to be different and its name has therefore been changed. "Brachium" is the Latin for the upper arm, so that the present name indicates its attachment to the radius and humerus. It is situated on the outer border of the forearm and gives rise to the rounded contour from the elbow to the base of the thumb (Fig. 69).

Origin.—The upper two-thirds of the external condyloid ridge of the humerus.

Insertion.—The external surface of the radius at its lower end.

Structure.—Arising directly from the humerus, the fibers join the lower tendon in a penniform manner.

Action.—The position of the brachioradialis indicates it as a flexor of the elbow; its leverage is long but its angle of pull very small; computation shows that when both are taken into account it has better mechanical advantage than the biceps. Its location suggests that it will turn the forearm into a position midway between pronation and supination.

Isolated action of the brachioradialis flexes the elbow with great force and either pronates or supinates, according to the position of the hand when it contracts.

Study of the normal action of this muscle, which is easily made, shows that it takes part in flexion of the elbow, its fibers lifting the skin near the joint as soon as the slightest flexion takes place. When it is observed during voluntary pronation and supination it is seen to lie idle in both cases, but if any movement of flexion occurs with the rotation it at once springs into action.

BRACHIALIS.

Literally translated, "muscle of the upper arm." It is located between the biceps and the humerus near the elbow (Fig. 50).

Origin.—Anterior surface of the humerus for its lower half.

Insertion.—Anterior surface of the ulna near the elbow.

Structure.—The tendon of insertion flattens into a thin sheet and the muscular fibers, arising from the humerus, are attached obliquely to its deeper surface.

Action.—Simple flexion of the elbow is indicated by conditions of action and verified by electric stimulation. It can be felt during strong flexion of the elbow, swelling out laterally between the biceps and the bone; its leverage fits it for speed rather than power.

PRONATOR TERES.

A small spindle-shaped muscle lying obliquely across the elbow in front and partly covered by the brachioradialis (Fig. 69).

Origin.—Front side of the internal condyle of the humerus.

Insertion.—Outer surface of the radius near its middle.

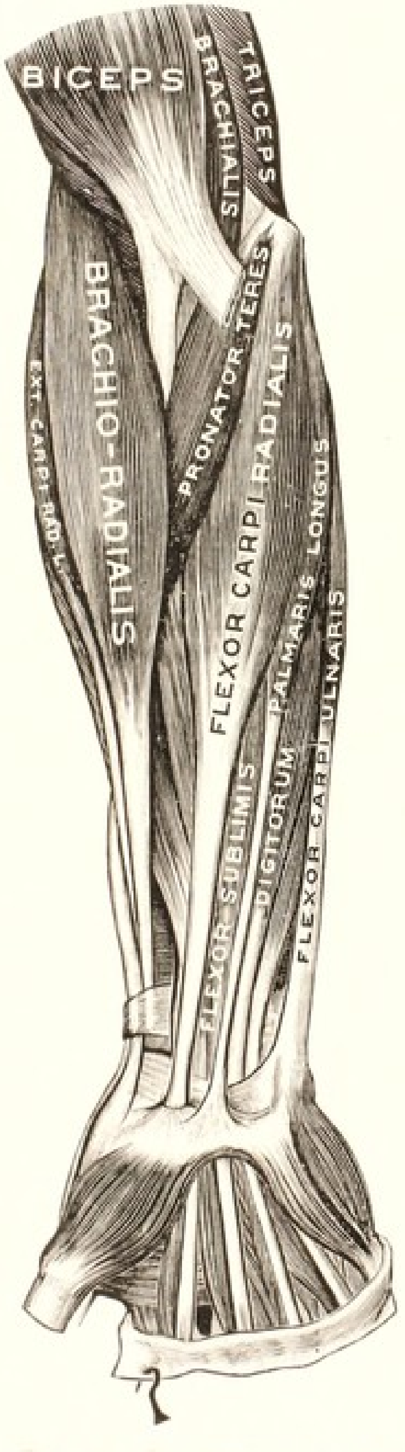


Fig. 69.—Superficial muscles of the front of the forearm. (Gerrish.)

Structure.—Fibers arising from short tendons join the tendon of insertion obliquely, the latter lying beneath the muscle for half its length.

Action. — A rubber band looped around the radius at its middle so as to pull from the outer side, with its free end held with some tension at the inner condyle, readily produces pronation, followed by a slight amount of flexion. Isolated action gives the same result.

The pronator teres can be seen and felt in contraction without much difficulty in favorable subjects. In pure flexion it acts with the biceps, its pronating action neutralizing some of the supinating action of the larger muscle. In pure pronation against a resistance the triceps can be felt in mild contraction to neutralize the flexing action of the pronator teres, just as it acts with the biceps in supination, but much less vigorously.

PRONATOR QUADRATUS.

A thin square sheet of parallel fibers lying deep on the front of the forearm near the wrist (Fig. 70).

Origin.—Lower fourth of the front side of the ulna.

Insertion.—Lower fourth of the front side of the radius.

Structure.—Parallel fibers attached directly to the bones.

Action.—Pronation, as judged by its position. Isolated and normal action not tested.

SUPINATOR.

Formerly called "the supinator brevis" to distinguish it from the so-called "supinator longus" which has been renamed, making

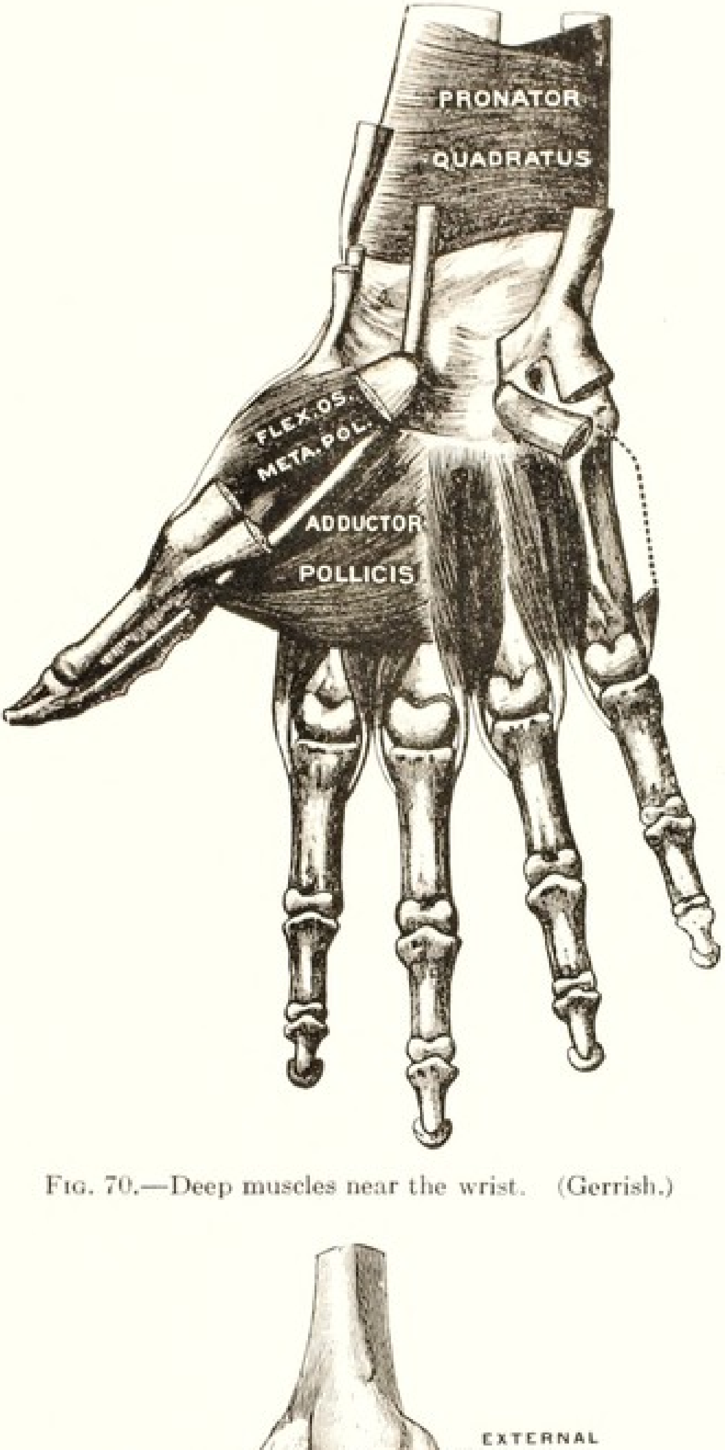


FIG. 70.—Deep muscles near the wrist. (Gerrish.)

FIG. 71.—The supinator. (Gerrish.)

the adjective unnecessary. The muscle is a small one situated on the back of the arm just below the elbow.

Origin.—External condyle of the humerus, neighboring part of the ulna, ligaments between.

Insertion.—Outer surface of the upper third of the radius.

Structure.—Mostly parallel fibers.

Action.—Supination, as shown by its position and isolated action.

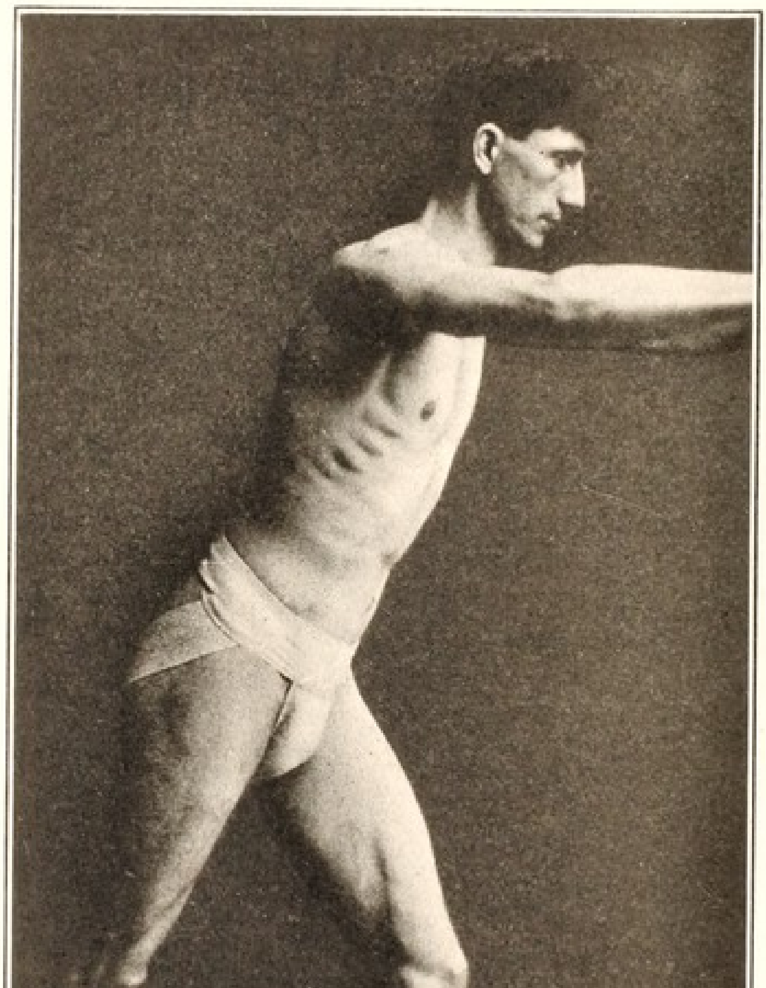


Fig. 72.—Pushing forward with both arms.

FUNDAMENTAL MOVEMENTS.

The upper limb as a whole has at least four fundamental movements definitely fixed in the nervous system: pulling, pushing, striking, and throwing.

Pulling.—Pulling is a combination of elbow flexion and arm depression, illustrated well by grasping the handles of the chest pulleys with arms at front horizontal and drawing them to the chest;

the same is true when handles of overhead pulleys are pulled down to same place. The elbows are completely flexed and the humerus depressed and carried far backward.

Pushing.—Pushing, which is most readily done forward, is a combination of extension of the elbow with elevation of the arm, produced by action of the triceps, anterior deltoid and upper pectoralis major, aided by the serratus to bring the scapula forward.

Striking.—Striking forward, as in *boxing* (see Fig. 61), involves the same movement of the arm as pushing and uses the same muscles, but the manner of doing it is very different. In pushing one places his hand on the object to be pushed before the push is made, while in boxing the fist is given the utmost speed by the arm movement before the object is reached.

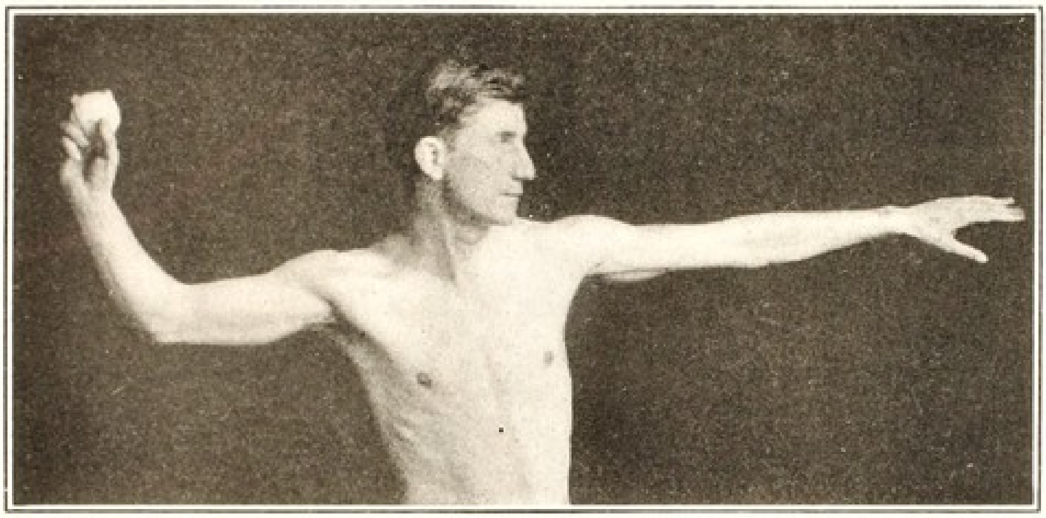


Fig. 73.—A starting position for throwing.

A turn of the body can increase the speed of the blow and for that reason the boxer can do best by striking with one hand at a time.

When striking is done with a weapon or tool the blow may be made forward as in boxing, illustrated by a thrust with a sword, but more often is given by a downward swing of the arm as in driving nails with a hammer, using the arm depressors along with the triceps. This gains the advantage of the weight of the arm and tool and permits momentum to be gained by the wide swing.

Throwing.—Throwing, in its simplest form, as seen in throwing done by small children and by older people who have not had much practice, consists of a forward swing of the straight arm. The hand holding the object to be thrown is raised high overhead and then swung forward by the action of the arm depressors. The hand describes the arc of a circle about the shoulder-joint as a center, and when the object is released by relaxing the grasp it goes on in the direction it was travelling at that instant, following a line tangent to the circle. A ball can be thrown with considerable force in this way, but it is not easy to aim accurately because the hand, moving in a circular path, changes its direction at every moment and the object must be released at the exact instant or it goes wide of the mark.

In the more complex coördination used by ball-players who have had much practice the circular movement of the hand is changed to almost a straight line. This makes it easier to hit the mark, for if the projectile is moving in a straight line toward any point it matters little when it is released. To change the motion from a curve to a straight path the arm is moved far back instead of upward, and as the humerus swings forward by action of the pectoral and serratus, the elbow is flexed and then extended to just the right extent. Beginners who try this plan make a zigzag at first, but with practice a straight line can be made in the air by the moving hand.

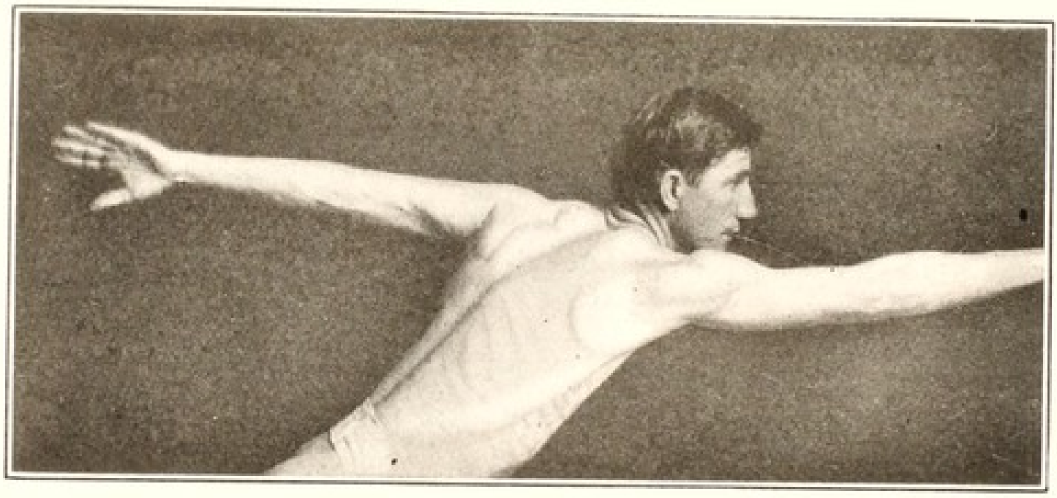


Fig. 74.—The finish in throwing.

Accurate throwing depends on making a nearly straight line and making it in exactly the right direction. Speed of throw depends upon how long the hand keeps in contact with the ball and keeps increasing its speed; the farther back one starts and the farther forward the ball is released the more speed one can give it.

Throwers use the triceps, posterior deltoid, lower serratus and trapezius mildly in preparing to throw. In the throw they use the biceps group followed quickly by the triceps, and at the same time the pectoralis major and the serratus 1 and 2 contract with all the speed and power they possess.

Fundamental movements	Pushing (forward)	Extension of elbow	Triceps.
		Elevation of humerus	Deltoid 1. Supraspinatus. Pectoralis major 1. Coracobrachialis.
		Abduction of scapula, rotation upward	Serratus 1. Serratus 2.
	Pulling (backward)	Flexion of elbow	Biceps. Brachialis. Brachioradialis. Pronator teres.
		Depression of humerus	Latissimus. Teres major. Deltoid 3.
		Adduction of scapula, rotation downward	Rhomboid. Levator. Latissimus.
	Throwing (forward)	Extension of elbow	Triceps.
		Forward swing of humerus	Deltoid 1. Pectoralis major. Coracobrachialis.
		Abduction of scapula, rotation upward	Serratus 1. Serratus 2.
	Striking (downward)	Extension of elbow	Triceps.
		Depression of humerus	Latissimus. Pectoralis major 2. Teres major. Deltoid 3.
		Rotation downward of scapula	Rhomboid. Pectoralis minor.

GYMNASTIC MOVEMENTS.

Shoulders Firm.—This is an exercise intended to adduct the scapulæ and expand the chest. Starting with arms hanging at the sides, the elbows are flexed and the hands brought up by the shoulders and carried to the rear as far as possible; at the same time the elbows are held as close to the sides as possible (Fig. 75). The effort to put the hands far back calls the posterior deltoid into action along with the infraspinatus and teres minor, while the effort to keep the elbows down brings in the rhomboid, latissimus, and teres major. The outward rotation wraps the tendon of the latissimus around the humerus and thus increases its pull on the arm and shoulder, while the inner head of the biceps tends to resist the rotation outward. The backward movement of the arm and shoulder pulls on the two pectoral muscles and thus lifts the ribs.

Arm Stretching or Thrusting.—These are vigorous extensions of the elbows starting from "neck firm," "shoulders firm," or some other position in which the elbows are flexed. The arms finish in one or another of the positions taken in arm raising—forward, sideward, upward, downward, or backward. In the first three of these the action of the triceps is combined with arm elevation; in the latter two it is combined with vigorous arm depression. Besides the muscular training of the extension movements these exercises are useful because they afford variation in a continued practice of "neck firm" and "shoulders firm," two of the best posture exercises.

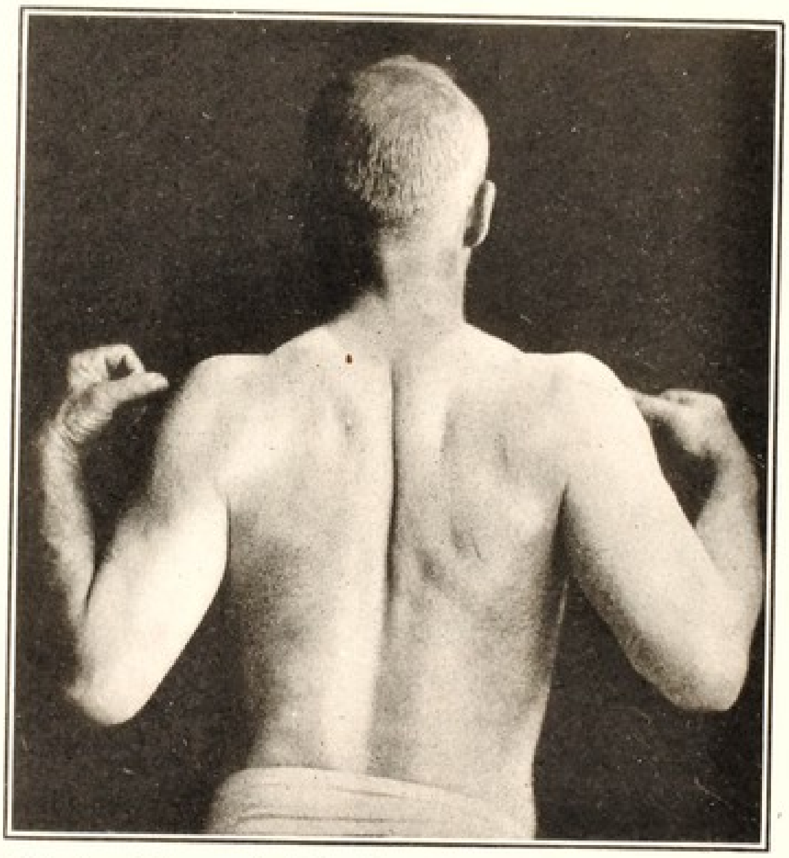


Fig. 75.—The Swedish exercise "shoulders firm," or "arms bend." The position of the right arm illustrates a common fault; the hand is not held back far enough to give complete adduction of the scapula.

Several *pulley exercises* belong here. Grasping handles of overhead pulleys and moving them downward in parallel straight lines until the arms are down beside thighs, combines work for the flexors of elbow and depressors of arm until elbows reach the sides, when extension of elbow takes the place of flexion. Standing facing the chest pulleys and moving handles to chest uses elbow flexors and arm depressors; standing with back to same pulleys and with ropes just over or under arms move them forward to horizontal from the chest brings in extensors of elbow with elevators of arm. Grasping handles of floor pulleys beside thighs and moving them in parallel straight lines upward to vertical position illustrates typical lifting, an exercise so important as to need special notice.

If one wishes to *lift* a heavy dumb-bell in the easiest way he keeps as near a vertical line as possible, since this makes the shortest possible weight-arms to work against. The complete movement of lifting any such weight up to vertical position includes three stages: (1) a vertical lift from the position beside the thigh to the level of the armpit; (2) a short semicircular movement from the point just below the shoulder-joint to the point above and in front of it; (3) vertical movement until the arm is extended upward. Stage (1) is performed by the flexors of the elbow, with the acromion held up by the levator and second part of the trapezius; the elbow projects far to the rear, due to the weight, which will hang vertically below the shoulder-joint if free to do so. When this point is reached the flexors hold the elbow completely flexed while the elevators of the arm carry the humerus forward nearly to the horizontal, which moves the weight through the curved path of stage (2). From this point on to vertical position upward the extensors of elbow act with the elevators of the arm to complete the movement. The question as to which stage of the lift is most difficult will be answered differently, depending on which muscles are most fully developed—flexors, extensors, or elevators. This analysis of the movement may often be seen by observing labor of various kinds, such as loading railroad iron on cars, loading crates into a high wagon, loading trunks on a train, etc.

Hanging by the Hands.—When one grasps something above his head and hangs vertically downward, the flexors of the hands are the only muscles that must act, because the weight of the body holds the arms and body in the erect position that would under ordinary circumstances require some muscular action. Two muscles, the pectoralis major and latissimus, join the arm to the trunk; the weight of the body is partly borne by these and partly by the muscles joining the humerus to the scapula and those that join the scapula to the trunk. Of all these the two pectorals and the lower fibers of the latissimus attach to the ribs, and since most of the weight of parts below is joined to the spinal column rather than to the ribs hanging by the hands is apt to produce some chest expansion and hence has value as a posture exercise. If the subject, while hanging by his hands, can adduct his scapulæ by the use of any or all the muscles on the back of the shoulders, more tension will be thrown on the pectorals and the ribs will be lifted still more.

Chinning the Bar.—When a person who is hanging by his hands tries to lift his body with his arms he brings into play the flexors of the elbow and depressors of the humerus. The exercise, commonly called "chinning the bar," is a popular test of the muscles, a boy of fourteen who can lift himself in this way until he can rest his chin on the bar six times in succession being considered fairly strong. Besides developing the arms the exercise is considered good for the posture of the chest if the subject is able to do it without bowing his back and lifting his legs, because the action of the pectorals on the ribs is stronger than in simply hanging by the hands and will lift them farther unless other muscles that pull down on the ribs from below prevent it; for this reason the exercise is not devised as a corrective of posture unless it can be done in good form. Letting the body slowly down to full arms' length

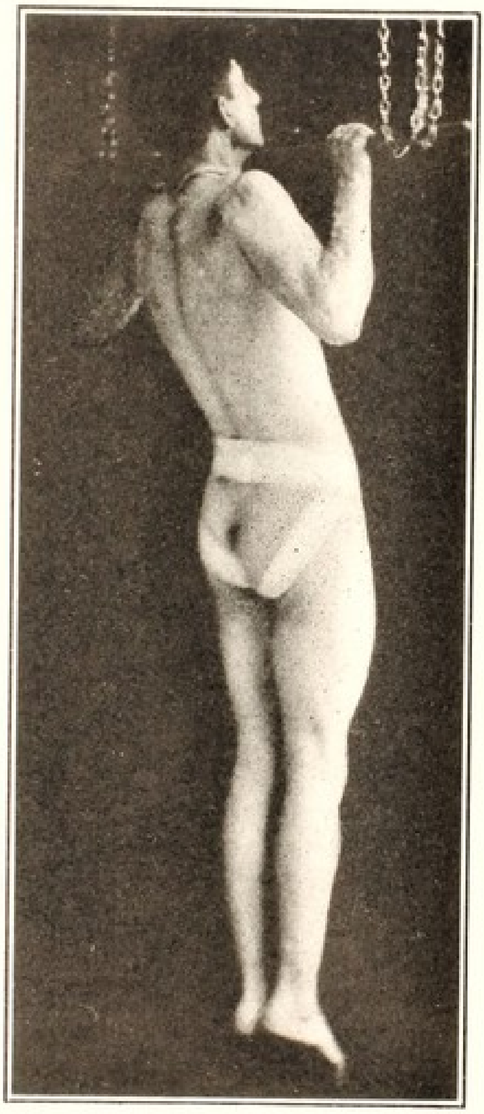


FIG. 76.—Chinning the bar.

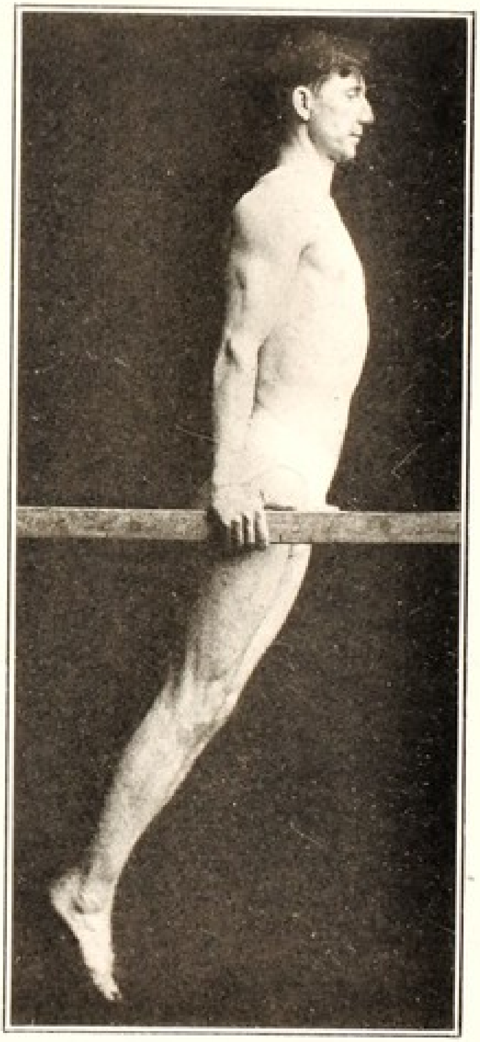


FIG. 77.—Cross rest on parallel bars.

from the position uses the same muscles more mildly, and this may be used to develop strength for the chinning movement, the subject standing on a bench to get the higher position and stepping off to let himself down. Lifting the legs during the exercise prevents it from producing chest expansion because it brings into action muscles that hold the ribs down.

Climbing Rope.—Climbing rope, if done with the aid of the feet and legs to grasp the rope, gives the same exercise for the arms as chinning the bar; if the legs are not used it is much more vigorous because the weight of the body must be held momentarily by one arm and then the other. Swinging on the travelling rings is similar but milder.

Cross Rest.—Cross rest on the parallel bars (German) is a familiar exercise to develop the extensors of the elbow and depressors of the humerus. The position is usually gained by a spring from the floor to make it easier for the two muscle groups just mentioned, but they are brought into use strongly in the last part of the lift of the body and must maintain vigorous contraction to keep the balance. Swinging legs and body forward and backward and walking forward and backward along the bars on the hands are among the various movements used to add to the vigor of the work. To hold one's position securely he must maintain an accurate balance between the relative force of contraction of the pectorals and the latissimus as the body weight is shifted (Fig. 77).

GAMES AND SPORTS.

Rowing.—Rowing is one of the simplest exercises for the arms. It consists of two parts; a rather mild forward push combined with arm depression and a stronger pull.

Beginning with arms flexed and body inclined well backward, the first part involves the triceps, pectorals, anterior deltoid and upper serratus to push the handle of the oar forward, the lower pectoralis major acting also as an arm depressor to lift the other end of the oar. If the outer end of the oar is heavy the deltoid may be left out of the work, since it tends to raise the arm as well as to advance it. During this phase of the movement the wrists are sometimes flexed to "feather" the oar.

As the forward motion is completed a relaxation of the pectorals lets the oar drop into the water and then the pull begins. Flexion of the elbow by the biceps group is combined with depression and backward movement of the humerus, produced by action of the latissimus, teres major and rhomboid, and the posterior deltoid.

Basketball.—The use of the arms in basketball consists principally of raising them to intercept or catch the ball and of throwing the ball by a forward movement, sometimes combined with extension of the elbow. There is a great deal of variation but the triceps and elevators of the arms, with the upper pectoral and serratus in the forward throw, have the main part of the work.

Volley Ball.—In volley ball the work of the triceps and arm-raising group is more prominent, since the ball is always batted and more often upward than in any other direction.

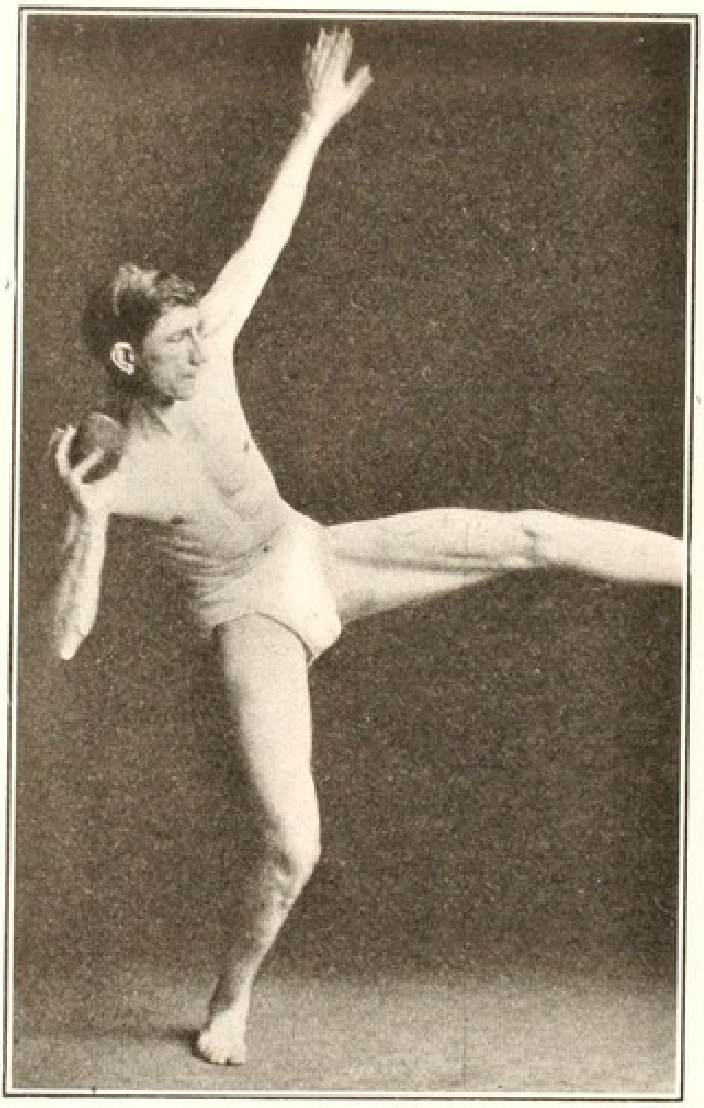


FIG. 78.—The starting position in putting the shot.

Bowling.—In bowling the ball is sent forward by a forward swing of the arm, using the arm-raising muscles.

Putting the Shot.—Putting the shot, like bowling, is mainly work for one arm. The object is to send the heavy shot as far as possible and this requires it to be elevated at an angle of about 45 degrees. The rules require that it shall be pushed from the chest, no swinging or throwing movements of the arm being allowed (Figure 78.)

In preparation for putting the shot is held close to the shoulder, the elbow completely flexed and the arm and shoulder held well back. This position puts the anterior deltoid, pectorals, and serratus on a stretch and in a favorable condition for strong action. Strong and quick contraction of these muscles and the triceps extends the arms diagonally upward and projects the shot into the air.

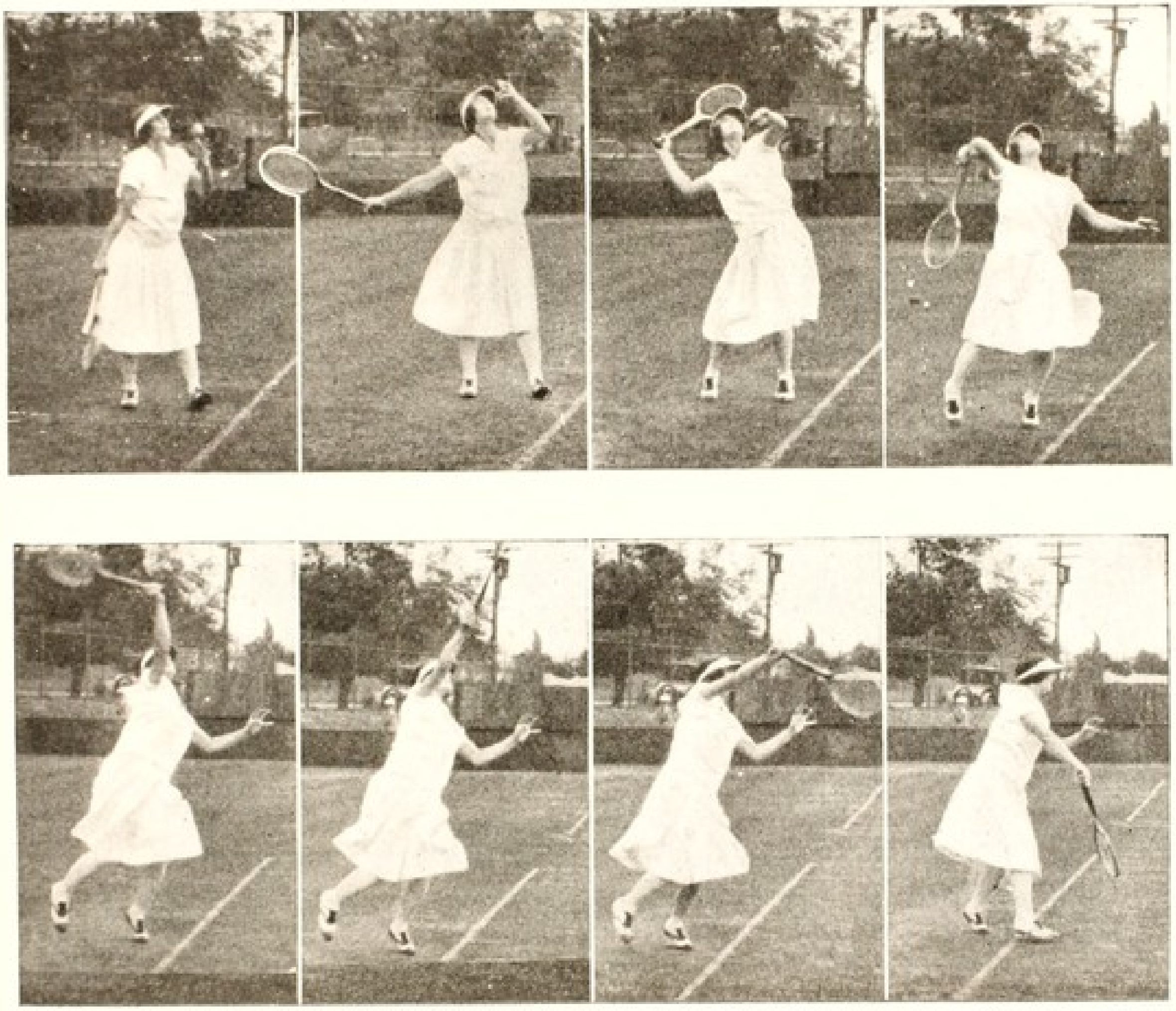


FIG. 79.—Helen Wills serving. Courtesy of American Lawn Tennis, Inc. (From "Mechanics of the Game." By J. Parmly Paret.)

Batting.—Batting in baseball and cricket is a form of striking, the club or bat being held in both hands and swung forward and across the body. Right-handed batters stand with the left side toward the pitcher and hold the bat with the right hand uppermost. The bat is swung over the right shoulder in preparation for striking, and when the ball comes it is swung to left to meet it.

Batting requires strong use of the flexors of hands and fingers to grasp the bat, action of the triceps of both arms to extend the elbows, with a different motion of the two upper arms. The right arm is swung across the chest by the anterior deltoid and pectoral, supported by the serratus; the left arm is swung sideward and backward by the latissimus, teres major, and posterior deltoid. The trapezius acts on the right to aid the serratus and deltoid in raising the arm, while the rhomboid is in action on the left to support the teres major.

Fig. 80.—Starting position of the arms in serving.

Serving.—Serving in tennis is a form of striking in which one arm is used. The movement begins with the arm that holds the racket held back of the head, with elbow flexed, wrist overextended and flexed laterally, and humerus slightly above shoulder level and drawn well back. The ball is struck forward, the racket hitting it at a point directly above the head. The flexors of the wrist, triceps, and pectoral, supported by the upper serratus and aided somewhat by the lattissimus and teres major, do the work (Figs. 79 and 80).

To give the ball the spin that makes it curve, the racket hits it a diagonal blow in such a way that the ball travels across the face of the racket while in contact with it. In the form of stroke just described and shown in the figure, the drop curve can be produced by an extension of the elbow, the racket moving upward as well as forward while in contact with the ball.

Archery.—Archery, or shooting with bow and arrow, employs the arm elevators of both sides, holding the arms well up so as to bring the hand that grasps the arrow and bowstring near the ear. The flexors of the elbow are used on one side and the extensors on the other. The upper arms are both drawn backward strongly, but the raised elbow on the string side and the lowered elbow on the bow side bring into action different muscles—trapezius and middle and posterior deltoid on one side and latissimus, teres major, and rhomboid on the other.

QUESTIONS AND EXERCISES.

1. Pick out an ulna from the bones of a dismembered skeleton; point out the olecranon; the styloid process; show how it articulates with the humerus, and tell whether it is from the right or left arm.

2. Pick out a radius from the bones, point out its head, styloid process, and bicipital tuberosity, and tell whether it is from the right or left arm.

3. Mention a movement in which the biceps acts along with the triceps; along with the pronator teres; along with the infraspinatus; along with the middle deltoid; along with the upper pectoralis major.

4. Explain why a lady seldom holds her head up straight while combing her hair; how can it be made an exercise for improving posture of the shoulders? What muscles will be used most strongly?

5. Name the kinds of sport that tend to develop one arm more than the other; those that tend to develop both arms but in different ways; those that develop both arms but keep them too much in front of the chest and thus induce round shoulders.

6. When the arm-depressing muscles are used in driving nails, which way do they tend to rotate the humerus? Is this rotation useful or a hindrance in driving nails? What muscles are there that can prevent this rotation? Do they contract in this movement or not?

7. When one strikes two dumb-bells together forward at the level of the shoulders, what movement of the elbow-joint does the hitting of the bells tend to produce? What prevents it? When will muscles act to aid? What muscles can do it? See if they act.

8. With a tape line measure the girth of the forearm at the largest place (1) when the hand is closed firmly as possible, (2) when the hand is opened widely as possible, (3) when it is left relaxed. Explain the variation in girth.

9. Show a case of supination of the hand in which the biceps is not in action, and explain why this muscle does not act and what produces the supination.

10. Does folding the arms behind the back tend to induce erect posture or not? Explain.

CHAPTER VII.

MOVEMENTS OF THE HAND.

THE muscular mechanisms of the shoulder, elbow, hip, knee and ankle are to be seen in very similar form in most vertebrate animals, but the hand is possessed by man alone. The hand is capable of a greater variety of movements than any other muscular mechanism, and this gives man his mechanical superiority over other animals. Many animals excel man in ability to run, jump, swim, climb, and in other movements of the larger joints, but the superior mobility of the hand enables man to excel them all in the handling of objects and in the ability to make and use tools. His greater intelligence is of course the chief reason why man so far excels the other animals in constructive ability, and yet this is in part due to his possession of this most perfect of all mechanical instruments.

The hand includes twenty-seven bones and over twenty joints, while its action involves the use of thirty-three different muscles. Still the mechanism is not so difficult to comprehend as these figures might suggest, because the five fingers are constructed on the same general plan and the joints permit of only flexion and extension, with a limited amount of lateral motion in three instances. The larger muscles acting on the hand are located in the forearm and are connected with their insertions by long slender tendons. These tendons are held within a small space at the wrist by a deep concavity on the anterior surface of the carpal bones and by a flat encircling band of connective tissue known as the annular ligament of the wrist. There are several small muscles in the hand itself, the largest group making up what is known as the thenar eminence on the thumb side of the palm, and a smaller group forming the hypothenar eminence on the ulnar side.

The twenty-seven bones of the hand form three groups: (1) the carpal bones, eight in number, in two rows of four bones each; (2) the five metacarpal bones, numbered beginning at the thumb, and (3) the fourteen phalanges, in three rows, the proximal and terminal rows containing five each and the second row four, the phalanx of the middle row being absent in the thumb (Fig. 81). The carpal or wrist bones are very irregular in shape and are named as follows, beginning on the thumb side:

First row: scaphoid, semilunar, cuneiform, pisiform.

Second row: trapezium, trapezoid, os magnum, unciform.

The metacarpals are considerably larger and longer than any of the phalanges, and the latter decrease in size toward the tips of the fingers. The phalanges of the terminal row are small and pointed. The thumb is separated from the first or index finger more widely than the other fingers are from one another and is turned on its

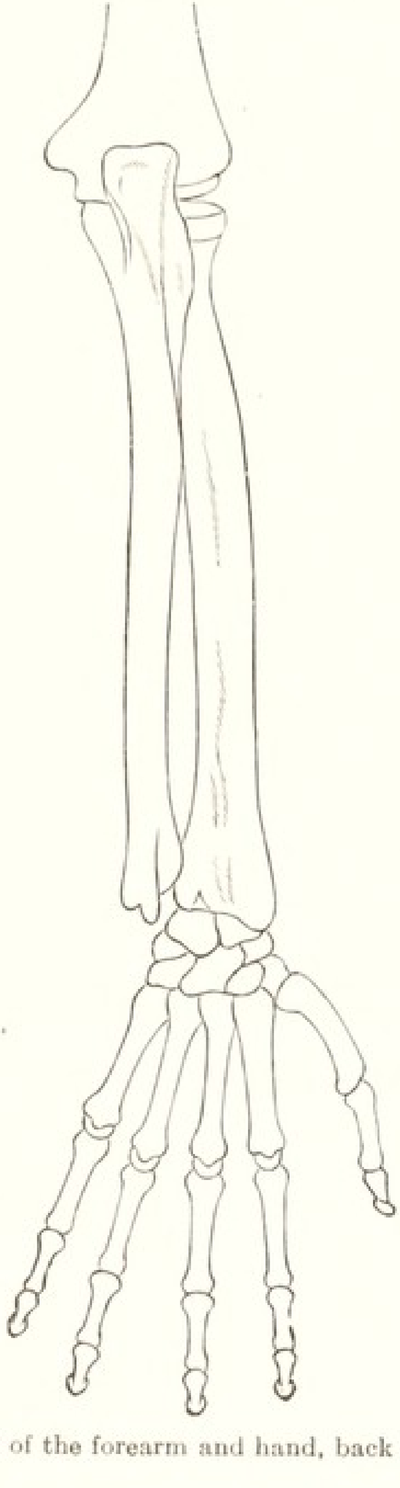


FIG. 81.—Bones of the forearm and hand, back view. (Gerrish.)

axis so that flexion is somewhat toward the others rather than in the same plane. Notice the rounded articular surfaces at the ends of the metacarpals and phalanges.

The wrist, which connects the rest of the hand with the forearm, has three distinct joints permitting movement of the hand: (1) the radiocarpal joint between the radius and the first row of carpal bones, (2) the midcarpal joint between the two rows, and (3) the carpometacarpal joint between the second carpal row and the metacarpals. These joints are all condyloid in form, rotation in the wrist being unnecessary because the free rotation of the shoulder and radio-ulnar joints give the hand freedom to turn through 270 degrees. Starting from the straight extended position the wrist can be flexed through from 60 to 90 degrees. The first and fifth metacarpals can be flexed farther than those between, making it possible to draw the two sides of the palm toward each other, forming a cup-shaped depression in the middle of the palm. The wrist can be overextended 45 degrees or more, making the entire movement considerably more than a right angle. Of the two lateral movements, that toward the little finger, called adduction of the wrist, takes place through about 45 degrees while abduction is less free. Besides the abduction of the whole hand just mentioned, the thumb can be abducted separately, moving away from the fingers through about 90 degrees. The carpometacarpal joint of the thumb is so shaped that when the metacarpal is flexed it rotates toward the fingers; this enables the thumb to flex toward the fingers to a varying degree to suit the work to be done. While this rotation is slight, it aids in bringing the ball of the thumb to meet the ball of each finger in turn, as the reader can easily observe by experimenting with his own hand.

The joints between the metacarpal bones and the phalanges permit flexion through about 90 degrees, but no overextension. These joints also permit a slight degree of abduction and adduction.

MUSCLES ACTING ON THE WRIST-JOINT.

There are six muscles acting on the wrist-joint, grouped as follows:

Flexor	carpi radialis. palmaris longus. carpi ulnaris.	Extensor	carpi radialis longus. carpi radialis brevis. carpi ulnaris.

Abduction of the hand is produced by the combined action of the radial flexor and extensor, while the ulnar flexor and extensor together adduct it.

FLEXOR CARPI RADIALIS.

This muscle lies on the upper half of the front of the forearm just beneath the skin, half-way from the brachioradialis to the ulnar side (Fig. 69, p. 122).

Origin.—The inner condyle of the humerus.

Insertion.—The anterior surface of the base of the second metacarpal.

Action.—Flexion and slight abduction of the wrist.

PALMARIS LONGUS.

A slender muscle lying just to the ulnar side of the preceding.

Origin.—The inner condyle of the humerus. It is often absent.

Insertion.—The annular ligament of the wrist and the fascia of the palm (see Fig. 69, page 122).

Action.—First to tighten the fascia of the palm, then to flex the wrist.

FLEXOR CARPI ULNARIS.

Located on the ulnar side of the forearm (Fig. 82).

Origin.—The inner condyle of the humerus and the upper two-thirds of the narrow ridge on the back of the ulna.

Insertion.—The palmar surfaces of the pisiform and unciform bones and of the fifth metacarpal.

Action.—Flexion of the wrist. Electrical stimulation of the flexor carpi ulnaris does not adduct the hand, but in voluntary adduction it contracts along with the extensor carpi ulnaris, probably to prevent the overextension the latter would otherwise produce.

By flexing the wrist strongly against a resistance the tendons of the three flexor muscles can be easily felt, the radialis near the middle and the others to the ulnar side. In some subjects it serves quite as well to make a complete flexion without resistance. Notice the position of these tendons in Fig. 69 to show you where to look for them.

EXTENSOR CARPI RADIALIS LONGUS.

This muscle is on the radial side of the upper forearm, just posterior to the brachioradialis (Fig. 69).

Origin.—The lower third of the outer condyloid ridge of the humerus.

Insertion.—The posterior surface of the base of the second metacarpal.

Action.—Flexion and abduction of the wrist-joint.

EXTENSOR CARPI RADIALIS BREVIS.

Situated just behind the preceding muscle.

Origin.—The outer condyle of the humerus.

Insertion.—The back side of the base of the third metacarpal.

Action.—Direct extension of the wrist.

EXTENSOR CARPI ULNARIS.

Situated on the back and ulnar side of the forearm (Fig. 82.)

Origin.—The outer condyle of the humerus and the middle third of the narrow ridge on the back of the ulna.

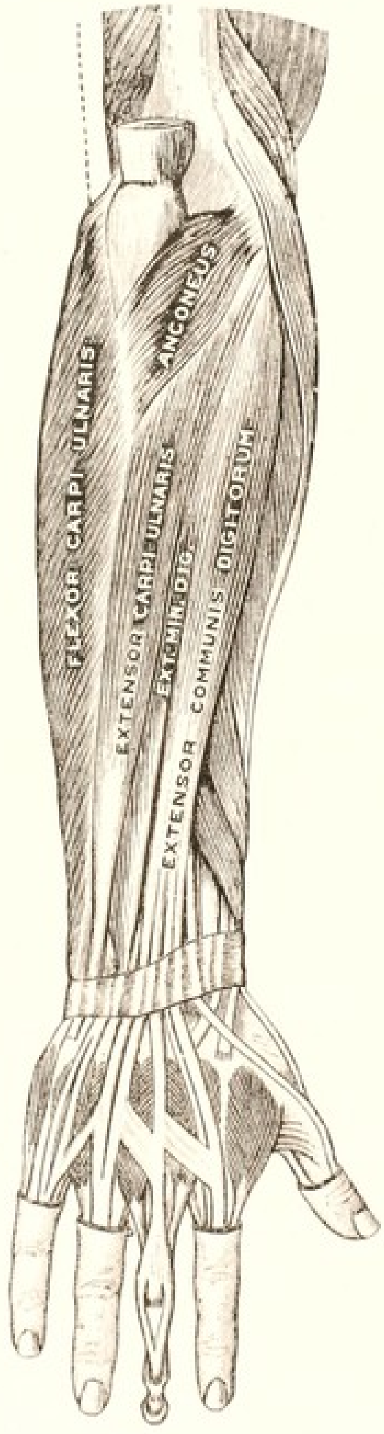


Fig. 82.—Posterior surface of the forearm and hand. (Gerrish.)

Insertion.—The posterior surface of the base of the fifth metacarpal.

Action.—Extension and adduction of the wrist.

By extreme extension of the wrist the tendons of the extensor muscles can be brought out so that they are readily felt at the back of the wrist. The radial pair of tendons can also be brought out by abduction of the wrist and the ulnar pair by adduction. The ulnar pair can be felt to contract when the thumb is strongly abducted.

The force of flexion of the wrist is nearly double that of extension, and the power of extension is lessened in the flexed position. This fact is recognized in Jiu Jitsu.

MUSCLES MOVING THE FINGERS.

There are three muscles in the forearm that act on all four fingers at once, two of them flexors and one extensor. They are named—

Flexor sublimis digitorum,
Flexor profundus digitorum,
Extensor communis digitorum,

meaning superficial and deep flexors and common extensor of the fingers. Each of these muscles has four tendons going to the four fingers, beginning at the lower fourth of the forearm, and each tendon is acted upon by separate groups of muscle fibers, making it possible to flex and extend the fingers separately as well as all at once.

FLEXOR SUBLIMIS DIGITORUM.

Situated just beneath the flexor carpi radialis and the palmaris longus on the front side of the forearm (Fig. 69).

Origin.—The inner condyle of the humerus, the coronoid process of the ulna, and a long oblique line on the middle half of the anterior surface of the radius.

Insertion.—By four tendons which separate after passing the wrist and go to the four fingers. Opposite the first phalanx each tendon splits into two, which are inserted into the sides of the base of the second phalanx (Fig. 85).

Action.—Contraction of the flexor sublimis first flexes the second phalanx; if the movement continues after the second phalanx is fully flexed it then flexes the first phalanx, and finally flexes the wrist.

FLEXOR PROFUNDUS DIGITORUM.

Located just beneath the flexor sublimis (Fig. 83).

Origin.—The middle half of the front and inner surfaces of the ulna.

Insertion.—By four tendons which separate after passing the wrist and go to the four fingers. Each tendon passes through the split in the corresponding sublimis tendon and is inserted into the posterior surface of the base of the last phalanx (Fig. 85).

Action.—Flexion of the third phalanx. If the movement continues after the third phalanx is flexed it then flexes the second phalanx, then the first and finally the wrist.

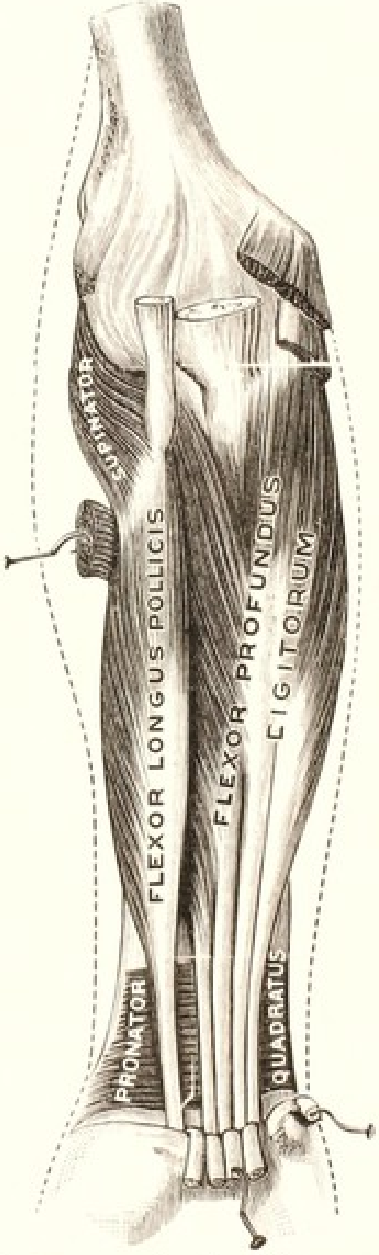


Fig. 83.—The flexor profundus digitorum. (Gerrish.)

Although the flexors sublimis and profundus each forms a single muscular mass, the separate tendons to the fingers are moved by separate groups of muscle fibers, so that it is possible to flex the fingers separately. The wide difference that we see in the abilities of different persons to do this is due to differences in coördination resulting from various amounts and kinds of training and not from differences in the structure of the muscles.

The flexor tendons pull on the wrist with a longer leverage than on the phalanges to which they are inserted, especially after the fingers are partly flexed, thus tending to flex the wrist every time one flexes the fingers strongly. Flexion of the wrist slackens the flexor tendons and thus lessens the power they can exert on the fingers, so that we must keep the wrist extended if we wish to clench the fist or grasp anything firmly with the hands. This is provided for without our being aware of it by contraction of the extensors of the wrist whenever one flexes the fingers forcibly. By placing the finger tips on the back of the lower forearm close to the ulna one can feel the extensor carpi ulnaris contract every time the fingers are flexed. Paralysis of the extensors of the wrist therefore makes it impossible to flex the fingers forcibly. Notice how feeble the flexion of the fingers becomes when you hold the wrist in a flexed position and how much stronger it is when you change it to a position of overextension.

EXTENSOR COMMUNIS DIGITORUM.

Situated on the middle of the back side of the forearm (Fig. 82).

Origin.—The outer condyle of the humerus.

Insertion.—By four tendons which separate after passing the wrist and go to the four fingers. Each tendon is attached by fibrous slips to the back of the first phalanx and then divides into three parts; the middle part is inserted into the posterior surface of the base of the second phalanx and the other two unite to form a tendon which is inserted into the posterior surface of the base of the third phalanx.

Action.—Contraction of the extensor communis first extends the first phalanx and then extends the wrist. If the first phalanx is held flexed the muscle will extend the other phalanges, but if the first phalanx or the wrist are allowed to extend its contraction has little effect on the last two phalanges. This is partly due to the insertion of the tendons into three successive segments of the finger and partly to leverage and slack, as explained in case of the flexors. Since the extensor communis has the best leverage on the wrist, strong extension of the fingers is impossible unless the wrist is prevented from overextending as the muscle contracts. Notice how feeble and incomplete extension of the fingers you can make with an overextended wrist and how much better the action is when you hold it partly flexed. By placing the finger tips on the front of the lower forearm one can easily feel the flexor carpi radialis and the palmaris longus contract every time a strong effort is made to extend the fingers.

The extensor communis also separates the fingers as it extends them. It is not able to move the fingers independently to the same degree as the flexors because of three fibrous bands that connect the tendons across the back of the hand (Fig. 82). The ring finger is especially limited in this way. As a partial remedy for this condition there are two small muscles lying one on each side of the extensor communis and providing independent extension for the index and little fingers. They are named extensor indicis and extensor minimi digiti, and their tendons join the tendons of the extensor communis opposite the first phalanx of the finger to which they belong.

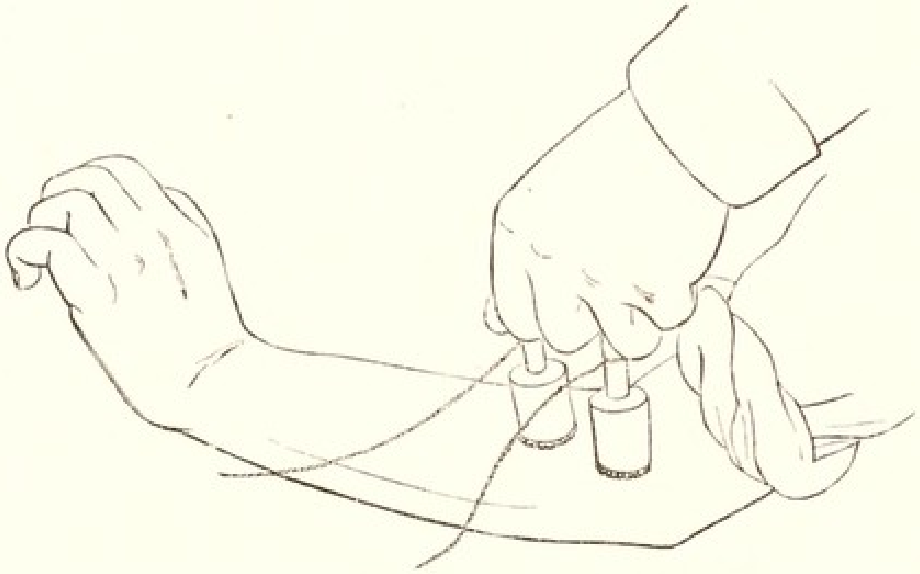


Fig. 84.—Isolated action of the extensor communis digitorum, extending the first phalanx of the fingers and the wrist without extending the second and third phalanges. (Duchenne.)

Enough has been said to show that the names of the three muscles we have just been considering are misleading if we try to apply them in an exact way to the actions they perform. They are in fact flexors and extensors of certain segments of the fingers rather than of the fingers as a whole. What is more, the parts acted upon by the flexors sublimis and profundus are not the same as those principally controlled by the extensor communis, so that the posture of the hand when at rest, if caused by the elastic pull of these muscles alone, would not give the familiar normal posture but instead the "claw-hand" shown in Fig. 86. Notice that the peculiarities of this ungraceful position consist of a flexion of the last two phalanges, which is the action of the two common flexors, and extension of the first phalanx, the proper action of the extensor communis.

There are three groups of small muscles placed in the hand itself that help to flex and extend the fingers and also to adduct and abduct them. There are eleven of these muscles, as follows:

Four lumbricales.
Four dorsal interossei.
Three palmar interossei.

The lumbricales are in the palm and the interossei lie between the metacarpal bones. The action of the entire eleven on flexion and extension is the same.

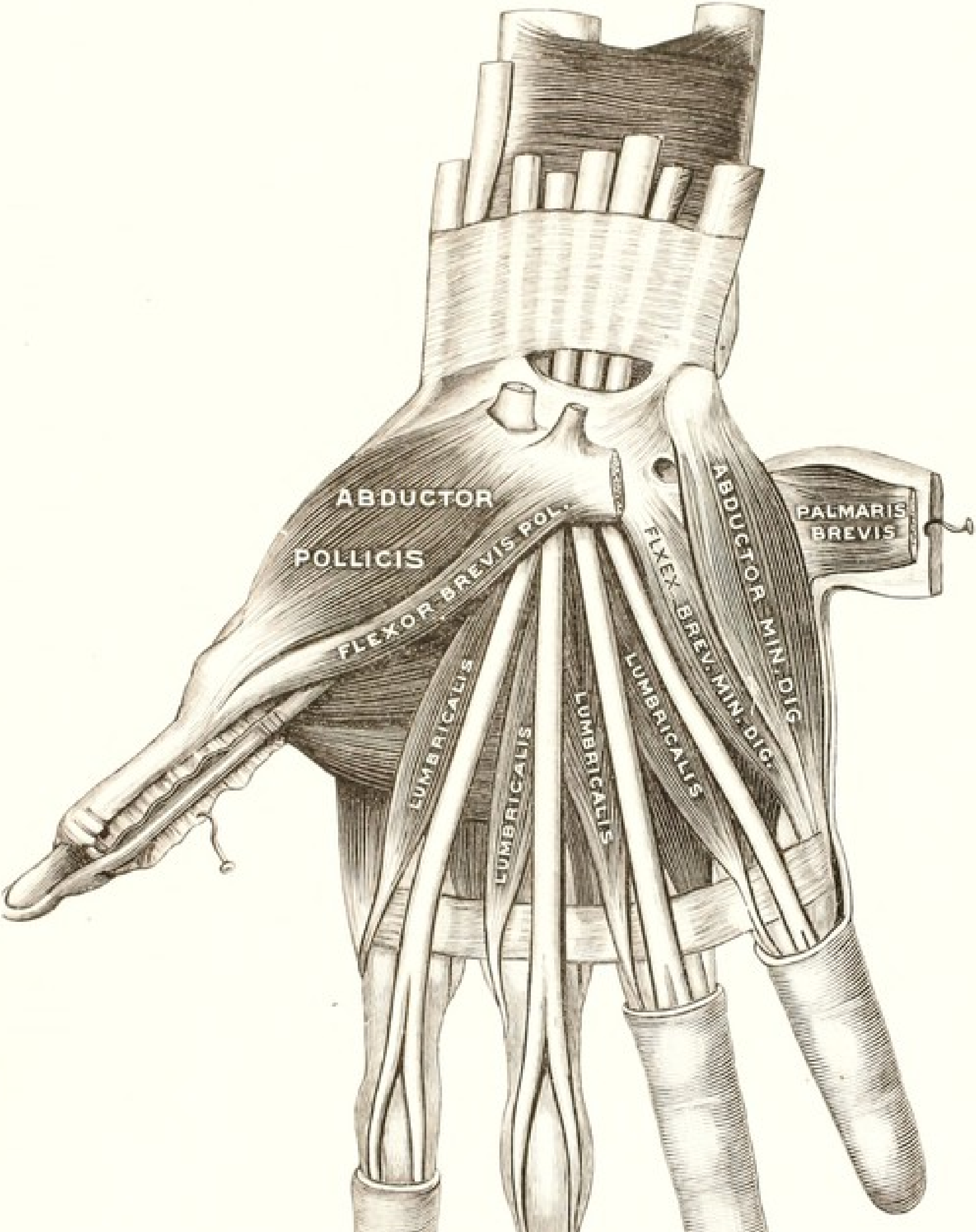


Fig 85.—Muscles of the right palm. (Gerrish.)

THE LUMBRICALES.

Four little spindle-shaped muscles, named from their resemblance to an earthworm (lumbricus). (Fig. 85.)

Origin.—The tendons of the flexor profundus digitorum.

Insertion.—The tendon of each muscle turns around the radial side of the metacarpal bone and is inserted into the tendon of the extensor communis.

Action.—To flex the first phalanx and extend the second and third.

THE DORSAL INTEROSSEI.

Four small muscles lying between the five metacarpal bones at the back of the hand.

Origin.—Each from the two bones between which it lies.

Insertion.—The base of the first phalanx and the tendon of the extensor communis for each finger.

Action.—To abduct the fingers away from the middle finger, to flex the first phalanx and to extend the second and third.

THE PALMAR INTEROSSEI.

Three small muscles in the palm, on the central sides of the second, fourth, and fifth metacarpals (Fig. 70).

Origin.—Sides of the metacarpals except the first and third.

Insertion.—Same as the dorsal interossei, but on the inner rather than the outer surfaces of the phalanges.

Action.—Adduction of the fingers, flexion of the first phalanx and extension of the second and third.

MOVEMENTS OF THE FINGERS.

The muscles that act on the hand are controlled through three nerves, the ulnar, median and musculospiral nerves. The ulnar supplies the ulnar flexors and extensors, the lumbricales and interossei that lie on the ulnar side of the midfinger, and a part of the flexor profundus. The median supplies the other flexors and the musculospiral the other extensors. Interesting light is thrown on the action of these muscles by the forms of paralysis resulting from disease and injury of these nerves.

Ulnar paralysis frequently involves the lumbricales and interossei. When these muscles are paralyzed, especially when no other muscles are involved, the hand takes the claw-like form shown in Fig. 86. The explanation is that when the normal tone of lumbricales and interossei is gone the unopposed tension of the extensor communis pulls the first phalanx into a position of overextension while the flexors sublimis and profundus for the same reason produce pronounced flexion of the other two phalanges. Any attempt of the patient to flex or extend his fingers only exaggerates the deformity. The hand is useless, for without the ability to flex the first phalanx it is impossible to close the hand or grasp anything between the fingers and thumb. Recovery frequently occurs, and then the claw form is gradually lost and the posture of the normal resting hand resumed, as the small muscles gradually take on normal vigor and tone.

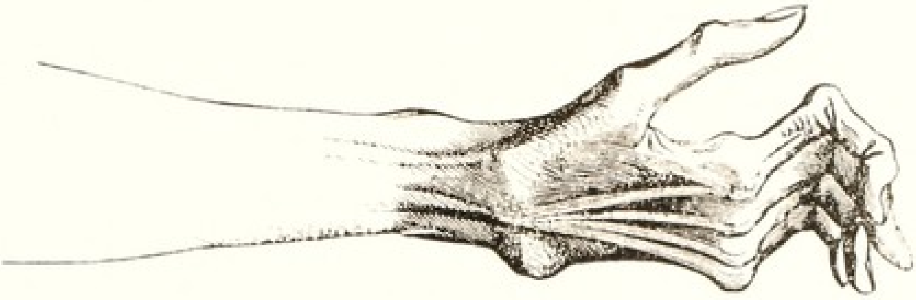


FIG. 86.—Claw-shaped hand resulting from paralysis of the lumbricales and interossei caused by an injury to the ulnar nerve. (Duchenne.)

Another condition that makes it impossible to close the hand or grasp an object with fingers and thumb is paralysis of one or both of the long flexors of the fingers. Fig. 87 shows the effect on the posture of the hand of paralysis of the middle half of the flexor sublimis. Here it is the normal tension of the lumbricales and interossei that is unopposed, and the second phalanx is pulled into marked overextension. If the paralysis affects the profundus, it is the terminal phalanx that is drawn out of normal position.

FIG. 87.—Deformity of middle and ring fingers caused by paralysis of the middle half of the flexor sublimis digitorum. (Duchenne.)

Another class of cases of paralysis of the hand is due to lead poisoning. This affects the musculospiral nerve. The extensor communis is most often paralyzed; the extensors of the wrist less often.

When the extensor communis is alone paralyzed the resting position of the hand is characterized by marked flexion of the first phalanx, caused by the unbalanced tension of the lumbricales and interossei. Flexion of the fingers is nearly normal, so that the ordinary uses of the hand to grasp and carry objects is not abolished as in paralysis of the flexors or the small muscles of the hand. The second and third phalanges can be extended but not the first.

Paralysis of the extensor communis causes one peculiar defect that has always puzzled physicians. The patient can flex and extend his wrist readily when his fingers are flexed, and this is what one would expect, for in the class of cases we are considering the flexors and extensors of the wrist are normal. But if the patient tries to extend his fingers his wrist takes a flexed position and he cannot extend it. The extensor communis being paralyzed, the only muscles he can bring into action to extend his fingers are the lumbricales and interossei, which acting alone flex the first phalanx while they extend the second and third. What causes the flexion of the wrist?

Attention has been called to the fact that in normal extension of the fingers the action of the extensor communis is always accompanied by a contraction of the flexors of the wrist. This seems to be an inherited coördination so firmly fixed in the nervous system that individuals cannot leave the wrist flexors out of the performance even if they wish to do so. This, as suggested by Beevor, is probably the explanation of the case just mentioned. When the person with paralyzed extensor communis tries to extend his fingers he unconsciously brings into action the entire group normally used in the movement. Realizing his inability to completely straighten the fingers he makes an unusually strong effort which brings the wrist flexors strongly into action and inhibits the wrist extensors. Under normal conditions this serves to balance the strong pull of the extensor communis on the wrist, but as the communis does not act the wrist is so strongly flexed that contraction of the wrist extensors cannot overcome it. The extension of the last two phalanges also takes up slack in the tendons of the long flexors of the fingers and this probably helps to keep the wrist flexed.

A common test for lead poisoning is to support the forearm in a pronated position with the hand and wrist unsupported and see how much the latter drop down from the weight of the hand. Paralysis of the extensor muscles greatly increases the extent of the "wrist-drop" and so indicates something of the presence and severity of the poisoning.

MUSCLES MOVING THE THUMB.

Of the eight muscles moving the thumb, four are in the forearm and four in the thenar eminence, commonly called the "ball of the thumb." Some of these muscles correspond to muscles that act on the fingers, and it will help in understanding and remembering the new ones to keep such resemblances in mind.

Three of the four muscles of this group that are located in the forearm are extensors of the thumb, one for each of its three segments.

EXTENSOR LONGUS POLLICIS.

The extensor longus pollicis lies on the back of the forearm next to the extensor indicis and like it may be considered as a part of the extensor communis digitorum. The tendon is shown in Fig. 82.

Origin.—Posterior surface of the middle third of the ulna.

Insertion.—The posterior surface of the base of the last phalanx of the thumb.

Action.—It extends the last phalanx of the thumb and then if the movement is continued it extends the other joints, drawing the thumb into the plane of the rest of the hand. The tendon of the extensor longus pollicis lacks the attachment to the first phalanx found in the extensor communis and consequently it extends especially the last phalanx, which the common extensor fails to do.

EXTENSOR BREVIS POLLICIS.

This muscle lies deep beneath the extensor communis on the back of the forearm.

Origin.—Small spaces on the back of both radius and ulna near their middle.

Insertion.—The posterior surface of the base of the first phalanx of the thumb.

Action.—Extension of the first phalanx. When the movement is strongly made the whole thumb is abducted and the extensor carpi ulnaris comes into action to prevent abduction of the wrist.

EXTENSOR OSSIS METACARPI POLLICIS.

This, the last of the long extensors, acts, as its name indicates, on the metacarpal bone of the thumb. It lies just toward the radial side of the preceding muscle. Sometimes called "long abductor of the thumb."

Origin.—A small space on the ulnar side of the radius near its middle.

Insertion.—The posterior surface of the base of the first metacarpal.

Action.—To extend or abduct the metacarpal bone of the thumb. Its action on the whole thumb is very much like the preceding muscle, but it pulls a little more toward the back of the hand. The extensors of the thumb have very little to do with the act of grasping objects, which is the most important action of the hand. Paralysis of these muscles allows the thumb to be drawn so far inward by the muscles of the thenar eminence that it is in the way of closing the fingers.

There are three flexors of the thumb, corresponding to the three extensors in that there is one for each segment.

FLEXOR LONGUS POLLICIS.

This is the only flexor of the thumb located in the forearm. Since the thumb lacks the second phalanx the flexor sublimis, flexor of the second phalanx of the fingers, naturally has no counterpart among the thumb muscles. The flexor longus pollicis lies beside the flexor profundus in the forearm and is attached to the last phalanx like the latter. It can therefore be considered as a part of the deep flexor (Fig. 83).

Origin.—Anterior surface of the middle half of the radius.

Insertion.—The anterior surface of the base of the last phalanx of the thumb.

Action.—To flex the last phalanx of the thumb. Loss of this muscle makes it impossible to grasp an object forcibly between the ends of the thumb and fingers and so interferes seriously with some of the finer uses of the hand, such as sewing, knitting, drawing, painting, etc. It has little or no influence on the other joints of the thumb.

The two short flexors of the thumb lie side by side in the thenar eminence, the flexor brevis toward the palm and the flexor ossis metacarpi pollicis external to it and toward the wrist (Fig. 88). The abductor pollicis covers most of the two, but a small part of the flexor brevis projects from under its palmar edge.

FLEXOR BREVIS POLLICIS.

This is the inner of the two short flexors.

Origin.—The trapezium and the front side of the annular ligament.

Insertion.—Base of the first phalanx of the thumb.

Action.—Flexion of the first phalanx, and movement of the entire thumb toward the little finger.

FLEXOR OSSIS METACARPI POLLICIS.

Formerly called the "opponens pollicis" or opposing muscle of the thumb (Fig. 88).

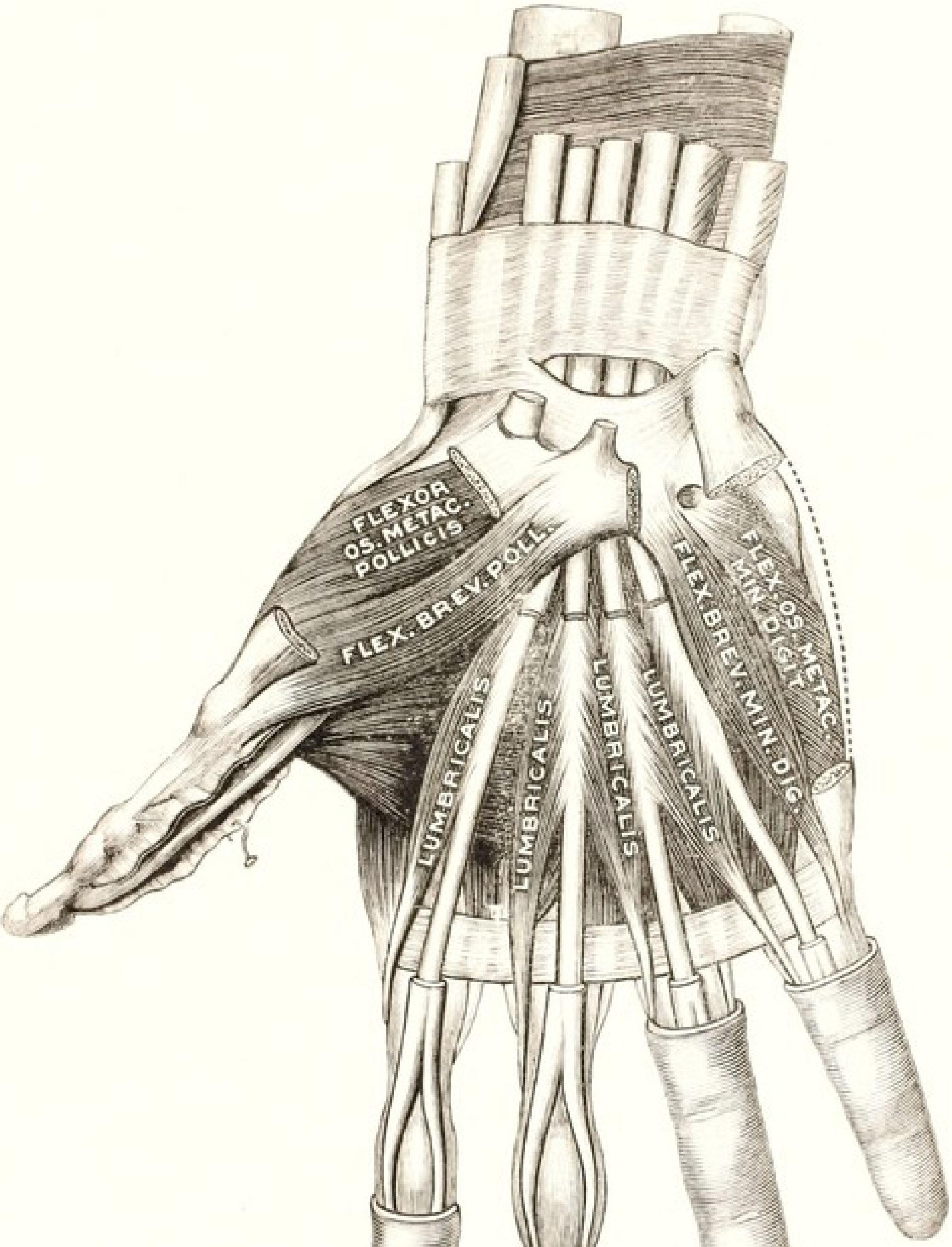


Fig. 88.—Muscles of the right palm. (Gerrish.)

Origin.—The trapezium and the annular ligament.

Insertion.—The shaft of the metacarpal bone on its radial side.

Action.—Flexion and inward rotation of the metacarpal, and with it the whole thumb. By its use the tip of the thumb can be made to meet the tips of the four fingers in turn.

The two remaining short muscles of the thumb are the abductor and adductor pollicis, corresponding closely to the interossei of the fingers.

ABDUCTOR POLLICIS.

This is the most superficial muscle of the ball of the thumb and is on the side of the thumb opposite the first finger (Fig. 85).

Origin.—The trapezium and scaphoid bones and the annular ligament.

Insertion.—The outer surface of the base of the first phalanx of the thumb and into the tendon of the extensor longus pollicis.

Action.—To draw the thumb away from the first finger, move the second phalanx laterally, and to extend the last phalanx. At the same time it rotates the thumb inward, placing it in opposition to the fingers. This is not considered a true rotation, such as takes place in a ball-and-socket joint, but the shape of the articular surfaces produces a small degree of rotation when the metacarpal is flexed or abducted.

ADDUCTOR POLLICIS.

This is the deepest of the thenar muscles (Fig. 70).

Origin.—The os magnum, the annular ligament and the lower two-thirds of the third metacarpal bone (Figs. 215, 216).

Insertion.—The inner surface of the base of the first phalanx of the thumb and the tendon of the extensor longus pollicis.

Action.—To draw the thumb toward the first two fingers, move the first phalanx laterally and extend the last phalanx.

Experts on accident insurance estimate the value of the thumb at half that of the whole hand. Its usefulness is largely due to its position of opposition to the fingers and the resulting ability to grasp and hold objects between them. In the finer work in which man excels other animals certain tools are moved by action of the fingers and thumb. In this work it is the muscles of the thenar eminence that are of greatest value in moving the thumb. The hand of man differs from that of the anthropoid apes mainly in the greater development of the muscles of the thenar eminence and in the habitual position of the thumb, which is one of much more complete opposition to the fingers.

FUNDAMENTAL MOVEMENTS OF THE HAND.

In forcible closing of the fist the flexors of the fingers and thumb and the abductor pollicis are used and also the extensors of the wrist.

In the simplest but strongest uses of the hand, such as grasping the rungs of a ladder or hanging by the hands from a bar, the most of the work is done by the flexors sublimis and profundus working with the extensors of the wrist. The flexors of the thumb help more or less, depending on the size of the bar and the consequent need of holding it firmly to the palm. With a small bar gymnasts often leave the thumb free.

In chopping and in using a hammer there is also strong adduction of the wrist. In the use of coarse tools, such as the axe, hammer, saw, plane and wrench, it is mainly the three flexors of the thumb that come into action. In finer work, such as the use of a pen, pencil, needle, or other small instruments, where the tips of the thumb and fingers must be brought together, it is necessary to keep the thumb in a position of abduction and flex the first phalanx of the fingers to nearly a right angle, because the thumb is so much shorter than the fingers. Duchenne points out the interesting fact that when the abductors of the thumb are paralyzed and the thumb flexors have to bring it into opposition to the fingers alone, the tip of the thumb meets the second phalanx of the fingers, unless the second and third phalanges of the latter are sharply flexed, and this renders the hand very clumsy and reduces its ability to do fine work accurately or rapidly.

Writing with a pen or pencil and using the so-called "finger movement" requires the use of many muscles. The grasping of the pen between the thumb and the next two fingers calls into action the flexors profundus and sublimis. The three flexors of the thumb along with the abductor are likewise required. To make an up-stroke with the pen the lumbricales and interossei contract and extend the last two phalanges while still further flexing the first; in the thumb a similar movement takes place, the metacarpal bone being flexed on the wrist and the other joints extended. Then to make a down-stroke the two flexors of the fingers join with the extensor communis in order to pull the finger tips closer to the palm, while the extensor ossis metacarpi pollicis acts with the flexors longus and brevis pollicis to accomplish the same on the thumb side.

PART III.

THE LOWER LIMB.

CHAPTER VIII.

MOVEMENTS OF THE HIP-JOINT.

Everyone is familiar with resemblances between the upper and lower limbs, so great that they seem to be constructed on the same general plan, and the reader will perhaps notice some resemblances new to him as we proceed. We are met at the outset, however, with a marked difference in that the pelvic girdle, which corresponds to the shoulder girdle, is not movable like the latter, with the consequence that the entire set of movements and muscles studied in Chapter IV has no counterpart in the lower limb.

The pelvic girdle consists of three bones: the *ilium* above and at the side of the hip, the *pubes* below and forward, the *ischium* below and backward. These three bones are separate in early life, but in the adult they are joined to make one solid bone—the hip bone. Each hip bone joins the hip bone of the opposite side at the front of the pubes and each joins the sacrum at the rear, forming the pelvic basin or pelvis. The three articulations just mentioned do not permit any considerable movement, and hence are held together by ligaments only. The sacrum is a solid bone formed by the fusion of five vertebræ; the spinal column rests upon its summit and is joined firmly to it.

The hip-joint is formed by the articulation of the head of the femur with the *acetabulum,* which is the name given to the socket on the outer surface of the hip bone just where the ilium, pubes and ischium join. It is a ball-and-socket joint, having less freedom of motion than the shoulder-joint, the socket being deeper and the bones fitting so closely that much force is required to pull it apart. The usual capsular ligament is present and is thickened on the front side by an A-shaped band called the iliofemoral band or the inverted Y-ligament (Fig. 90).

The femur is the longest bone in the body and corresponds in a way to the humerus; like the humerus it has a head, shaft, and two condyles; in place of tuberosities it has two large prominences, the great and small *trochanters;* along the back of the shaft is the *linea aspera,* or rough line.

The hip-joint permits movement of the femur most freely forward, and therefore this is called flexion; it can take place through 150 degrees or more, when it is stopped by contact of the thigh with the front of the trunk. When the knee is extended the hip-joint can be flexed only to the extent of a right angle, but this is due to tension of the hamstring muscles and not to the form of the joint.

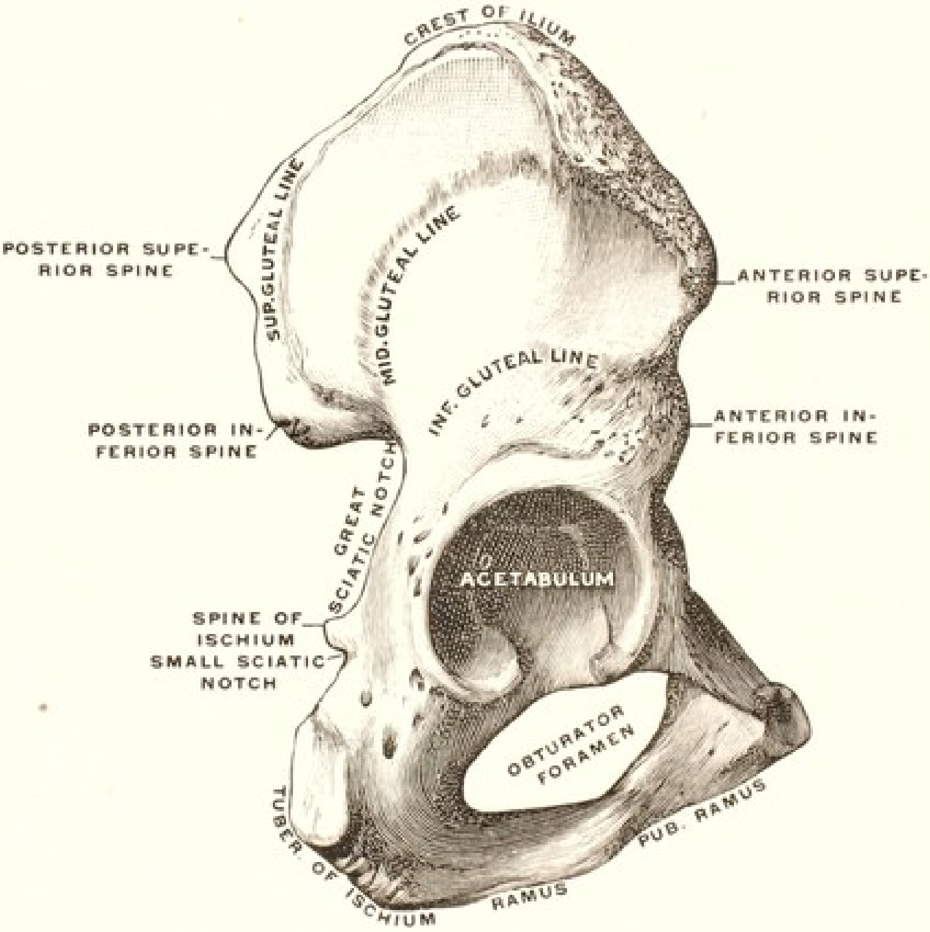


FIG. 89.—The hip bone of right side, outer surface. (Gerrish.)

The reverse of flexion, movement of the femur downward and backward, is called extension, and is free until the limb is vertically downward in line with the trunk, when it is stopped by tension of the iliofemoral band and of the psoas and iliacus muscles, making any overextension of the hip impossible in normal subjects. Careful examination will show that in apparent overextension of the hip, which occurs when one pushes one limb as far back as possible while standing on the other limb, the pelvis tilts back with the moving femur, the movement really being a slight flexion of the other hip and slight overextension of the spinal column in the lumbar region. The fact that we bend forward to reach the floor but not backward is due to the impossibility of overextending the hip-joints.

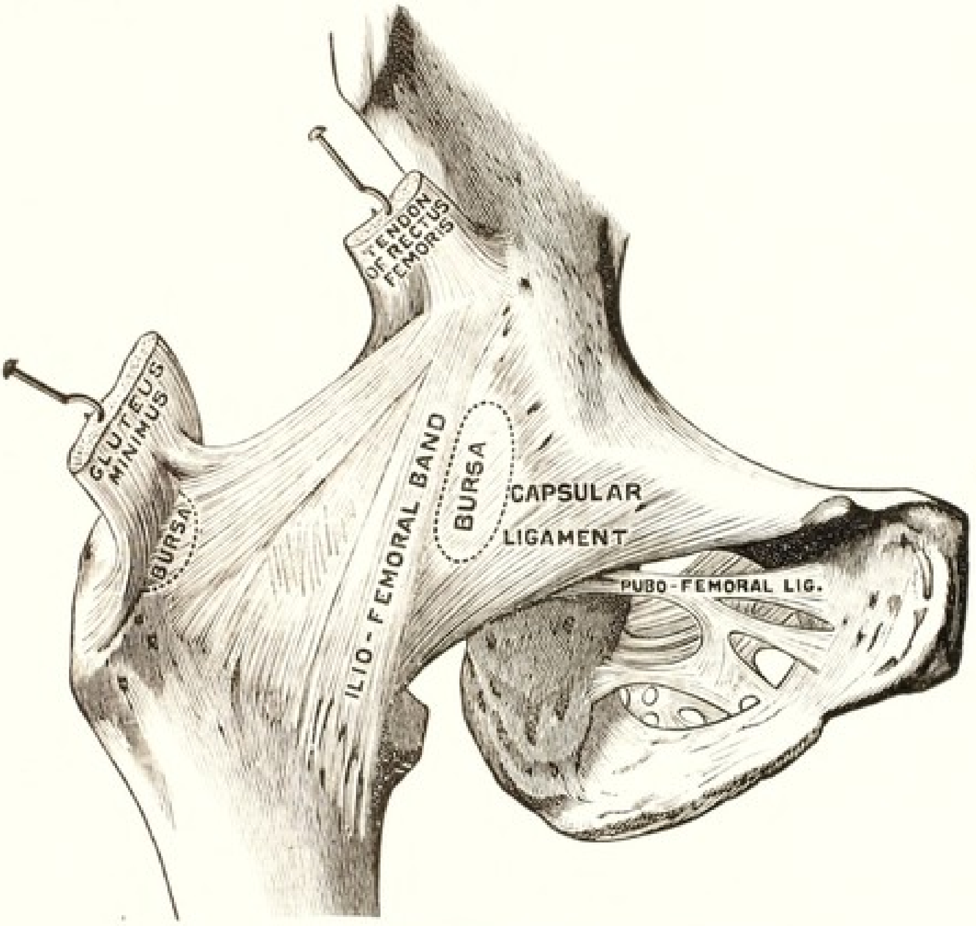


FIG. 90.—Right hip-joint, front view. (Gerrish.)

Movement of one limb away from the other toward the side is called abduction, and is usually possible through 45 degrees or more. The limitation here is due to resistance of opposing muscles, the joint itself permitting nearly 90 degrees of abduction, especially if the toes are turned outward. Abduction may also take place by movement of the trunk; for example, the right hip-joint is abducted by inclining the trunk to the right while standing on the right foot. Adduction is limited by contact of the moving limb with the other limb; it can take place further when the moving limb is a little front or rear from the other, or when the trunk is inclined to the side, as in the last example; the right hip is also adducted when the left hip is dropped below the level of the right while standing on the right leg.

Movement of the limb in a circular manner by a combination of the four movements above described is called circumduction; turning the limb on its central axis is called rotation. This axis is a line through hip-, knee-, and ankle-joints, passing considerably inside of the shaft of the femur because of the sharp bend of that bone near the trochanters. Rotation is possible through about 90 degrees, and is said to be outward or inward according to the way the toes are turned. Because of the sharp bend of the femur just mentioned the head of the bone rotates in the joint in the movement called flexion, and the neck of the femur strikes the side of the socket and limits the movement called rotation of the limb. One can easily see by noticing the way the bones come in contact why flexion is so free and why rotation is so limited.

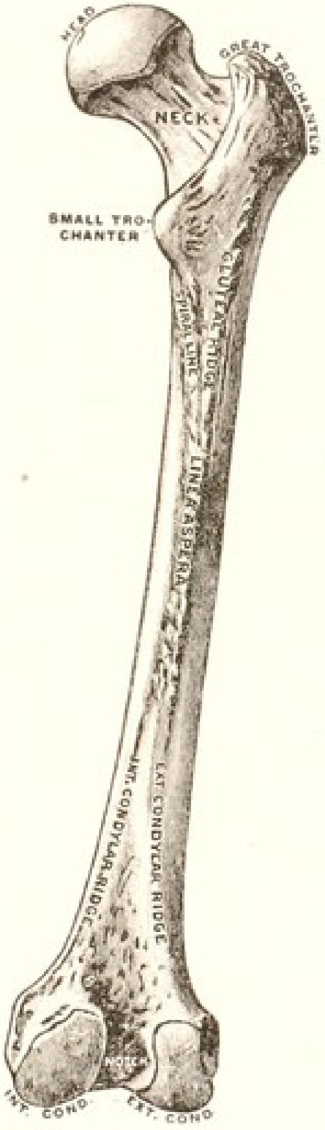


Fig. 91.—Right femur, rear view. (Gerrish.)

There are sixteen muscles acting on the hip-joint besides a group of six smaller ones; they are classified for our purposes as follows: Practically all of them have some less important action that will be explained as we study them individually, the grouping here being to help the beginner get a grasp on the main facts.

Six *flexors:* psoas, iliacus, sartorius, pectineus, rectus femoris, tensor.

Four *extensors:* gluteus maximus, biceps, semitendinosus, semimembranosus.

Two *abductors:* gluteus medius, gluteus minimus.

Four *adductors:* adductor gracilis, adductor longus, adductor brevis, adductor magnus.

Six *outward rotators:* pyriformis, obturator externus, obturator internus, gemellus superior, gemellus inferior, quadratus femoris.

PSOAS.

Nearly all of the psoas lies in the abdominal cavity behind the internal organs, where it cannot be easily observed during life. It is usually called the "psoas magnus" to distinguish it from a small muscle associated with it in most vertebrate animals and called the "psoas parvus." The latter muscle has no utility in an animal that stands erect, and is therefore an undeveloped rudiment in man.

Origin.—The sides of the bodies of the last dorsal and all the lumbar vertebræ.

Insertion.—The small trochanter of the femur.

Structure. — Muscle fibers arising directly from the bodies of the vertebræ and attaching obliquely into the tendon of insertion.

Action.—The line of pull of the psoas is indicated by a string tied around the shaft of the femur, with the knot just below the small trochanter and the free end held beside the bodies of the lumbar vertebræ, passing across the front of the pelvis in a notch just in front of the hip-joint. Notice that the small trochanter, while it is on the inner side of the femur, is so nearly on the axis of rotation that the psoas can have little rotary effect, and that the pull is so directly across the front of the joint that it will tend to flex the hip.

Looking at the string used to represent the psoas from a position at the side of the skeleton, we can see that the origin of the muscle is farther to the rear than its insertion, that it makes a considerable angle where it pulls across the edge of the pelvis, and that as a result it pulls forward on the femur at a fairly favorable angle in spite of the fact that its origin is so far back. By lifting the femur forward and upward and noticing the angle of pull it is apparent that the leverage improves as the limb is raised. The turn across the front of the pelvis also gives the psoas considerable leverage in pulling the spinal column forward.

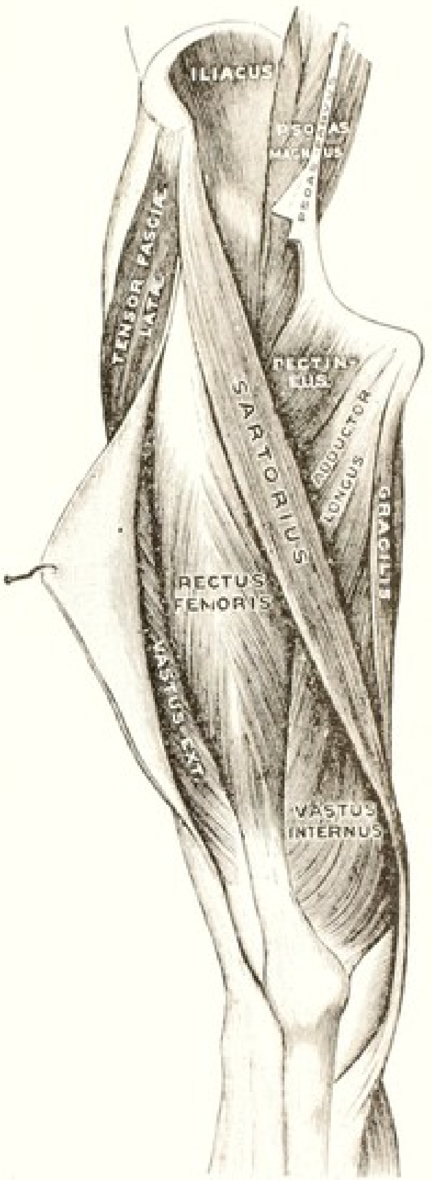


FIG. 92.—Superficial muscles of the front of the thigh. (Gerrish.)

Duchenne reports that he was unable to get isolated action of the psoas, and it is practically impossible to observe its action on a normal subject. It appears to be in a position to flex the hip, and especially well adapted to work where hip and spinal column are flexed at the same time, as in climbing rope and similar exercises. It is so closely associated with the next muscle that further statement will be made along with the latter.

ILIACUS.

Named from the bone on which it has its origin.

Origin.—The inner surface of the ilium and a part of the inner surface of the sacrum near the ilium.

Insertion.—Its tendon joins that of the psoas just where the latter crosses the front of the pelvis, to attach with it on the small trochanter.

Structure.—Muscle fibers arising directly from the ilium and joining the tendon obliquely.

Action.—The junction of the iliacus to the tendon of the psoas indicates a common action, except that the iliacus cannot flex the trunk. Duchenne states that in a few thin subjects he was able to stimulate the iliacus and that he secured in that way a powerful flexion of the hip-joint with a slight and weak outward rotation of the limb. This sets aside any doubt we might have as to the action of the two muscles and makes it highly probable that the two, which Duchenne suggests be named the "iliopsoas," act to flex the hip in all exercises, like walking, running, jumping, and climbing.

SARTORIUS.

The name means "tailors' muscle," because the ancient anatomists noticed that it is the muscle used in crossing the legs to take the position Oriental tailors assume at their work. It is the longest muscle in the body, and is capable of greater extent of contraction than any other.

Origin.—The notch between the two anterior spines of the ilium.

Insertion.—Lower front part of the inner tuberosity of the tibia.

Structure.—Parallel longitudinal fibers. The muscle lies between two layers of the fascia of the thigh, and some of its fibers are inserted into the fascia half-way down the thigh. The muscle curves around the inner side of the thigh, passing behind the inner condyle and then forward to its insertion.

The fascia of the thigh is a thick sheet of fibrous connective tissue that envelops the thigh just under the skin.

Action.—The position of the sartorius, curving around the front and inner sides of the thigh, makes it difficult to learn much of its action by a study of the skeleton. Its isolated action, under the influence of electricity, flexes both the hip and the knee, as one would expect from its general position. It is not difficult to observe the action of the sartorius on the living body, although its appearance in action is unusual, as it draws down into the mass of muscle beneath it when it contracts, forming a deep furrow down the inside of the thigh. It also pulls up on the fascia and the skin, forming a set of wrinkles for a distance of 2 or 3 inches below the groin. It acts in walking, running, and all movements combining flexion of the hip and knee.

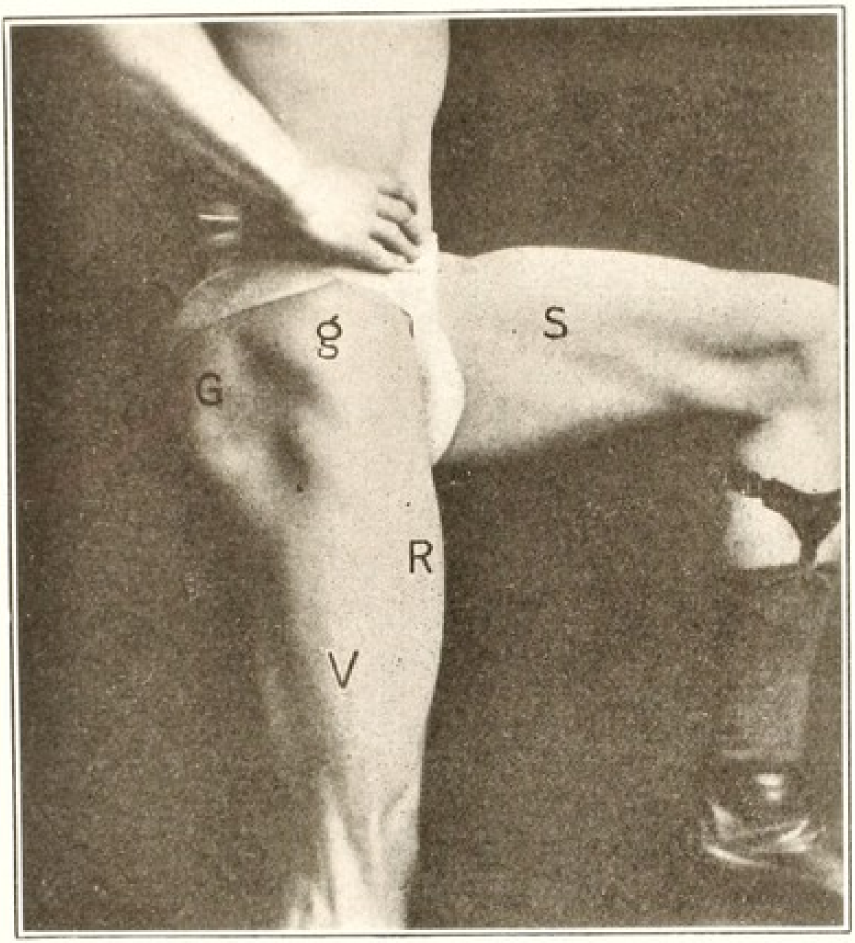


FIG. 93.—Muscles of the hip in action: *S*, sartorius; *R*, rectus femoris; *G*, gluteus maximus; *g*, gluteus medius; *V*, vastus externus.

RECTUS FEMORIS.

This large muscle, named from its position straight down the front of the thigh, corresponds closely to the long head of the triceps on the arm, being the middle part of a three-headed extensor.

Origin.—The antero-inferior spine of the ilium, between its tip and the hip-joint.

Insertion.—The upper border of the patella.

Structure.—The upper tendon passes down the middle of the muscle and the flattened lower tendon passes up beneath its deeper surface; the muscle fibers cross obliquely from one tendon to the other.

Action.—A cord looped around the patella and the free end held against the ilium just in front of the hip-joint shows the direction of pull; plain tendency to flex the hip, but a very short power arm and a pull nearly in line with the femur, favorable for speed but not for force; there is very little change in leverage when the limb is lifted. Any force keeping the knee flexed will make the tension on the rectus femoris much greater.

Isolated action of the rectus femoris causes flexion of the hip and extension of the knee with great speed and power, giving the motion employed in kicking a football. It is the only muscle that could do this alone and therefore might be properly called the "kicking muscle." It forms a conspicuous ridge down the front of the thigh as it contracts and can be seen and felt in action in all movements of combined flexion of the hip and extension of the knee. Its action on the knee will be discussed further in connection with the muscles extending the knee.

PECTINEUS.

A short thick muscle just below the groin, partly covered by the sartorius and the rectus femoris (Figs. 92, 217, 220).

Origin.—A space an inch wide on the front of the pubes, just below the rim of the pelvic basin.

Insertion.—A line about 2 inches long on the back of the femur, extending downward from a point just behind the small trochanter.

Structure.—Penniform, both ends of the muscle having muscular and tendinous fibers intermingled. It is twisted through 90 degrees as it passes from origin to insertion.

Action.—A rubber band looped about the femur just below the small trochanter and held at the point of origin shows a pull forward and inward at about equal angles; its attachment to the femur so far back seems to indicate rotation outward. Its power arm is several inches and its angle of pull about 60 degrees, indicating lifting power rather than speed of movement. Leverage improves as the femur is moved forward and inward.

Isolated action of the pectineus produces powerful flexion of the hip, adduction with less force, and feeble rotation outward. The pectineus can alone lift the thigh while the subject is sitting and place it across the other thigh.

It is easy to observe that the pectineus acts in vigorous flexion of the hip, whether it is combined with adduction or not. It is used in practically all vigorous flexion of the hip, especially in motions requiring force rather than speed.

TENSOR.

A small muscle at the front and side of the hip, often called "tensor fasciæ latæ" and "tensor vaginæ femoris" from its action to tighten the fascia of the thigh. It is peculiar in having no bony insertion (Fig. 92).

Origin.—A line about an inch and a half long just below the anterior extremity of the crest of the ilium.

Insertion.—The fascia of the thigh, one-fourth of the way down the outside of the thigh.

Structure.—The muscle lies between two layers of the fascia and the longitudinal muscle fibers are inserted into these two layers.

Action.—The peculiar position of the tensor makes it difficult to study its action on the skeleton. Early anatomists had many disputes about its action until electric experiment settled the matter finally, proving that it is mainly a flexor with some abducting action and slight inward rotation. Study of defective cases also proves that it is a strong flexor of the hip, aiding in the forward swing of the limb in walking, with its abducting and rotating power useful to counteract the opposite effect of other flexors, giving a pure flexion as a combined effect of the group.

ACTION OF THE FLEXORS.

The flexor muscles of the hip, like those of the shoulder, are more indispensable than any other group acting on the joint. Walking is impossible without them, the subject lacking the use of the flexors of the hip being unable to bring the foot forward to take a step. This refutes the theory of the Weber brothers, two famous German students of kinesiology, who taught that the limbs swing like a pendulum without need of muscular action to bring them forward.

When one stands at ease the flexors of the hip do not act, because the iliofemoral band is able to prevent the trunk from falling over backward; but if one who is standing pushes forward with the arms against a strong resistance or in any other way brings strong tension on the iliofemoral band, the flexor muscles at once come into action to protect it from injury. Sensory fibers like those in Fig. 2 probably give rise to the stimulus in such cases, the tension on the ligament squeezing and thus stimulating the sensory endings. Such action has often been called "acting in sympathy" with a ligament or a muscle, because until recently the true cause of the action was not known and a poetic one was assumed.

GLUTEUS MAXIMUS.

A very large fleshy muscle at the back of the hip.

Origin.—The outer surface of the ilium along the posterior one-fourth of its crest, the posterior surface of the sacrum close to the ilium, and the fascia of the lumbar region.

Insertion.—A rough line about 4 inches long on the back of the femur between the greater trochanter and the linea aspera.

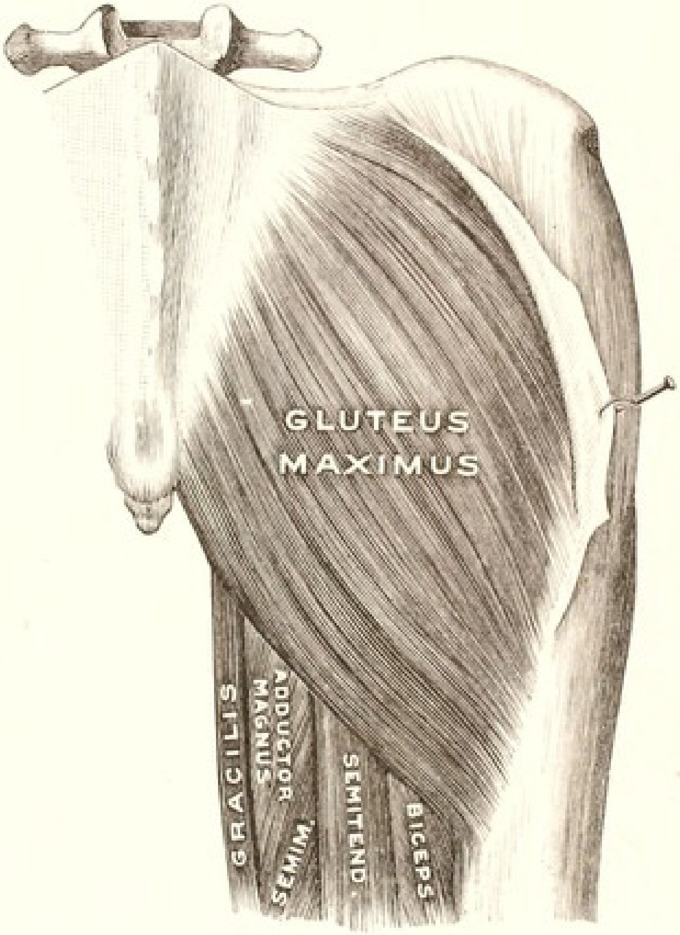


Fig. 94.—Gluteus maximus of right side. (Gerrish.)

Structure.—Muscular fibers arising directly from the pelvis and making an oblique junction with the tendon of insertion, which is a flat sheet extending up from the femur and along the posterior edge of the muscle.

Action.—From time immemorial anatomists have disputed over the action of the gluteus maximus, and the disagreement is not surprising to one who tries to figure it out on the skeleton. It has been called an abductor, and adductor, and an extensor of the hip, with all possible combinations of these movements with both kinds of rotation. It remained for Duchenne with his electric methods to finally determine its true action, which is powerful extension with weak rotation outward and no adduction or abduction.

An observer can easily experiment on himself in studying the action of the gluteus maximus, as it can easily be felt with the hand

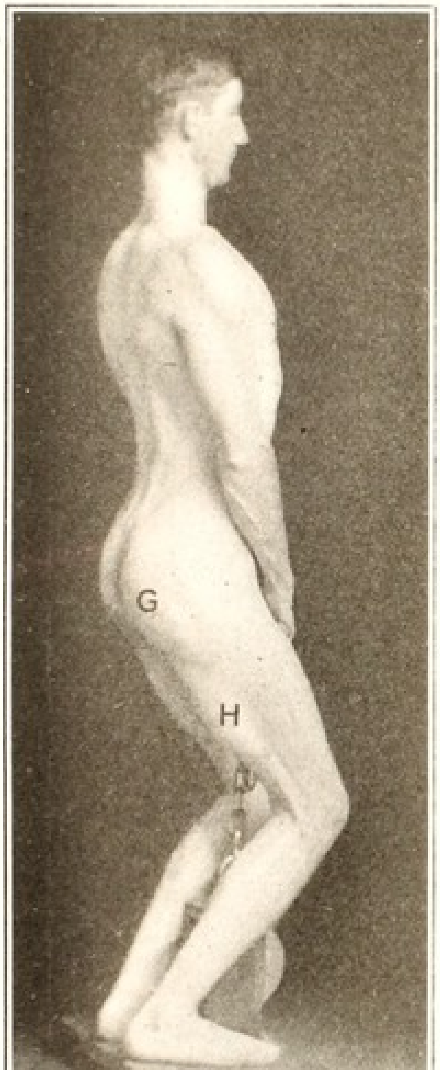


FIG. 95.—The extensors of the hip in action: *G*, gluteus maximus; *H*, hamstring group.

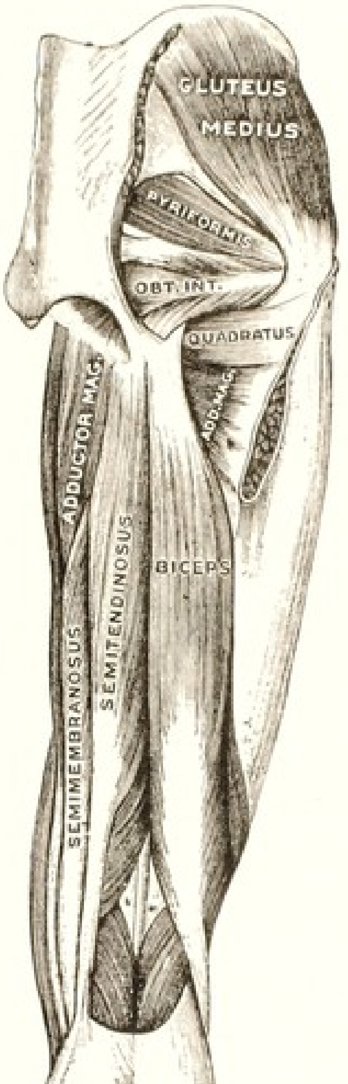


FIG. 96.—Superficial muscles of the back of the thigh. (Gerrish.)

while various movements are performed. It is easy to convince one's self in this way that it contracts in raising the trunk from a position of inclination forward and from a position in which the knees are bent deeply, and that in such cases it ceases to act before the erect position is reached. It can be observed similarly that it acts in walking up stairs or up a steep incline, but not in walking on a level. These peculiarities in the action of the gluteus maximus are instances of a peculiar rule governing the coördination of extension of the hip somewhat similar to one noticed as to the upward rotation of the scapula, where the lower serratus magnus failed to work in certain positions. The rule here seems to be that the gluteus maximus is not called into action in extension of the hip unless the hip is flexed more than about 45 degrees, except when there is strong resistance, when the angle of limitation is less. The rule explains several otherwise mysterious cases, such as the tendency of bicyclists to stoop forward, the demonstrated advantage of the crouching start in sprint racing, and the tendency of old people to incline the trunk forward in going up stairs. In all such instances the position gives the person stronger use of the gluteus maximus.

Persons who have lost the use of the gluteus maximus walk normally but cannot go up stairs nor up an incline without extreme fatigue, while running, jumping, or dancing quickly exhausts them.

BICEPS.

Similar in several respects to the biceps of the arm.

Origin.—The long head from the tuberosity of the ischium; the short head from the lower half of the back side of the shaft of the femur, along the linea aspera and the external condyloid line.

Insertion.—The outer tuberosity of the tibia and the head of the fibula.

Structure.—The tendon of origin is long and flat and forms a septum between the biceps and the semitendinosus; the lower tendon extends half-way up the thigh; the muscle fibers are short and pass obliquely downward from the upper tendon and the femur to join the lower tendon.

Action.—A cord drawn tight from the head of the fibula to the tuberosity of the ischium indicates the line of pull, showing that the muscle is in a position to extend the hip and rotate it outward and to flex the knee. The leverage is much longer at the hip. The short head will act only on the knee, and its main action there will be described later.

Isolated action of the biceps extends the hip, rotates it outward, and also flexes and rotates the knee-joint outward.

SEMITENDINOSUS.

Named from its long tendon of insertion, which reaches half-way up the thigh; it is a close companion of the biceps.

Origin.—The tuberosity of the ischium, by a common tendon with the biceps.

Insertion.—The lower front side of the inner tuberosity of the tibia, along with the sartorius.

Structure.—The short muscle fibers pass diagonally downward from the tendon of origin to join the tendon of insertion, the bulk of the muscle being in the upper half of the thigh.

Action.—The conditions under which the semitendinosus acts make it plain that it can extend the hip and flex the knee just like the biceps, but with opposite rotary action on both hip and knee. The tendency to rotation of the hip is less than that of the biceps.

Isolated action of the semitendinosus verifies these conclusions and shows that, like the biceps, it acts with most power on the hip.

SEMIMEMBRANOSUS.

This muscle, which is named from its knife-like shape, lies just inside of the semitendinosus and partly beneath it.

Origin.—The tuberosity of the ischium.

Insertion.—The inner half of the posterior surface of the inner tuberosity of the tibia.

Structure.—Similar to the preceding muscle, but a longer upper tendon and a shorter lower one brings the muscular mass lower down.

Action.—The conditions of action here are practically the same as the two preceding muscles as regards the hip-joint; isolated action indicates the most powerful action on the hip of the three.

ACTION OF THE EXTENSORS.

The biceps, semitendinosus, and semimembranosus form a group known as "the hamstring muscles." These muscles, while smaller and less powerful extensors of the hip than the gluteus maximus are much more useful for the ordinary purposes of life because they act normally in walking and in standing, while the gluteus maximus does not. The consequence is that one who has lost the use of the gluteus maximus may stand and walk normally, while one who has lost the hamstring muscles can stand and walk only by throwing the weight of the trunk so far back that it tends to overextend rather than to flex the hip, putting a tension on the iliofemoral band. Such a position can be maintained without the use of the hamstring group while standing still and in walking carefully on a smooth and level place, but one who has lost the hamstring group cannot walk rapidly or irregularly, nor can he run, hop, jump, dance, or incline the trunk forward without falling.

When the trunk in a normal individual is inclined forward on the hip-joints as an axis, the knees being kept extended and the trunk held as straight as it is in the erect position, the average adult can incline until the flexion in the hip-joints is about 45 degrees; the hamstring muscles, somewhat shortened by contracting to sustain the weight of the trunk, permit no further flexion. One can flex one hip farther than this while standing on the other foot, because in this position the hamstring group is relaxed and therefore longer than in the preceding case. The same is true when one sits on the floor with the legs out straight in front; by using all the force of the flexors most people can hold the trunk erect, the stretched and relaxed hamstring muscles permitting a flexion of 90 degrees. While sitting on a chair or bench there is no difficulty in holding the trunk erect, because now the hamstring muscles are not only relaxed but further slackened at the lower end by flexion of the knee; the hips will flex several degrees farther here and also in sitting on the floor if the knees are flexed, tailorwise.

GLUTEUS MEDIUS.

A short thick muscle situated at the side of the ilium and giving the rounded contour to the side of the hip (Figs. 93 and 96).

Origin.—The outer surface of the ilium near its crest.

Insertion.—The back part of the top of the great trochanter.

Structure.—The fibers arise directly from the ilium and converge to a penniform junction with the flat tendon of insertion.

Action.—It is easy to observe by reference to the skeleton that the power arm here, which is a straight line from the top of the trochanter to the center of the hip-joint, is an unusually long one and that the muscle pulls upon it at almost a right angle, giving the muscle great mechanical advantage. The vertical pull given by the central fibers will swing the limb away from the median line, the other parts swinging it a little to front and rear, according to their position; some rotary action seems likely when front or rear parts act alone.

The back part of the gluteus medius is covered by the gluteus maximus, so that the former cannot be stimulated by electricity entire unless the latter is gone. Duchenne found many cases in which the atrophy of the gluteus maximus made this possible, and he reports that the whole muscle stimulated at once gives vigorous abduction; the anterior fibers give a combination of abduction with movement forward and rotation inward; posterior fibers movement backward and rotation outward. Stimulation of the successive fibers from front to rear swings the limb first sidewise and forward, then gives it a curving movement toward the side and then to the rear.

GLUTEUS MINIMUS.

A smaller companion of the preceding, lying just beneath it.
Origin.—The lower part of the outer surface of the ilium.
Insertion.—The front part of the top of the great trochanter.
Structure.—Similar to the medius.
Action.—Same as the medius.

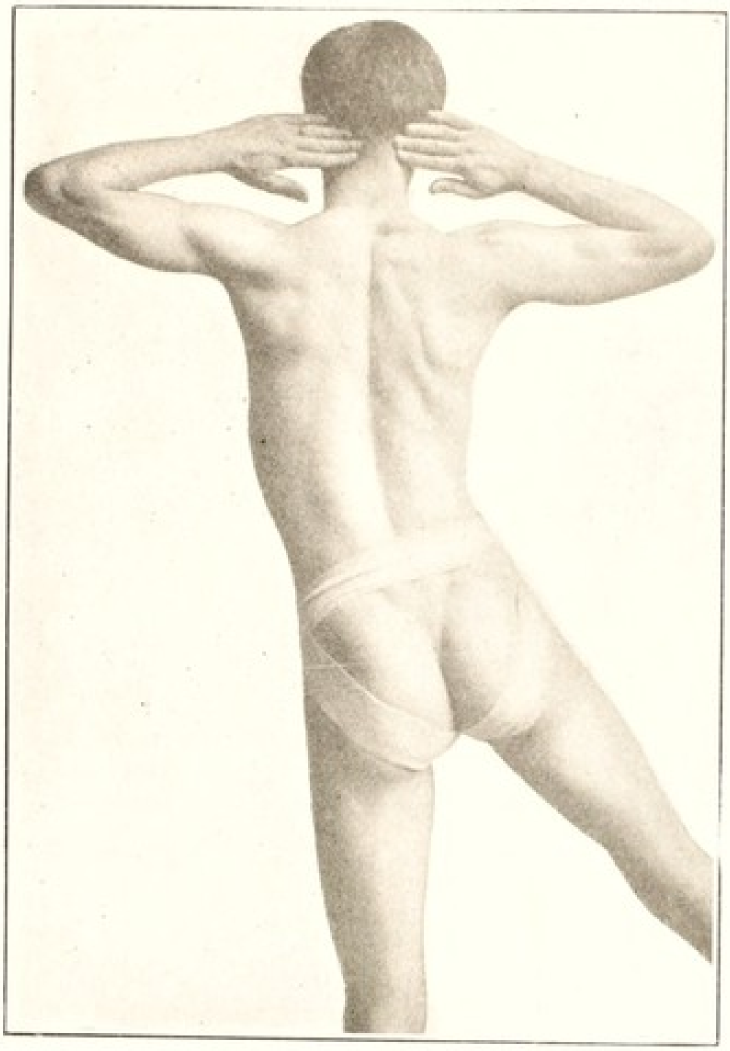


FIG. 97.—Balancing on one foot, involving abduction of both hip-joints.

ACTION OF THE ABDUCTORS.

The gluteus medius can be felt in action in all movements involving abduction of the hip, and it is highly probable that the gluteus minimus joins with it. It should be noticed, as before stated, that abduction can take place either by movement of the limb or movement of the pelvis; this is illustrated in Fig. 97, which shows abduction in both hip-joints, the right joint being abducted by a sidewise swing of the right limb and the left joint by elevation of the right side of the pelvis. When the trunk is held erect, as in this figure, the abductors on the side that supports the weight of the body have much the greater work to do; when the trunk is inclined to the left the center of gravity is brought more nearly above the left hip-joint and the abductors of that side have less to do.

The very common habit of standing on one foot is a serious menace to good posture or not, depending on the efficiency of the two muscles just studied. If the abductors have enough tone and power and are brought into action by the habitual coördination to keep the pelvis at practically the same height on the two sides, little harm comes from it; but if the free hip is allowed to drop down by relaxation of these muscles a lateral deviation of the spinal column necessarily results, eventually causing lateral curvature of the spine. It is better for this reason to form the habit of standing on both feet instead of one, and this is particularly true with girls and women because they have a wider pelvis and usually less tone and strength of muscle; to make the harmful results as slight as possible when the habit of standing on one foot is formed, it is well to have in all gymnastic work a considerable amount of exercise that will tone up the abductors of the hip, such as poising and balancing on one foot, running, hopping, and dancing.

ADDUCTOR GRACILIS.

A slender muscle passing down the inner side of the thigh. (Figs. 92, 217, 221.)

Origin.—The inner edge of the ramus of pubes and ischium.

Insertion.—The inner tuberosity of the tibia, along with the sartorius and the semitendinosus.

Structure.—A thin flat tendon above, slightly converging fibers, a round tendon below.

Action.—The pull is directly inward and at a considerable angle with the femur; it is also in a position to flex the knee. It can be felt to act in all vigorous adduction of the hip and flexion of the knee.

ADDUCTOR LONGUS.

This muscle lies just to the inner side of the pectineus (Fig. 92).

Origin.—The front of the pubes, just below the crest.

Insertion.—The linea aspera in the middle third of the thigh.

Structure.—A thick triangular muscle, arising by a short tendon and diverging fanwise to its wide insertion.

Action.—The pull of the adductor longus is similar to that of the pectineus but it is plainly in a position to adduct more and flex less than the latter muscle. Isolated action of the adductor longus is a combination of flexion and adduction, but it does not flex enough to lift the thigh over the other one while sitting, as the pectineus does.

ADDUCTOR BREVIS.

A short muscle beneath the adductor longus (Fig. 98).

Origin.—The front of the pubes, just below the longus.

Insertion.—The upper half of the linea aspera.

Structure.—A fan-shaped sheet similar to the longus but shorter.

Action.—The position of the brevis gives less power to flex the hip and better angle of pull for adduction.

ADDUCTOR MAGNUS.

One of the largest muscles of the body, situated beneath the gracilis on the inner side of the thigh (Fig. 98).

Origin.—The front of the pubes, the tuberosity of the ischium, and the whole length of the ramus connecting the two.

Insertion.—The whole length of the linea aspera and the inner condyloid line.

Structure.—The fibers from the pubes pass horizontally across to the femur, much like those of the brevis; those from the ramus lower on the linea aspera; those from the tuberosity of the ischium go to the lower end of the condyloid line.

Action.—The upper half of the magnus works under the same conditions as the longus and brevis except that the origin farther back causes less tendency to flex the hip; the lowest fibers have almost the same pull as the semitendinosus. Stimulation of the whole muscle gives rise to adduction; the upper fibers give some rotation outward; the lower fibers, extension and rotation inward.

ACTION OF THE ADDUCTORS.

Loss of the adductors causes some difficulty in walking and running but is not nearly so serious as the loss of either the flexors, extensors, or abductors. Those lacking the adductors swing the limb forward and sideward in walking, pure flexion of the hip being impossible, probably because of the abducting action of the tensors.

Vigorous action of the adductors is necessary in such exercises as riding on horseback, climbing a rope or a tree, and a few similar ones, but these are so unusual that one is apt to wonder what should cause the development of so large a muscular mass as the adductors when there is apparently so little work for them to do. The explanation is probably the fact that most of these muscles have some other action that is largely responsible for their development; the longus used in flexion, the magnus in extension, and the gracilis in flexion of the knee.

The ability of the adductor magnus to extend the hip is not mentioned in text-books of anatomy nor by the investigators of muscular action, but it is in a position to act on the hip exactly like the semitendinosus and semimembranosus, with an origin close alongside these muscles and the course of its lower fibers parallel with them. Its lower attachment on the inner condyloid line should

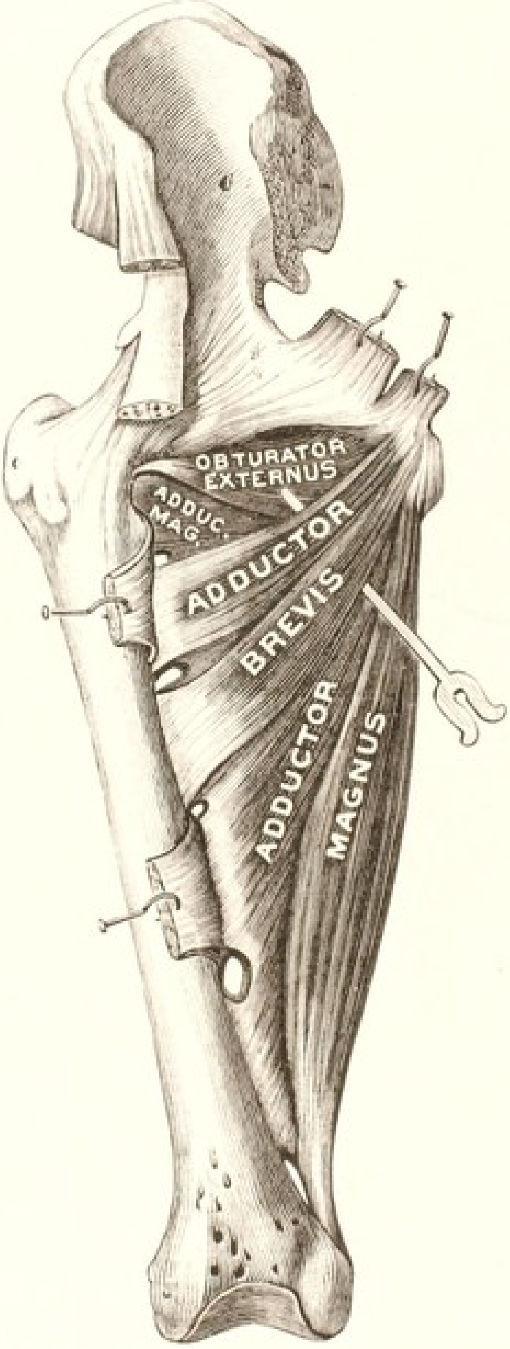


FIG. 98.—Front view of the adductors brevis and magnus. (Gerrish.)

give it the same power of extension as if it were attached to the tibia, a short distance below. Study of the muscles during extension gives every evidence that the posterior fibers of the adductor magnus takes part in this movement of the hip, and the size of the muscle indicates important assistance in the work if it acts at all.

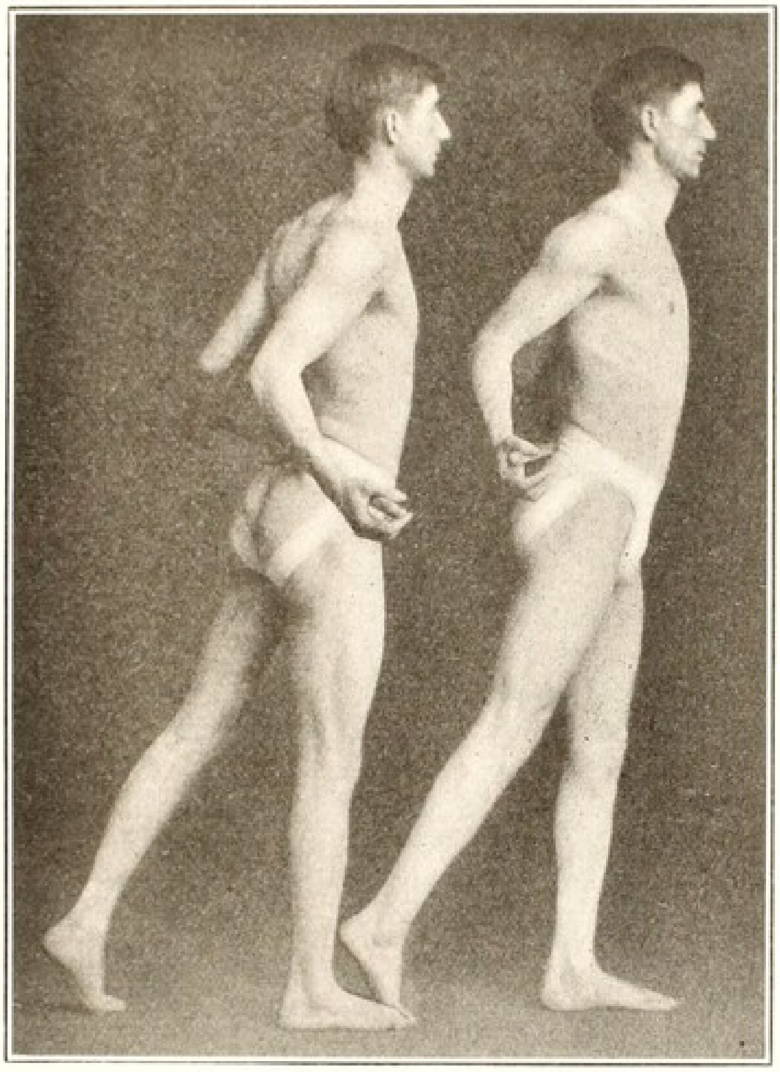


FIG. 99.—Rotation in the hip-joints during walking. The amount of rotation is indicated by the position of the stick.

THE SIX OUTWARD ROTATORS.

The reader will recall that inward rotation of the arm is performed incidentally by the large muscles having the larger duty of swinging the arm, and that outward rotation is performed by a special group of two muscles, the infraspinatus and teres minor. It is interesting to find that in case of the hip we have a similar arrangement, inward rotation being performed incidentally by the three abductors along with their main work, and outward rotation by a special group, in this case of six in place of two; the pyriformis, obturator externus, obturator internus, gemellus superior, gemellus inferior, quadratus femoris.

Origin.—The posterior portions of the pelvis.

Insertion.—The great trochanter of the femur.

Structure.—Fig. 96 shows five of these muscles; three of them are named in the figure and the gemellus superior and inferior are assistants of the obturator internus, the former above and the latter below. The obturator externus is shown in Fig. 98.

Action.—The position of this group of six muscles indicates outward rotation as their main action, and electric experiment gives the same answer. It is true here, just as in case of the arm, that forward movement of the limb through a right angle puts the group in a position to produce abduction as well as rotation; it is easy to observe on a mounted skeleton that contraction of the outward rotators while sitting will separate the knees.

If in walking and running the hips do not swing forward and backward there is no rotation in the hip-joints, but usually the hip goes forward as the foot goes forward, the amount of the swing varying considerably in different individuals. Now a forward swing of the hip as the limb swings forward will swing the toe in unless there is outward rotation in the hip-joint. It follows that in walking and running the limb must be rotated outward on the side where the large muscles are doing little, calling for an extra group to do it, while inward rotation must occur on the side where the extensors and abductors are doing the main work of the movement, and so they perform incidentally the slight work of rotating the limb. In throwing and putting the shot and in batting and serving the same is true; inward rotation is done with much more power than the opposite.

QUESTIONS AND EXERCISES.

1. Pick out a right femur from the bones of a dismembered skeleton; point out its great and small trochanters, its inner and outer condyles, its linea aspera and its two condyloid lines.

2. Point out a sacrum, the ilium, the ischium, the pubes. Point out the place of attachment of four muscles on each.

3. Measure on the mounted skeleton the breadth of the pelvis, the length of the femur and the lengths of the gluteus medius, adductor magnus, semitendinosus, rectus femoris and psoas.

4. When one stands on one foot and lifts the other knee to the level of the hip, what muscles do the work on the limb that is lifted? On the limb on which the subject stands? How is this changed if one holds a weight out sidewise at shoulder level on the side of the knee that is lifted? How if one grasps instead a solid means of support with that hand?

5. Give a list of five exercises for developing the flexors of the hip, arranged in progressive order, proceeding from the easiest to the most difficult, basing the progression on amount of strength required rather than difficulty of coördination.

6. Stand with feet separated sidewise two foot lengths and hands at "neck firm" and see how far you can incline trunk forward by a movement in the hip-joints, without bending either the knees or the trunk. Have several other persons try it and estimate the number of degrees of inclination. Explain why one cannot bend farther and why a slight flexion of the knees enables one to do so.

7. What acts as the lever in the forward inclination of the trunk just mentioned? Where is the axis of movement? Where is the power arm? The weight arm? Length of each? How does the angle of pull vary as one inclines forward? Why does one move the hips backward in making the movement instead of merely moving the head forward?

8. What advantage is there in swinging the hip forward as the foot goes forward in walking? What disadvantage? Notice how people swing the arms while walking. Do the arms swing in the same direction as the hips or opposite? What is the advantage of the swing of arms?

9. Study the movements of the hip-joints in rowing a boat. What movement takes place in hip-joints as the oars are pushed forward? What muscles work to perform this movement of the hips? When the pull is made upon the oars? Which of the two sets of muscles do the most work in rowing?

10. What movements of the hips take place in climbing a ladder? How different in climbing a stair? In climbing a rope? What muscles are used in the first two cases and not in the third? In the third and not in the first two?

CHAPTER IX.

MOVEMENTS OF THE KNEE-JOINT.

The knee-joint is the largest and most complex joint in the body and consists of two separate articulations between the tibia and the femur. The two condyles of the femur rest upon the two tuberosities of the tibia and fit into shallow depressions made by two cartilages, the semilunar cartilages, which are joined to the rather flat surface at the summit of the tibia. Near the median line of the knee, between these two articulations, are two strong ligaments, the crucial ligaments, connecting the tibia and femur and limiting the movements of the joint. Around the outside of all these structures is the capsular ligament, reinforced by strong bands of fibrous tissue on the inner and outer sides and the rear; the patellar ligament, which connects the patella with the tibia, is blended with the capsule on the front and strongly reinforces it there.

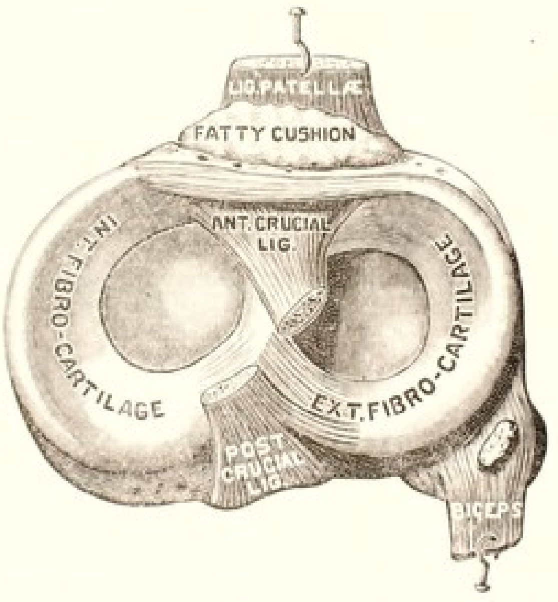


Fig. 100.—The cartilages and ligaments within the capsule of the knee-joint, viewed from above. (Gerrish.)

The knee acts much like a hinge joint, permitting only flexion and extension excepting when it is flexed to 90 degrees or more; this slackens the tension on the ligaments so as to permit 60 to 90 degrees of rotation of the tibia. One can easily notice the distinction between rotation in the hip and in the knee by observation of his own limb while sitting in a chair. If the knee is held firmly extended the toes can be turned in and out easily, and by feeling the knee while this is going on it is easy to discover that there is no rotation there, the whole thigh rotating upon its main axis with the motion in the hip-joint; if the knee is flexed to 90 to 100 degrees the toes can be turned in and out as before, but now the thigh does not turn, the rotation taking place in the knee only. The possibility of rotation of the knee in the flexed position is a convenience in climbing a tree or rope, enabling one to use the leg and foot in different positions; the absence of this rotation in the erect position is a great convenience in maintaining a stable position on the feet.

Flexion and extension of the knee takes place by a gliding of the condyles of the femur through the depressions on the head of the tibia, different parts of the wheel-like surface of the condyle being in contact with the tibia in different positions of the joint. In the extended position the lower and more flattened part of the condyle is in contact, giving a more stable support in the erect position; in complete flexion it is the most posterior and most curved part of the condyle and in semiflexion a portion between the two. The semilunar cartilages are attached to the tibia so loosely that they can adapt themselves to the changing shape the condyle presents as various portions of it come into the depressions.

The patella is a flattened and rounded bone that is developed in the tendon of the extensor muscles. Its anterior surface is rounded; its posterior surface has a vertical ridge across it and is covered with cartilage to lessen its friction as it glides over the front of the femur. The movement is a combination of sliding and rolling. The patella prevents the tendon of the extensors from drawing into the groove between the condyles of the femur and thus improves the leverage of these muscles on the knee-joint. The portion of the extensor tendon below the patella, which is usually called the patellar ligament, joins the tibia at a tubercle located at the lower edge of the front side of the inner tuberosity.

Flexion of the knee is possible through about 135 degrees, when it is brought to a stop by contact of the tissues on the back of the thigh and leg and by tension of the front of the capsular ligament and the crucial ligaments. Overextension is usual to a slight extent so that in the erect position the weight of the body tends to cause further overextension; the crucial and posterior ligaments prevent further movement and thus the extensor muscles are not needed to hold the joint in extension, as long as one stands still and there is nothing happening to disturb the balance.

There are ten muscles acting on the knee-joint, all but four of which have been described; three of the four will be described in this chapter and the fourth, which acts mainly on the ankle-joint, will be described in the next chapter.

Six flexors: semitendinosus, semimembranosus, biceps, sartorius, adductor gracilis, gastrocnemius.

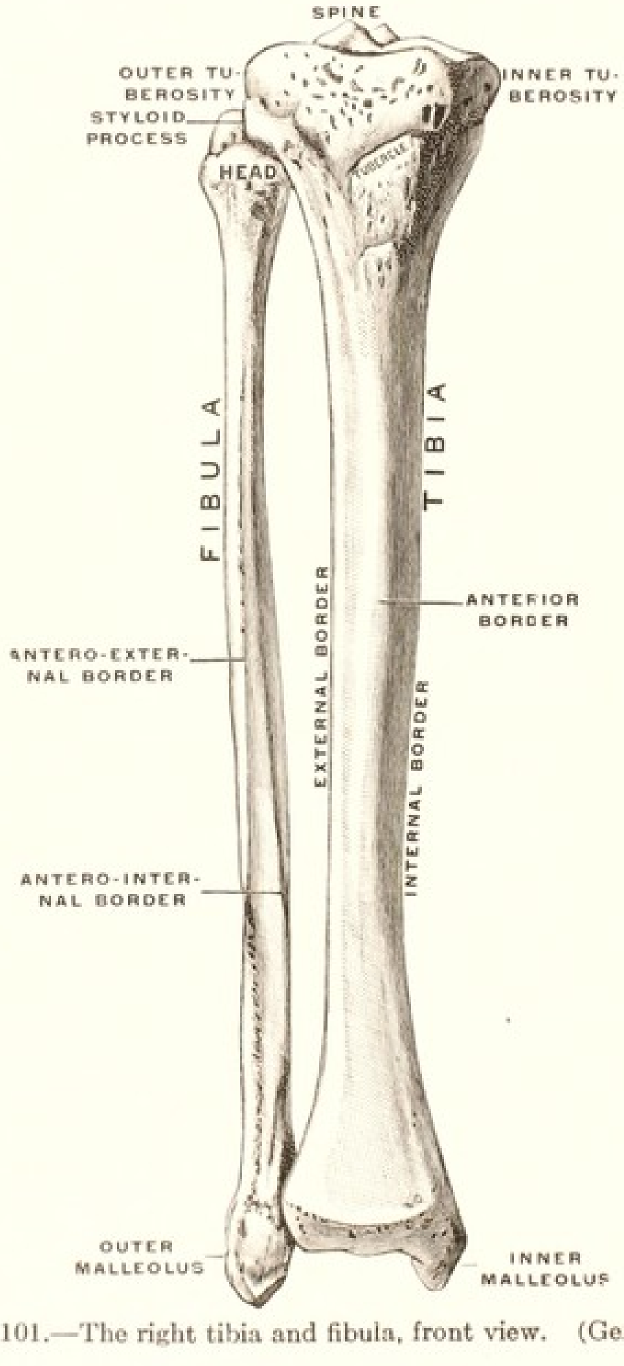


Fig. 101.—The right tibia and fibula, front view. (Gerrish.)

Four extensors: rectus femoris, vastus externus, vastus internus, vastus intermedius.

Four rotators inward: semitendinosus, semimembranosus, sartorius, adductor gracilis.

One rotator outward: biceps.

Among the flexors the semitendinosus and sartorius have the best leverage, since they attach lowest on the tibia; next to them are the gracilis and the biceps, with the semimembranosus nearest the joint. The angle of pull is least at the start, when the knee is in complete extension, and is best when it is flexed through a little more than 90 degrees.

This group of muscles acts to lift the foot from the ground in walking, running, hopping, climbing, jumping, and dancing, but the resistance to be overcome is small, the weight of the leg and foot being slight in comparison with the weight of the body, which most of the muscles of the lower limb have to lift. It is surprising, therefore, to find that when tested by a dynamometer the flexors of the knee are nearly as strong as the extensors of the hip or of the knee, in spite of the small amount of work they have to do in flexing the joint. The explanation is to be found in the fact that the three strongest of these flexors are also extensors of the hip, and that they are able to use in flexing the knee all the power they develop in the vigorous work they have in extending the hip.

VASTUS EXTERNUS.

A large muscle located half-way down the outer side of the thigh and making the rounded eminence to be found there. It corresponds closely to the outer head of the triceps of the arm (Fig. 93).

Origin.—The outer surface of the femur just below the great trochanter and the upper half of the linea aspera (Figs. 219, 220).

Insertion.—The outer half of the upper border of the patella.

Structure.—A small portion of the muscular fibers arise directly from the femur near the trochanter; the greater part arise from a tendon shaped much like a sheet of paper covering the outer surface of the muscle for its upper two-thirds, with its posterior edge attached to the linea aspera. The lower tendon is a flat sheet attached to the upper border of the patella and serving as a tendon of insertion for the three "vasti" muscles; it lies beneath the vastus externus, and the muscle fibers pass obliquely downward and inward from the upper tendon to join it.

Action.—The line of pull indicates plainly that the vastus externus can extend the knee, and that it needs a companion from the inner side to give a straight pull on the patella. The angle of pull is nearly 90 degrees in the extended position and the presence of the patella keeps it good in flexion as far as a right angle; the power arm of the lever is about two inches in an average adult subject. Electric stimulation of the vastus externus extends the knee powerfully and tends to pull the patella sidewise out of its groove; paralysis of it makes a person liable to displacement of the patella inward by action of the next muscle.

VASTUS INTERNUS.

This muscle, corresponding to the inner head of the triceps of the arm, is located on the inner side of the thigh, somewhat lower than the externus and partly covered by the rectus and the sartorius.

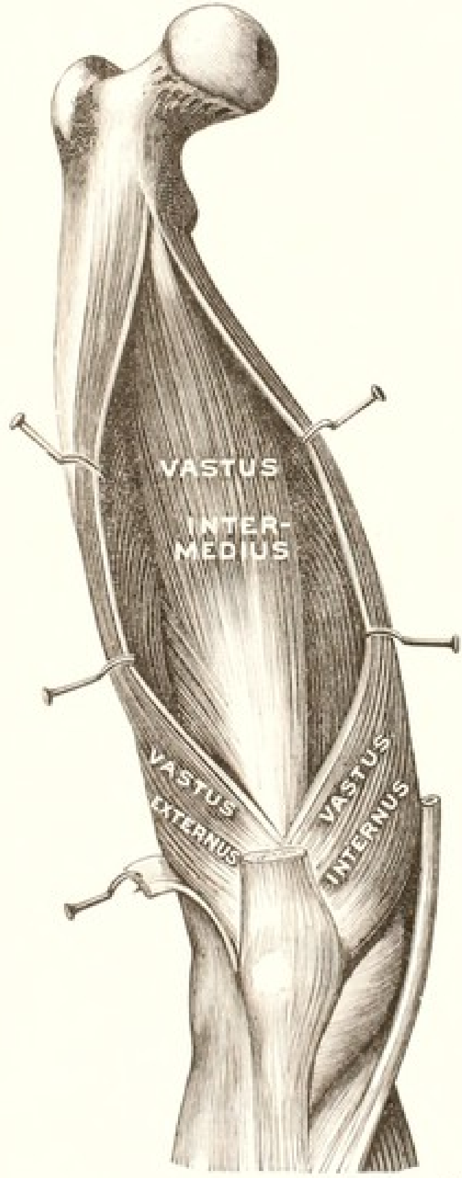


FIG. 102.—The three "vasti" muscles. (Gerrish.)

Origin.—The whole length of the linea aspera and the inner condyloid line (Figs. 219, 220).

Insertion.—The inner half of the upper border of the patella.

Structure.—Similar to the externus. The tendon of origin is a flat sheet arising from the linea aspera and the tendon of insertion is the same sheet to which the others join.

Action.—The line of pull is just like that of the externus except that it is directed diagonally inward instead of outward. Isolated action causes inward displacement of the patella and paralysis makes the subject liable to outward displacement.

VASTUS INTERMEDIUS.

A companion of the two preceding, lying between them and beneath the rectus femoris.

Origin.—The surface of the upper two-thirds of the shaft of the femur.

Insertion.—The upper border of the patella.

Structure.—The muscle fibers arise directly from the bone and pass downward and forward to join the deeper surface of the sheet which serves as a tendon for the two preceding muscles.

Action.—The line of pull, like that of the rectus, is directly upward on the patella, producing extension of the knee. The muscle lies too deep to be readily observed or stimulated, but its leverage and its junction with the common tendon of the vastus externus and vastus internus makes it reasonable to assume that its action is the same.

ACTION OF THE EXTENSORS.

The three muscles named "vastus," with the rectus femoris, make up what is sometimes called the "quadriceps extensor" of the knee; sometimes the internus and intermedius are considered as one muscle, and then the group is called "triceps extensor," to correspond to the like muscle of the arm. There are several similarities; the external head is higher than the inner, the middle head goes up past the joint above, and the inner head is the strongest; the olecranon is somewhat like the patella, although the former becomes in the adult a solid part of the ulna while the patella remains detached from the tibia through life.

The extensors of the knee take part in all such exercises as walking, running, jumping, squatting, climbing, dancing, etc., where the weight of the body tends to flex the knees; sometimes, as in going up stairs or climbing a tree, they lift the weight of the body; sometimes, as in going down the stairs or the tree, they perform a "lengthening contraction" at each step, lowering the body without fall or jar; sometimes, as in running and jumping, they do these two things in alternation.

The extensors of the knee are very important factors in the performance of the exercises mentioned in the last paragraph; they are absolutely essential to running, jumping, climbing, and all movements involving any considerable flexion of the knee from the standing position, and their loss also causes serious trouble in standing and walking. Anyone can observe upon himself that in ordinary standing position the patella hangs loosely in the lax front of the capsular ligament, so that it can be easily moved about with the hand, and it is found that persons with the extensors of the knee paralyzed can stand erect without difficulty, because of the tendency of the weight of the body to overextend the knee. Such persons can walk, providing they avoid flexing the hip far enough to cause flexion of the knee by the weight of the leg and foot. They do this by taking very short steps, which they lengthen somewhat without danger by swinging the hip forward as far as possible at each step, giving them a waddling and stiff gait. If they try to hurry or swing the foot too far forward they fall. Children with the extensors lost are apt to walk with the hands resting on the knees, so as to keep them from flexing by the use of the hands; this is laborious and leads to deformity of the trunk. What is still worse, after the extensors have been lost for some time the flexors shorten from lack of antagonism, keeping the knees flexed and making walking impossible. This makes it necessary to wear an appliance that keeps the knee extended, and then the waddling walk described above can be executed.

When the knee is flexed through 90 degrees or more it can be rotated outward by contraction of the biceps and inward by the semitendinosus, sàrtorius, and adductor gracilis, which attach to the tibia together. This is easily observed by reference to one's own knee, while sitting with the feet on the floor and the knees flexed to about 100 degrees. Place the hands on the sides of the thigh near the knee, the thumbs on top and the fingers beneath; notice the tendon of the biceps, plainly felt on the outer side, and the tendons of the three muscles together on the inner side. Now

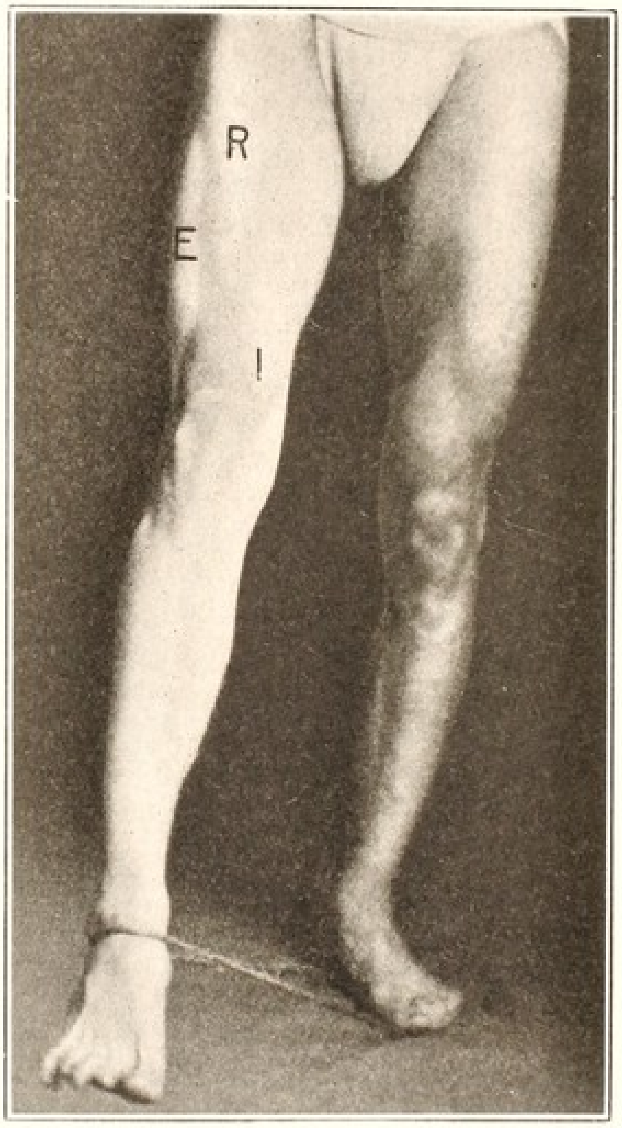


FIG. 103.—The extensors of the knee in action: *R*, rectus; *E*, vastus externus; *I*, vastus internus.

turn the toes forcibly outward and notice that the tendon of the biceps springs into greater prominence and the inner group of tendons disappears under the finger-tips; reverse the rotation and notice the reversal of the action of the muscles, as felt by the finger-tips. This not only demonstrates the action of the muscles employed in rotating the knee but also furnishes one of the best illustrations of the inhibition of antagonists. It is easy to feel the tendons of both the inner and outer hamstrings when the foot rests on the floor in normal position, but as soon as the tibia is rotated in either direction the opposing tendon loses tension, in spite of the fact that the rotation of the tibia would increase its tension if the tone of the muscle were not diminished by nervous influence.

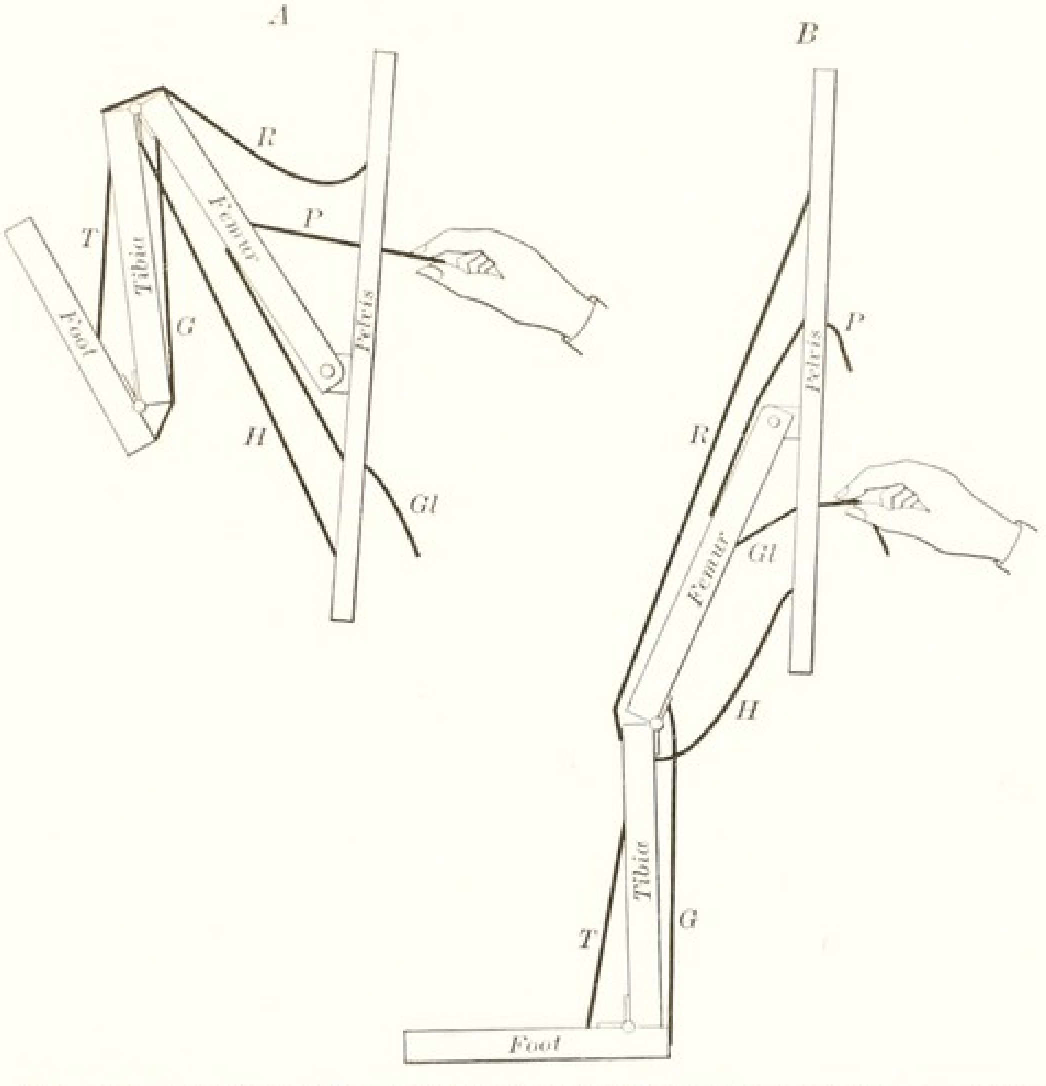


FIG. 104.—The so-called tendinous action of the two-joint muscles of the thigh: *R*, rectus femoris; *P*, psoas; *Gl*, gluteus maximus; *H*, hamstring; *T*, anterior tibial; *G*, gastrocnemius. (Lombard.)

TWO-JOINT MUSCLES.

We have noticed that the rectus femoris and the hamstring muscles reach past two joints—the hip and knee; this fact has led to their being called "two-joint muscles" to distinguish them from the "one-joint muscles," which cross but one joint. Besides the actions we have studied thus far, and which may be called the individual actions of these muscles, the two-joint muscles of the thigh have a combined action due to their passing across the opposite sides of the two joints and which has been called their "tendinous action." When these two opposite sets of muscles are contracted enough to have considerable tension they serve to connect the two joints in the same way that a belt connects two pulleys, so that if you move one of them, the other moves with it. For example, if the hip is flexed by the psoas, iliacus, pectineus, and tensor (Fig. 104, *A*), which are one-joint flexors of the hip, the belt-like action of the two-joint muscles makes the knee flex also; this is because flexion of the hip puts extra tension on the hamstring group and lessens the tension of the rectus femoris, and the change of tension of the two opposing groups flexes the knee. Now while both joints are flexed, if the gluteus maximus, a one-joint extensor, contracts and extends the hip (Fig. 104, *B*), the change of tension on the belt will also extend the knee. These actions can be demonstrated with a model like that shown in Fig. 104, illustrating the general principle that the two-joint muscles of the thigh, when in contraction, exert a belt-like action on the hip and knee such that the two joints tend to take the same position and to move in the same direction and to the same extent. It is evident that this belt-like action will disappear when the two-joint muscles are relaxed and will be most effective when they are in strong contraction.

The two-joint muscles of the thigh are in strong contraction in running, jumping, squatting, and similar exercises, and are therefore tending in these cases to make the hip and knee flex to the same degree, thus keeping the trunk and tibia parallel, as in Fig. 105. This will explain why everyone naturally keeps the trunk and tibia parallel in such exercises, as all who have watched children at play or gymnastics must have noticed, and why it is difficult for most beginners to bend the knees and keep the trunk erect as in Fig. 106, which is the form prescribed in Swedish gymnastics. To take the position of Fig. 106 one must flex the knees to 90 degrees and the hips to 45 degrees; how can this be done? The gluteus maximus might stop the flexion of the hip at 45 degrees, but observation shows that this muscle is idle. The vasti muscles, however, are in strong contraction; the extent to which they lengthen will fix the extent of flexion of the knee; to give the required position of the trunk the hamstrings must shorten and the rectus lengthen slightly as the knees flex. Since this is not an inherited coördination, like running, it has to be learned by voluntary effort and practice.

The question naturally arises now whether the two-joint muscles lose their individual action to flex and extend the hip and knee when they act to tie these joints together and make their movements correspond. The group on one side tends to extend the hip and flex the knee while the opposite one tends to flex the hip and extend the knee; when both contract with the same force it seems as though they would neutralize each other's action and therefore act passively, as a belt or connecting rod acts, to transfer to the other joint any force applied at one of them. If, however, we replace the cords in the model shown in Fig. 107 by rubber bands, so as to bring to bear on the apparatus the natural tension of contracting muscles, the two-joint muscles acting alone will extend both joints; still more surprising, if we replace either one of the

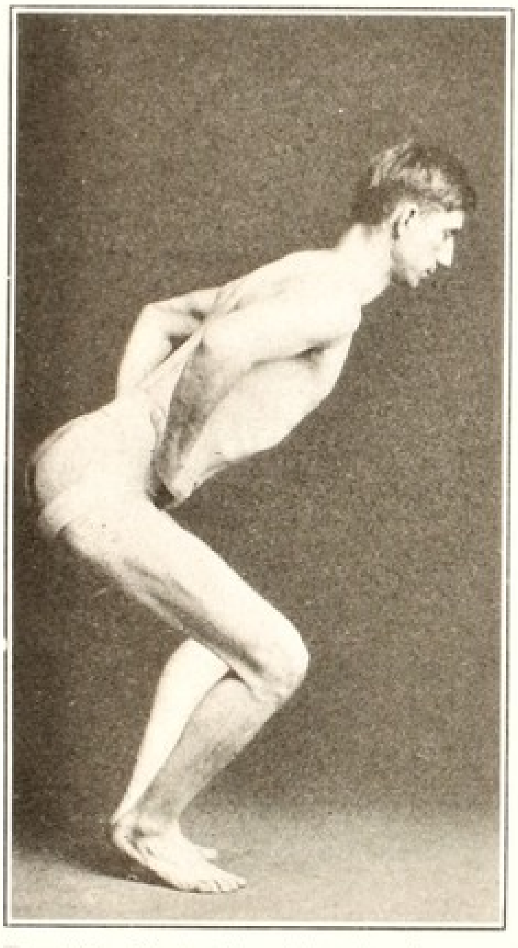


FIG. 105.—Natural position when knees are bent while standing.

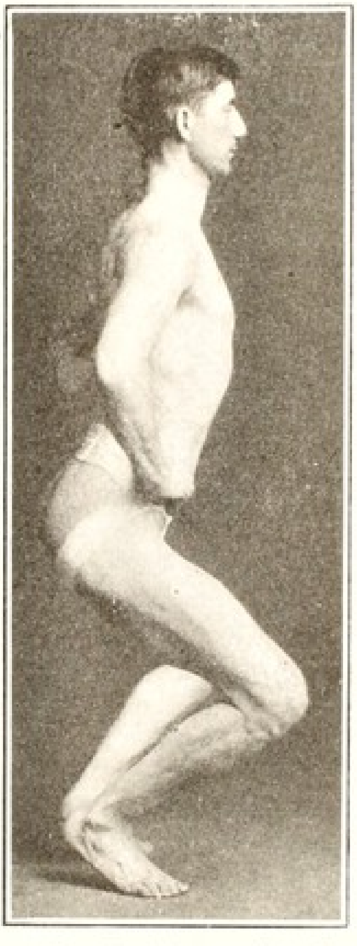


FIG. 106.—Position used in Swedish gymnastics.

two cords by a rubber band and leave the other cord in place, it will extend both joints as before. We are thus confronted by the problem, How can the hamstring-muscles, which are flexors of the knee, cause extension of the knee? How can a cord tied across two joints give to a muscle that is primarily a flexor of a joint the ability to extend it?

Dr. Lombard has explained this apparent contradiction by showing that the two-joint muscles of the thigh have better leverage as extensors than as flexors. The hamstring muscles have better leverage at the hip and the rectus femoris at the knee; the pull of the hamstring, Fig. 107, extends the hip in spite of the rectus because its leverage on the hip is better; the added tension thus put on the rectus causes it to extend the knee in spite of the direct pull of the hamstring; the result is that the model comes to rest in the position of complete extension of both joints. This advantage in leverage consists both in length of power arm and angle of pull, in erect standing position; when the hip and knee are flexed to a right angle the angle of pull is practically the same in all four places, so that the leverage in favor of extension is improving as we approach the erect position.

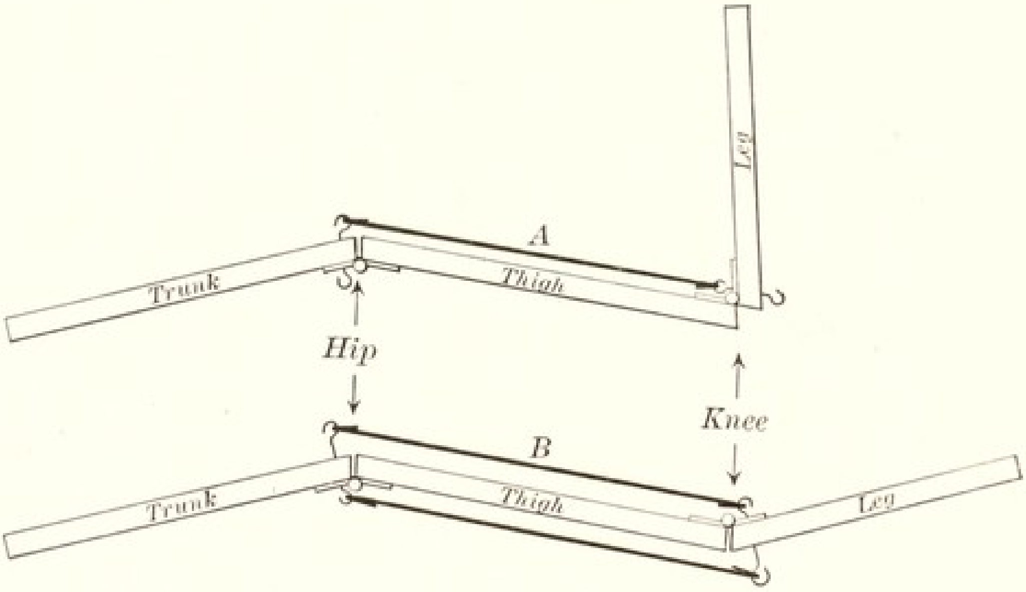


Fig. 107.—Lombard's paradox: *A*, hamstring extending hip and flexing knee; *B*, hamstring with aid of tendon action of rectus femoris, extending both joints.

The utility of having the leverage of these muscles favor extension is evident when we think of it. We have occasion constantly to use the lower limbs in extension against the weight of the body in standing, walking, running, climbing, dancing, and the like, while we have to flex both joints at the same time against resistance but rarely, as would be illustrated by lifting a weight attached to the feet while hanging by the hands.

Suppose, however, we wish to make the movement just described; can the two-joint muscles of the thigh help to perform it? Not when working together with their belt-like action, because their leverage always favors extension; the rectus can never help to flex the knee nor the hamstring to flex the hip, no matter what linkage is used. Such a movement can be made best by the action of the one-joint flexors of the hip and knee acting alone, for any assistance of the two-joint muscles will do more harm than good.

QUESTIONS AND EXERCISES.

1. Select from a group of bones a right tibia and point out its inner and outer tuberosities, its tubercle for the attachment of the patellar ligament, and the place of attachment of five other muscles upon it.

2. Using an unmounted femur and tibia, demonstrate that the axis of the lower limb passes through the tibia but not through the shaft of the femur; show how the inequality of the length of the condyles of the femur causes this; show that the knee is similar to the elbow in this respect.

3. Why is it more difficult to sit erect on the floor with knees extended forward than on a bench or chair? Why does it help in this case to cross the legs, tailorwise?

4. Study the action of the knees in rowing with a sliding seat. What movement of the knees is associated with the push on the oars? What muscles act to produce this movement of the knees? What movement of the knees is associated with the pull on the oars? What muscles do this? Test this out on the living body and make sure.

5. Study the act of kicking a football. What muscles move the limb that kicks the ball? Which way do they pull on the pelvis? What muscles act in the other limb while the kick is being made? Do they pull the same way on the pelvis or help to keep it in place? Which way does the player lean? Why?

6. What movement of the arm most closely resembles the rotation in the knee-joint? In what respects are the two movements alike? In what respects are they different? Amount of movement in each? Why cannot the foot be turned through as many degrees as the hand by the combinations of rotations in the two joints?

7. Explain why one can turn the pedals of a bicycle forward more easily than backward.

8. Is a football-player falling and having others pile on top of him more likely to have his knee ligaments strained if he flexes his knees or keeps them straight? Explain.

9. Standing on left foot with knees extended, place right foot on the floor behind the left heel, the arch of the right touching the heel of the left and the lines of the two feet at right angles; then place the right foot in front of left toe, arch of right at toe of left, right toe pointing directly to left, lines of the two feet at right angles; the right foot now points in exactly the opposite direction to the position it had at first. Explain where this movement takes place and what muscles produce it.

10. Explain how the short head of the biceps can help to flex the hip, and give an example of its action to assist the psoas and pectineus.

CHAPTER X.

MOVEMENTS OF THE FOOT.

The foot includes 26 bones so grouped as to form two arches, transmitting the weight of the body to the ground at three points. The bones are joined together by ligaments and the arches are kept from spreading by ligaments and muscles, forming an efficient shock-absorbing mechanism to lessen the jar that would otherwise result in walking, running, and jumping. The bones are as follows:

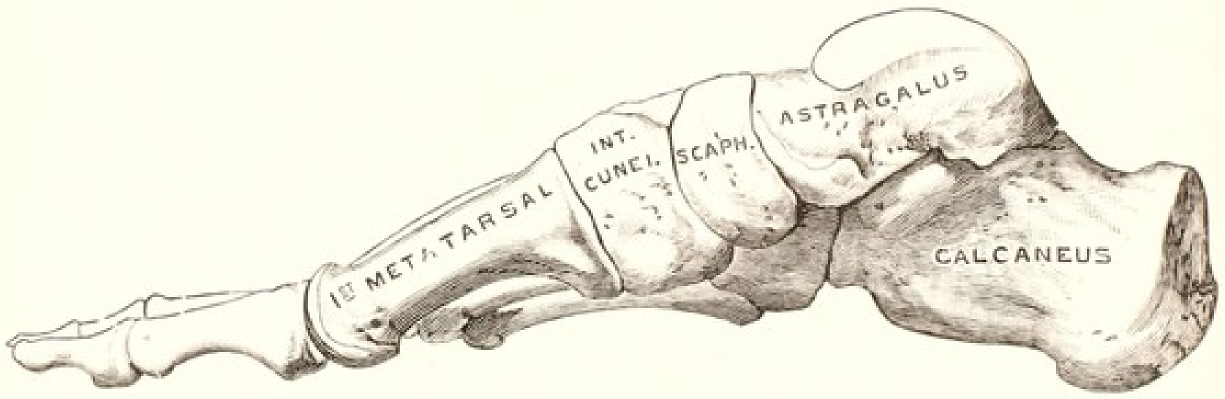


FIG. 108

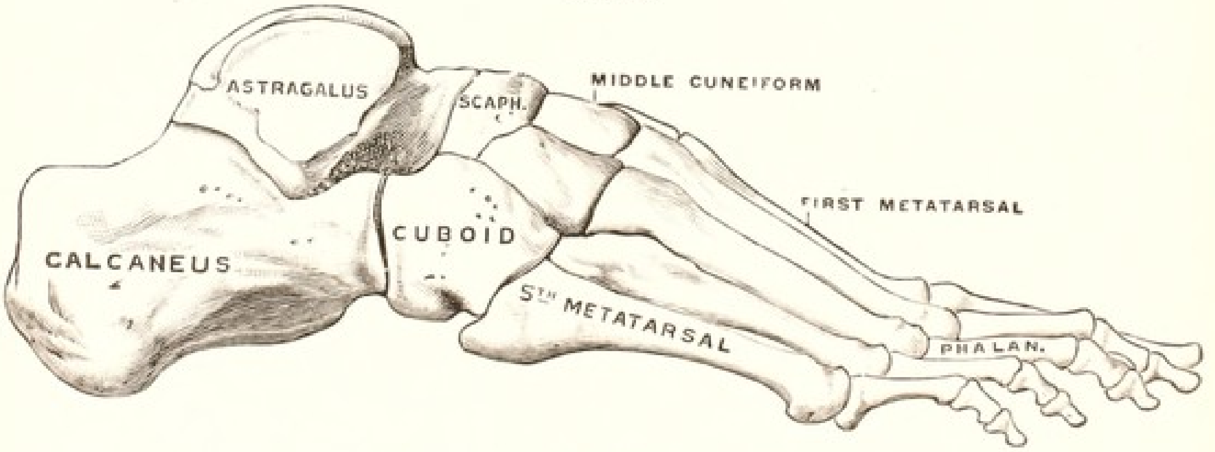


FIG. 109

FIGS. 108 and 109.—Bones of the foot. (Gray.)

Seven *tarsal* bones: astragalus, calcaneum, scaphoid or navicular, cuboid, and three cuneiform bones numbered from within outward;

Five *metatarsal* bones, numbered from within outward, and

Fourteen *phalanges,* three for each toe except the first, which has two.

The principal arch passes beneath the foot, as seen in Fig. 108, the calcaneum forming its rear base and the minor arch forming its front base. The minor arch is formed by the metatarsal bones, the anterior ends of the first and fifth resting upon the ground and the intervening three supported between them. The weight of the body is transmitted through the tibia to the astragalus, which serves as the keystone of the main arch. So great a weight pressing down on such flat arches tends to flatten them out, requiring three strong supports to tie together the three bases; one from the heel to the first metatarsal, one from the heel to the fifth metatarsal, and one between the inner and outer metatarsals. Of these three supports, acting like bow-strings to keep the arches intact, one is ligamentous and the other two muscular. The two calcaneocuboid or plantar ligaments, which are next to the patellar ligaments the strongest in the body, bind the calcaneum to the cuboid and the last three

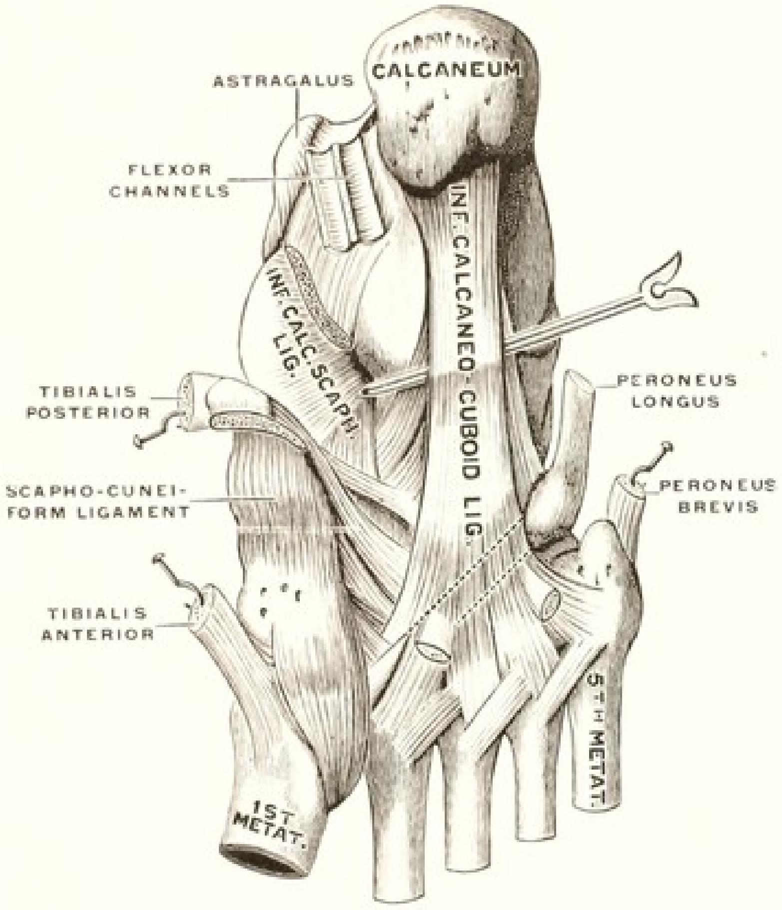


Fig. 110.—The plantar ligaments. (Gerrish.)

metatarsals beneath the outer side of the main arch, as seen in Fig. 110, so firmly that this side of the foot acts almost as one solid piece. The inner side of the main arch, which is better suited in some respects to climbing trees than to walking and standing, is much more pliable, the bones being linked together with smaller ligaments, leaving the support to be supplied chiefly by contracting muscles.

The foot and toes, like the hand and fingers, have many minor movements that do not concern us here, but there are four movements of the foot concerned in bodily posture and exercise that we need to study. These movements are as follows:

1. Elevation of the front of the foot and the toes, usually called dorsal flexion or merely flexion;
2. Depression of the front of the foot and toes, usually called extension or plantar flexion;
3. A rotation of the foot on a horizontal axis so as to turn the sole inward, named rotation inward;
4. The opposite of (3), turning the sole outward and called rotation outward.

These movements of the foot take place in four sets of joints:

1. The ankle-joint, which is a hinge joint formed by the articulation of the tibia and fibula with the astragalus. Projecting processes from above reach down past the joint, adding to its strength and forming two rounded eminences, the inner and outer malleoli. The ankle permits about 75 degrees of movement. Starting from standing position, the knees can be flexed until the tibia inclines forward 25 to 30 degrees with the foot flat on the floor; with further movement the heel is lifted by the posterior ligaments of the ankle-joint. The front of the foot can be depressed through about 45 degrees. The axis of the ankle-joint is parallel to that of the knee, so that the flexed knee always points in the direction of the toes; this is why in knee bending, as in Fig. 106, the knees separate at the same angle as that between the feet in the standing position from which the exercise is taken.
2. The tarsal joints, articulations between the seven tarsal bones. There is some movement here in the same direction as that in the ankle-joint, also rotation to turn the sole inward or outward, and a slight lateral bending of the foot, so as to make either the inner or outer border more concave. It is beyond our purpose to go into all the details of movement in the tarsal joints.
3. The joints between the tarsal and the metatarsal bones, in which the metatarsal bones can move slightly up and down and very slightly in a lateral plane.
4. The joints of the toes, which are hinge joints, flexed when the toes are bent downward and extended when they are raised.

Eight muscles do the main part of the work in producing the movements of the foot described above; the names of these muscles and the distribution of the work is as follows:

Three lifting the front part of the foot: tibialis anterior, extensor longus digitorum, extensor hallucis.

Three depressing the front part of the foot: gastrocnemius, soleus, peroneus longus, assisted slightly by the long and short flexors of the toes.

Three turning the sole inward: tibialis anterior, gastrocnemius, soleus.

Two turning the sole outward: peroneus longus, peroneus brevis.

Two bending the foot laterally: tibialis posterior, peroneus brevis.

TIBIALIS ANTERIOR.

A slender muscle lying just outward from the subcutaneous part of the tibia, on the front of the leg. (Fig. 111.)

Origin.—The upper two-thirds of the outer surface of the tibia and the corresponding portion of the interosseous membrane that joins the tibia and fibula.

Insertion.—The inner margins of the first cuneiform bone and the first metatarsal.

Structure.—The muscle fibers arise directly from the bone and are inserted obliquely into the tendon of insertion, which is held down at the ankle by a ring ligament.

Action.—If the tibialis anterior were to pull straight from origin to insertion it would raise the foot with very favorable leverage; binding the tendon down at the ankle makes it pull at a smaller angle, lessening the power and increasing the speed of movement. The insertion is so near the inner margin that it will lift the inner side most strongly, tending to turn the sole in.

Fig. 111.—Muscles of right leg, front view. (Gerrish.)

Isolated action of the tibialis anterior causes lifting of the forepart of the foot, the motion taking place in both the ankle and tarsal joints; the inner side of the main arch of the foot is straightened out; the sole is turned inward; the last joint of the great toe is flexed or depressed, because the lifting of the foot puts extra tension on the flexor muscles, beneath the foot. (See Fig. 112.)

EXTENSOR LONGUS DIGITORUM.

Similar to the preceding, and just exterior to it (Fig. 111).

Origin.—The outer tuberosity of the tibia, the front of the fibula, and the front side of the interosseous membrane.

Insertion.—Top of the bones of the four outer toes.

Structure.—A penniform muscle with a long tendon beginning at the middle of the leg. As it passes under the ring ligament of the ankle the tendon divides into four that pass to the toes.

Action.—The pull is like that of the tibialis except that it acts on the outer side of the foot, and therefore will tend to turn the sole out rather than in. Isolated action lifts the outer side of the foot with little effect on the inner side.

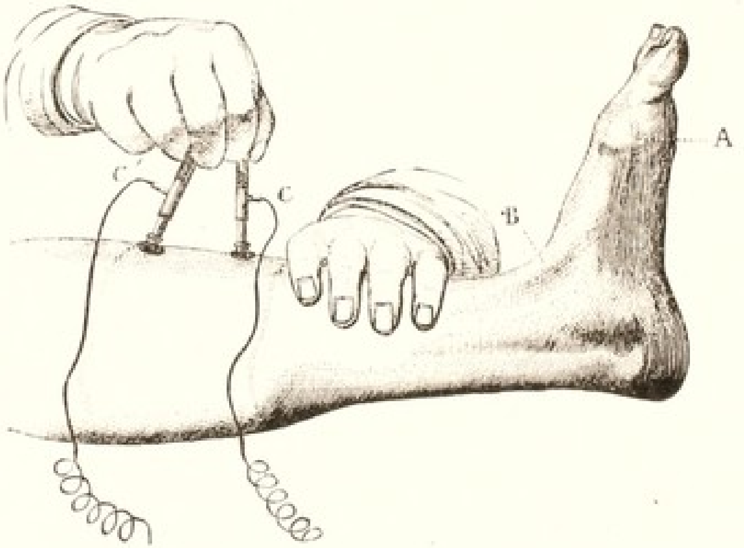


Fig. 112.—Isolated action of the tibialis anterior: *A*, insertion of the muscle; *B*, its tendon at the ankle; *C*, *C'*, the stimulating electrodes, applied to the skin over the muscle. (Duchenne.)

EXTENSOR PROPRIUS HALLUCIS.

A smaller muscle lying beneath the last two and between them (Fig. 111).

Origin.—The front side of the fibula and of the interosseous membrane, at the middle half of the leg.

Insertion.—The top of the last phalanx of the great toe.

Structure.—Like the preceding.

Action.—Strong extension of the great toe, feeble action on the tarsal joints, no effect on the ankle.

The three muscles just described, usually called the flexors of the foot, are brought into action in walking, running, and all similar movements to raise the toes and front of the foot and prevent their striking or scraping on the ground. The tibialis and the extensor longus are both needed to give even elevation of the foot; the extensor of the great toe is included in the coördination, as anyone can notice by observing this movement of his own foot, to counteract the depression of the toe caused by the action of the tibialis, as shown in Fig. 112. People who have lost the use of this group of muscles scrape the foot on the ground at each step in walking.

GASTROCNEMIUS.

The large muscle that gives the rounded form to the calf of the leg near the knee (Fig. 111).

Origin.—By two tendons from the back sides of the condyles of the femur (Fig. 220).

Insertion.—The back side of the calcaneum (Fig. 223).

Structure.—The upper tendons are flattened; the lower (tendon of Achilles) is very large and has a cross-section like a letter T, with the upright part between the right and left halves of the muscle and the crossbar on its posterior surface; the fibers from the two upper tendons pass diagonally downward to join the sides of the tendon of Achilles at various levels.

Action.—The upper attachments are too near the axis of the knee to give good leverage, but the wide movement of the condyles of the femur during flexion and extension of the knee will vary the tension on the gastrocnemius greatly. Its pull on the ankle is with a long lever arm and a large angle. Lifting the calcaneum, it will depress the front of the foot; since the plantar ligaments connect the calcaneum with the outer margin of the foot only, its entire force will be exerted there.

Isolated action of the gastrocnemius extends first the ankle- and then the tarsal joints; the latter joints being somewhat oblique, the last part of the movement depresses the outer margin of the foot more than the inner, turning the sole somewhat inward. If, while the muscle is being stimulated, the observer pushes strongly upward on the sole of the foot, the outer margin is found to be depressed with great power, while the inner margin can be easily lifted and the arch straightened out in spite of the contraction. Stimulation of the gastrocnemius while the subject is standing at rest on his feet causes the heels to be lifted and the weight to be sustained on the outer margin of the foot.

SOLEUS.

An associate of the gastrocnemius, lying beneath it on the back of the leg.

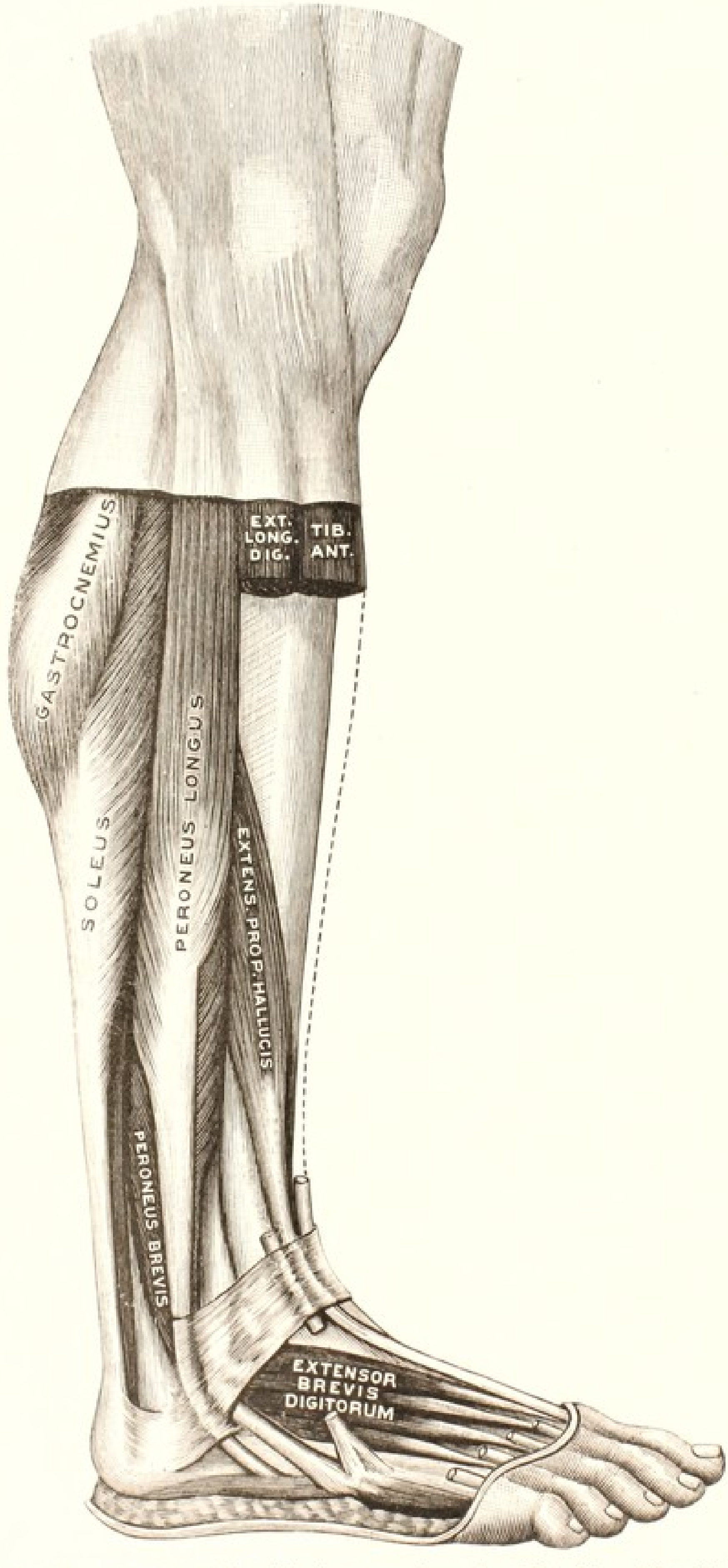


FIG. 113.—Muscles of the right leg, seen from the right side. (Gerrish.)

Origin.—The upper part of the posterior surfaces of the tibia, fibula, and interosseous membrane (Fig. 221).

Insertion.—By the tendon of Achilles into the calcaneum.

Structure.—Penniform sheets.

Action.—The soleus has the same pull and leverage on the foot as the gastrocnemius, but lacks any connection with the femur.

The gastrocnemius and soleus, sometimes called the triceps of the leg, act together in all such movements as standing, walking, running, jumping, dancing, climbing, etc., where the weight of the body is supported on the feet and lifted by them. When the knee is flexed to 90 degrees or more the gastrocnemius seems to be left out of the coördination, leaving the work of extending the foot to the soleus; in this position the heads of the former are so low that it cannot pull effectively.

In the frog the tibialis anterior reaches above the knee and is attached to the front of the femur, forming with the gastrocnemius a pair of two-joint muscles whose belt-like action tends to make the knee and ankle work in unison, like the hip and knee. This links the whole lower limb into a series of levers for extension of all the joints at once, with all the one-joint extensors as well as the two-joint extensors applying their force to the whole system. The result is a remarkable mechanism for jumping. In man the attachment of the tibialis below the knee leaves a gap in the system, but the gastrocnemius acts in much the same way alone. The attachment of this muscle to the condyles of the femur, causing increased tension upon it when the knee is extended, makes it possible to use any surplus of force in the thigh muscles to help lift the heel.

The leverage of the triceps of the leg in lifting the heel has been a puzzling question with anatomists, some claiming that it is a lever of the first class with the axis at the ankle and others that it is a lever of the second class with the axis at the toes. The confusion is due to the fact of the machine's lifting itself, the situation being too complex to be any form of simple lever. One assumption in simple levers is that the fulcrum is stationary; this is violated if we call it a first-class lever. Another is that the two forces acting on the lever are independent; if we call it a second-class lever we have the muscle pulling up on the lever and down on the weight to be lifted. The force of contraction of the muscles needed to lift a person of known weight can be computed by assuming it to be a lever of either class, but if we call it second class we must add in the reaction of the pull and this involves a geometrical series.

PERONEUS LONGUS.

This muscle is remarkable for its great power in proportion to its size and for the long and tortuous course of its tendon of insertion. It is situated along the fibula on the outer side of the leg, just beneath the skin.

Origin.—The outer tuberosity of the tibia and the upper two-thirds of the outer surface of the fibula (Fig. 221).

Insertion.—The outer margins and lower surfaces of the first cuneiform bone and first metatarsal (Fig. 224).

Structure.—The fibers are short and arise directly from the fibula, one of the best examples of simple penniform arrangement; the tendon of insertion passes down behind the outer malleolus, turns forward around its lower end at an angle of about 60 degrees, passes forward along the outer margin of the foot to the groove in the cuboid bone, where it makes another turn of about 100 degrees, then diagonally forward and across the sole of the foot to the place of insertion at the base of the great toe.

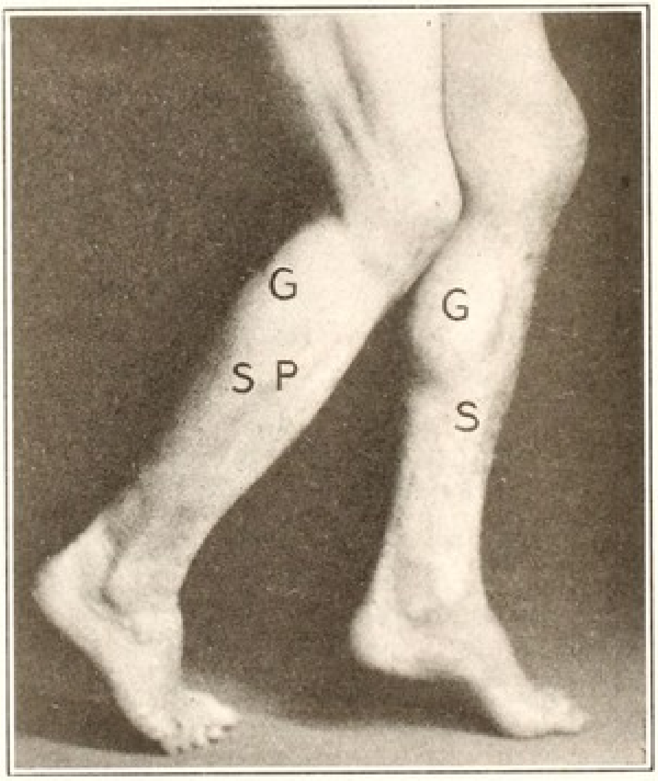


FIG. 114.—The extensors of the ankle in action: *G*, gastrocnemius; *S*, soleus: *P*, peroneus longus.

Action.—A cord looped around the base of the first metatarsal, drawn through the groove in the cuboid and around the outer malleolus and then held vertically beside the fibula, indicates the direction of pull. The mounted skeleton does not usually allow movement here so as to permit useful experiment. The direction of pull suggests that the peroneus will prevent the minor arch from spreading; whether it will move the tarsal or ankle-joints can be little more than conjectured, so far as one can judge from the course of the tendon.

Isolated action of the peroneus longus first depresses the great toe and draws it outward, increasing the curvature of the principal arch of the foot on the inner side; stronger action turns the sole outward; finally it extends the ankle slightly. All these movements are made with little force unless the ankle is forcibly extended by the tendon of Achilles, since the peroneus uses the cuboid bone as a pulley and its force is lost unless the pulley is held firm. Duchenne reports that pulling upon the tendon of the peroneus in a fresh cadaver produces exactly the same movements of the foot as electric stimulation, and that loss of the muscle also verifies it; he points out that electric stimulation of the gastrocnemius in a normal subject gives the same movement of the foot as voluntary attempt to depress the toes when the peroneus is lacking.

The work of Duchenne on the gastrocnemius and the peroneus longus is probably the most important of all his researches on the action of muscles, partly because of the great importance of these two muscles in the posture and movement of the body, and partly because the problems here are not problems of coördination but problems of mechanical nature which his methods are especially calculated to solve. Attacking these problems relating to the support of the body on the foot and the causes of deformities of the foot by three separate methods, he explains every detail so fully and clearly that, although published in 1867, his chapters on the movements of the foot are still the best by far of anything we have on the subject.

The gastrocnemius, soleus, and peroneus longus work together in all bodily exercises in which the weight is borne by the feet, and their combined action is necessary to the normal working of the foot; the loss of the triceps of the leg causes inability to extend the ankle and the loss of the peroneus longus causes a flat foot.

TIBIALIS POSTERIOR.

Situated deep beneath the triceps on the back of the leg.

Origin.—The upper half of the posterior surface of the interosseus membrane and the adjacent parts of the tibia and fibula.

Insertion.—The lower and inner surfaces of the scaphoid and the first cuneiform bone, with offshoots to adjacent bones.

Structure.—Simple penniform; the tendon turns through 90 degrees around the inner malleolus.

Action.—The pull is almost directly backward on the scaphoid and cuneiform bones, which can do little to flex or extend the ankle; it ought to help support the weaker side of the arch, preventing the weight of the body from crowding the astragalus down between the calcaneum and scaphoid; it does not reach the first metatarsal and therefore cannot act as an effective support for the arch.

Isolated action of the tibialis posterior, according to Duchenne, bends the foot laterally, making the inner margin more concave, increases the curvature of the arch, and has little or no effect on the ankle.

PERONEUS BREVIS.

A small associate of the longus (Fig. 115).

Origin.—The lower two-thirds of the outer surface of the fibula.

Insertion.—The lower side of the base of the fifth metatarsal.

Structure.—Fibers arranged like the longus, similar turn around the outer malleolus, direction forward and downward to the insertion.

Action.—From the direction of pull one would judge that the peroneus brevis will lift the outer margin of the foot and bend it laterally so as to make the outer edge more concave. In spite of the assertion of most anatomists that both the tibialis posterior and the peroneus brevis extend the ankle, Duchenne says that they neither flex nor extend it, but tend to hold it in the normal position between the two. On a mechanical question like this his experiments by electric stimulation and traction upon the severed tendons should give the most reliable conclusions.

The muscles shown in Figs. 116 and 117, with a few others beneath them, especially those toward the inner side, help to support the arch of the foot when the weight of the body is placed upon it. Their

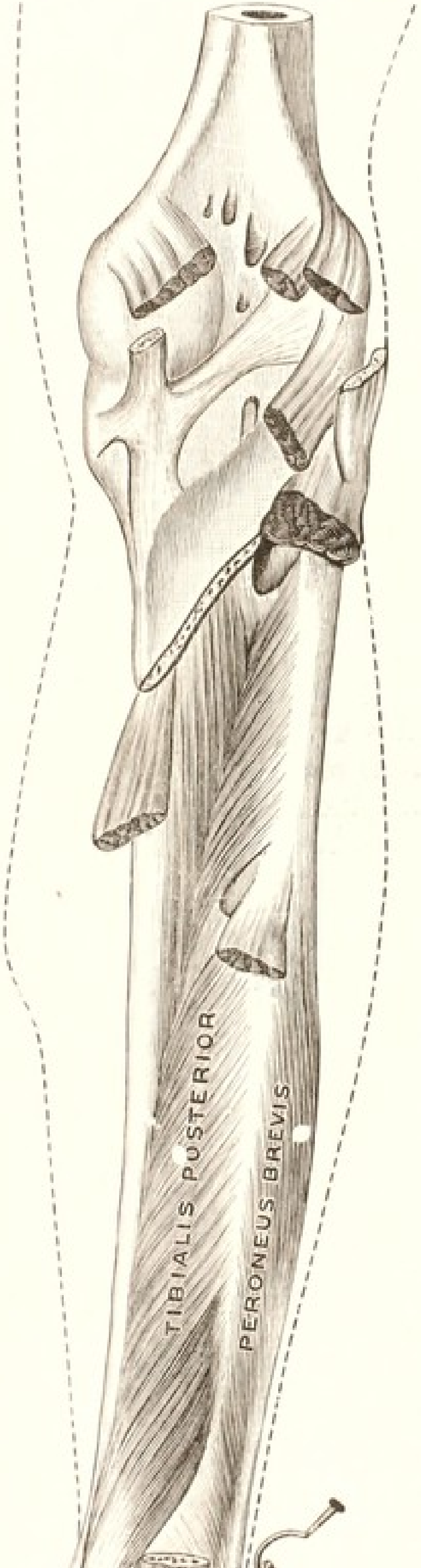


Fig. 115.—The tibialis posterior and peroneus brevis of right foot. (Gerrish.)

primary duty, however, is to move the toes and they are not able alone to keep the arch from flattening out under the body weight if the triceps of the leg or the peroneus longus or both of them are lost.

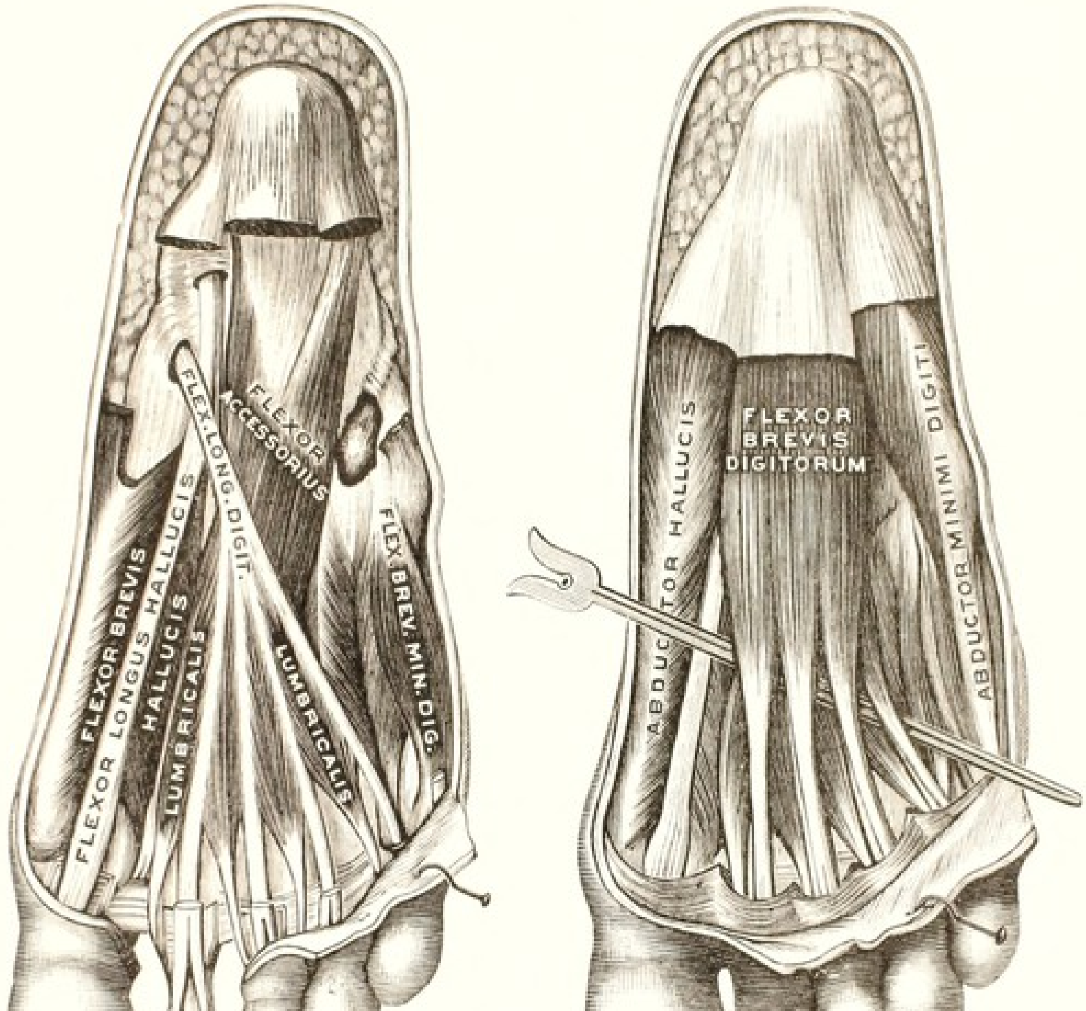


Fig. 116 Fig. 117

Figs. 116 and 117.—The first and second layers of the muscles of the sole. (Gerrish.)

DEFECTS OF THE FOOT.

Deformities of the foot are sometimes produced by paralysis or atrophy of certain muscles, as a result of which the remaining muscles pull the joints into abnormal positions; a similar deformity is sometimes caused by abnormal shortening of certain muscles which is called *contracture.* The most common of these deformities are as follows:

1. Paralysis of the gastrocnemius and soleus with the resulting shortening of the tibialis anterior and extensor longus give the deformity called *calcaneus*, where the forefoot is kept up and the patient walks on the heel.

2. Contracture of the gastrocnemius and soleus produces the form of defect called *equinus*, the weight being supported on the toes and the heel unable to touch the ground.

3. Contracture of the tibialis anterior and posterior or loss of the peroneus longus causes *varus*, in which the sole is turned in.

4. Contracture of the peroneus longus causes *valgus*, in which the sole is turned out and the patient walks on the inner margin of the foot.

5. Weak foot, pronated foot and flatfoot, which are successive stages of one and the same defect.

The deformities of the foot known as calcaneus, equinus, varus and valgus are marked deformities calling for surgical treatment; corrective exercises are of little or no value until surgical correction has been made.

The earlier stages of flatfoot are very common and are yearly becoming more common. In the very first stage the subject may notice that the feet are more easily fatigued than formerly but this may not be noticed at all. A careful observation of the feet during walking, running or dancing will often show that when the entire weight of the body is thrown upon one foot the inner side of the main arch flattens out, from inability of the muscles to support the weight. The outside of the arch, held up by the plantar ligaments, is apt to stand the strain better, and as a result the foot tips inward, making the inner malleolus prominent, bending the tendon of Achilles inward just above the heel, and thus throwing a greater share of the body weight on the weak inner side of the foot. In all such cases we have the beginning of the series of changes that end in flatfoot.

Unless remedial measures intervene, the condition gradually develops to the stage of pronated foot, with the scaphoid bone prominent and a bending of the foot at its middle, convex on the inner side.

The inability of the peroneus longus and the smaller muscles associated with it to depress the great toe is likely to result in flattening of the anterior arch of the foot as well as the inner side of the main arch. Sometimes the anterior arch gives way before the other. When this arch gives way the balls of the second, third and fourth toes have to bear too much weight and becomes inflamed and painful.

At the stage when the foot is becoming much pronated the subject is apt to experience a good deal of discomfort and often severe pain, caused by pressure and rubbing of the shoe over the scaphoid, by pressure between the bones of the arch at points not provided with smooth articular surfaces, and by pressure upon the nerves in the sole of the foot, to which these nerves are not accustomed. Sometimes the subject puts all his weight on the outer side of the foot for relief. In time the bones may develop new surfaces of contact and the nerves become accustomed to the pressure on the sole, so that the pain gradually grows less and perhaps ceases altogether, but the foot is no longer the elastic shock absorber and mechanism for graceful and springy locomotion that once it was.

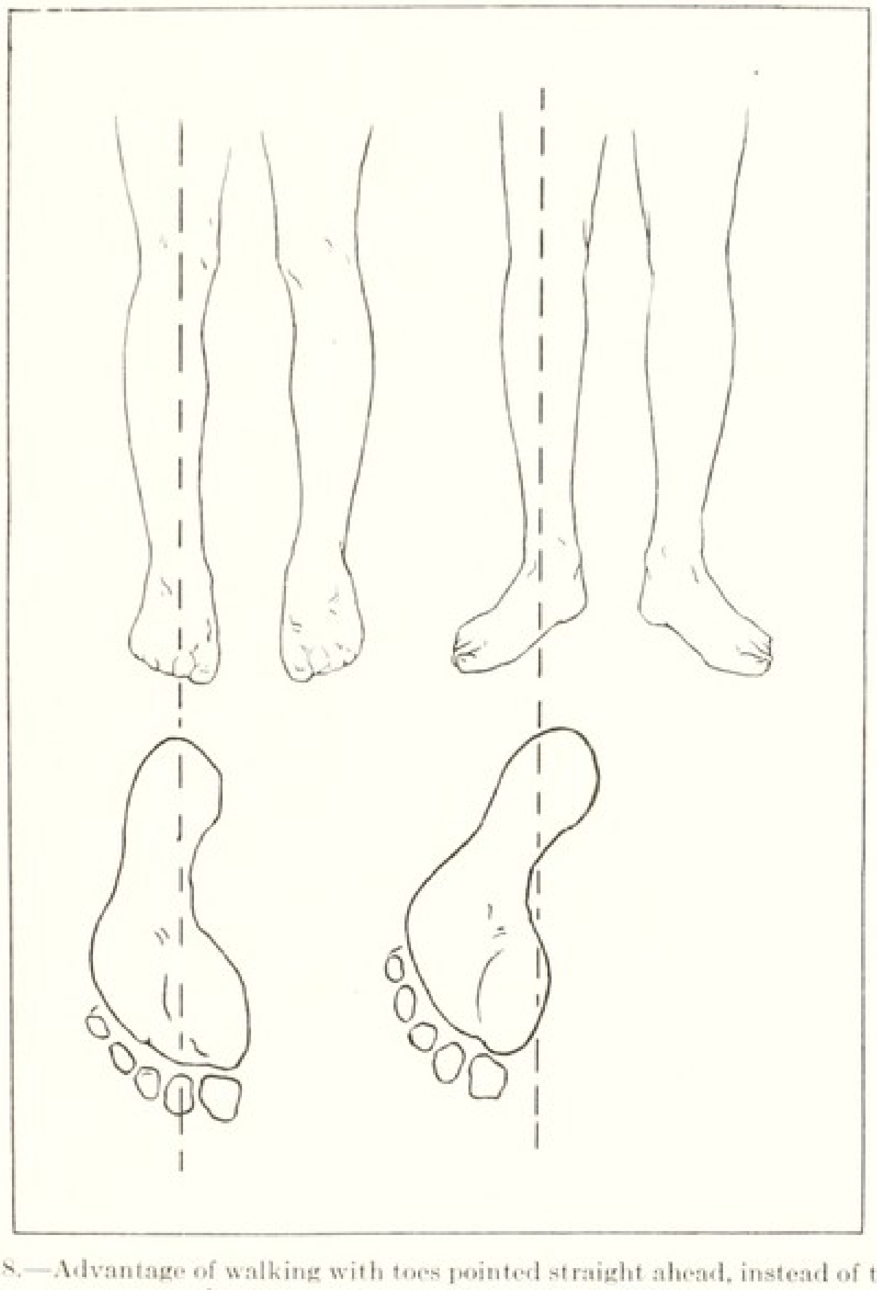


FIG. 118.—Advantage of walking with toes pointed straight ahead, instead of turning them out, as custom directs. (Drew.)

Sometimes it retains a wide flexibility, like the foot of the ape, but it has not the power of sustaining the weight and completely flattens out with every step, producing an awkward gait and inefficient locomotion.

To understand why the foot, in spite of the great amount of physical activity it has, should so frequently suffer from lack of muscular strength, we have to keep in mind that no other group of muscles in the body has to bear so often the entire body weight, nor are any other muscles so hindered in their action by clothing imposed upon them by the edict of civilized society.

Among the many causes of flatfoot the following are important:

(*a*) An inactive life in later childhood and youth often fails to develop the strength of muscles and ligaments, afterward needed to sustain the weight. School, with many hours of enforced quiet, is the most important of all influences toward an inactive life, developing a habit of physical inactivity and a tendency toward quiet amusements and a quiet occupation. The general range of physical activities of the playground and the gymnasium help to develop the feet and ward off muscular weakness with its attendant troubles, but as long as the schools compel so many hours of inactivity of the muscles a large amount of running and games will be necessary.

(*b*) A rapid laying on of adipose tissue in middle life very often occurs, increasing the strain on the feet and making an active life in earlier years all the more necessary; few people anticipate this change in weight and still fewer do anything to make their feet strong enough to meet the added strain.

(*c*) Constant walking on hard, even surfaces, such as cement sidewalks gives too hard an impact with each step; the even surface fails to provide the muscular development given by walking in open fields, where an uneven but softer surface causes the foot to take various positions instead of always striking in the same way.

(*d*) Badly fitting shoes have a large place among the causes of flatfoot. Most adult feet in civilized countries are deformed by wearing shoes that are too short or that fail in some other way to fit them. Manufacturers of shoes, like manufacturers of school seats, seem to pay little attention to the requirements of the body, trying to please the buyers by style instead.

A shoe that is too short tends to cause pronation of the foot, for as the weight is placed on the arch it tends to lengthen, and if a short shoe prevents, it pronates instead, tipping inward and starting the foot on the way to flatfoot.

Shoes that give a complete support to the arch do not give enough work to the muscles; those that are too flexible do not help enough in meeting the impact of the hard stairs and walks; a moderate degree of flexibility in the shank of the shoe is best.

Shoes that bend the great toe outward make it less able to bear its share of the weight and so help in producing the weak, flatfoot.

High heels cause the foot to slip forward into the front part of the shoe and thus have the same effect as when the shoe is short; extreme overextension is also produced at the ends of the metatarsal bones; the muscles attached to the tendon of Achilles become gradually shortened; all these things injure the foot and make it weaker.

(*e*) Walking or running with the toes turned far out, in the way custom has dictated, is bad for the feet because it throws the entire weight on the inner side of the foot, instead of dividing the weight, as is the case when the toes are pointed straight ahead. (See Figs. 118 and 119.)

Tight shoes may be a help temporarily in preventing too much strain on the foot in an emergency, such as running a foot-race or standing continually on the feet for several hours, as barbers and clerks often do. The tight shoe supports the foot and prevents pronation and flattening under the great strain it has to meet. It must be remembered, however, that the tight shoe does not develop the foot; it checks the circulation and interferes with free muscular action; the runner and the clerk should change to a looser shoe when the emergency is past, and should practise activities that will develop the feet while the looser shoes are worn.

Special exercises for the feet should include some taken with no weight on the foot; complete movements in all directions are desirable, while the leg rests across the opposite knee. Exercises lifting the inner end of the arch should be practised sitting, with the feet resting on the floor.

FUNDAMENTAL MOVEMENTS OF THE LOWER LIMB.

Walking, running, and jumping are inherited coördinations, sometimes modified for gymnastic, military, and athletic purposes. The main work of these movements being performed by the lower limb as a whole, we are in a position for the first time to study and analyze them.

Walking.—The photographic method enables us to observe exactly what movements occur and when they occur in such an exercise as walking, much more easily and accurately than we can by observation of the moving body. The sensitive film can record for our study several positions in regular intervals of time during one complete cycle of walking, beginning when one foot strikes the ground.

The photograph shows simultaneous extension of the hip, knee and ankle on the supporting side for the first stage of the movement, which brings into action all the one-joint and two-joint extensors of the whole lower limb except the gluteus maximus. At the same time the gluteus medius and minimus of the same side in action to keep the opposite hip from dropping down and to rotate the pelvis inward on the head of the femur. A slight flexion of the knee and ankle seen just as soon as the weight is transferred to the other foot is found, by a trial the reader can make upon himself, to be caused by the effect of the weight of the body at the instant the foot is placed on the ground, the extensors of the knee and ankle not being fully contracted as yet and thus permitting a slight flexion that avoids a jar and also avoids an immediate and sudden lifting of the whole body that would otherwise result from the slanting position of the left limb. The hip is fully extended when the body is exactly above the foot, and since the iliofemoral band will prevent further extension during the next interval the joint must be stationary, and the same is true of the following positions, but the extensors must be working and bearing the weight just the same. Test will also show the rectus femoris working during this phase of the step, although it is sometimes a flexor of the hip.

After the transfer of the weight we have simultaneous flexion of hip, knee and ankle in the free limb, requiring much less force than the preceding stage. The rectus femoris can be felt to cease contraction at this time, but the sartorius, pectineus, adductor longus and tensor contract, and probably also the psoas and iliacus. The hamstring muscles continue in contraction and, being relieved of the weight of the body and the extensors of the knee relaxing, they quickly flex the knee. At a certain stage the knee is seen to be flexed to almost a right angle; after that the hamstring muscles relax and the knee swings passively into almost complete extension just before the foot comes to the ground again. The ankle, which is fully extended in the middle position, the foot giving a final push just before leaving the ground, flexes in a passive manner while it is swinging forward, and later it is flexed actively by the anterior tibial group to keep it from scraping the ground. During the last half of the cycle the limb is being rotated outward by the six small rotators. Notice that the arm is swung forward as the limb moves backward.

The extent of each of these movements is increased as the step is lengthened. Practice in observation will enable us to notice and analyze the peculiarities of walk of individuals, which are due in part to muscular peculiarities and in part to habits of coördination. Some strike the foot too hard on the ground by contracting the vastus group too strongly at the time the knee and ankle should yield to the weight of the body; some wear their shoes through on the inner side by failing to use the adductors of the free limb sufficiently while others drop the free hip at each step by failing to use the abductors of the supporting hip sufficiently; many children turn the toes in on one or both sides while walking by failing to use the outward rotators as the limb swings forward.

Marching.—Marching is a modification of walking in which the individual is taught to avoid some of his peculiarities of gait by standing erect and keeping time with the other members of the company or class; one learns by such practice to walk at any given rhythm and at the same time to vary his stride to any length used by his associates. To emphasize the development of the extensors of the foot, marching is sometimes done with extra effort to extend just as it comes to the ground, making the toes strike first. For development of the thigh muscles and for purposes of display, marching has been modified in several ways, one of the most extreme forms having the knee raised as high as the hip and then the knee extended forward. "Bent knee" marching, described at length by Regnault and Raoul, is a march with long strides and with the knees in deeper flexion than in the usual forms; it is advocated for its economy of force and speed.

Running.—Running differs from walking in a few minor details. The most important of these is the spring from the ground, the body being unsupported for a part of each stride. One foot is on the ground for about one-third of the time and the other foot for the same, leaving the body unsupported for about one-third of the time; this will vary with the length of the stride. As the weight is borne by the front of the foot alone, the heel not touching, the flexion of the knee when the foot first strikes is not so much needed to prevent jar as in walking. The greater speed of the run makes it possible to leave the ground at each step and still have but little more up-and-down oscillation of the body than in walking. Notice that the hip and knee are flexed considerably just as the body is over the foot and the limb inclines forward as it extends, making the vertical oscillation very slight.

Jumping.—Jumping does not differ essentially from running, the spring from the foot being made in the same manner, only in jumping we do not repeat the movement but alight on both feet. In the running jump the spring is made as in running, while in the standing jump the spring is from both feet. In both cases we get the most efficient use of the mechanism of the lower limb, which, as we have seen is so constructed that all the one-joint and two-joint extensors can bring their forces to bear on the system of levers at once. As soon as the feet leave the ground in the jump the limbs flex by a sort of recoil from the violent extension, the extensors of the knee relaxing first and allowing the hamstring muscles to flex the knees; just before alighting the knees are again nearly extended, to yield again to the weight of the body when the feet strike. In alighting as well as in the spring the whole mechanism of the limb comes into action to support the weight and at the same time to prevent injury from its being stopped too suddenly in its flight.

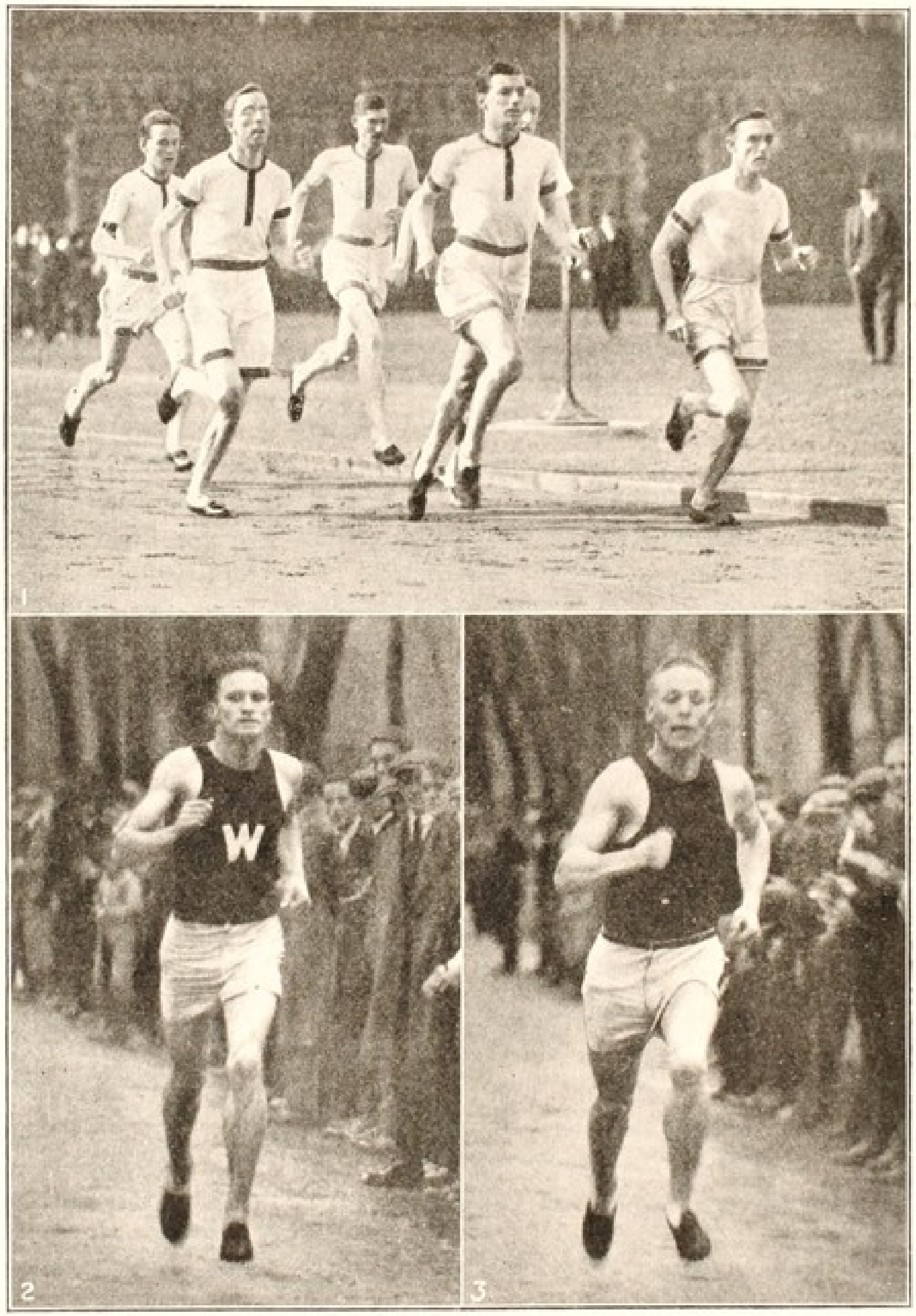


Fig. 119.—Running. (From Jones, Track and Field. Courtesy of Charles Scribner's Sons, New York.)

In the high jump, as well as in the broad jump, the best record can be made from a run, because this carries one quickly over the bar, so that one can clear it without remaining above it so long.

QUESTIONS AND EXERCISES.

1. Point out the two arches of the foot, the tarsal bones, the metatarsal bones, the position of the plantar ligaments.

2. Explain how the gluteus maximus can help to extend the ankle.

3. A man alighting from a high jump strikes a hard spot on the mat with the ball of the great toe. What muscle is apt to be strained? Explain how this strain will be felt high up on the outside of the leg. Explain how he can also have a sore spot near the top of the instep, caused by the same accident.

4. Explain how contracture of the peroneus longus and weakness of the same muscle both result in walking on the inner margin of the foot.

5. Why are those who walk or run flat-footed more likely to sprain their ankles than those who go on the toes?

6. A man weighing 100 pounds stands on a table with his heels projecting slightly over the edge, so that your fingers can be placed under them. If you lift up on his heels, his feet act as second-class levers, and if his ankle-joints are one-quarter of the distance from heel to toes it will require a lift of but 75 pounds to raise his heels from the table. Under the same conditions he must contract his triceps of legs with a force of 300 pounds to accomplish the same movement himself. Explain.

7. How far can you flex your knees while standing and still keep your heels on the floor? Why cannot one flex them farther without lifting the heels? How account for the difference found between individuals in this respect?

8. Explain the advantages and disadvantages of high-heeled shoes.

9. It is a favorite stunt among boys to jump and strike the feet together two or three times before striking the ground again. What muscles perform this movement and how is it done?

10. Write in a column the names of all the muscles of the lower limbs. Write in a parallel column several inches away a list of all the movements of all the joints. Draw a line from each muscle to all the movements it takes part in, making a complete chart of the actions and the muscles.

PART IV.

THE TRUNK.

CHAPTER XI.

MOVEMENTS OF THE SPINAL COLUMN.

THE bony axis of the trunk, called the spinal column, consists of 33 vertebræ; 24 of these are joined to form a flexible column. Seven vertebræ are in the neck and are called cervical vertebræ; 12 are in the region of the chest and are called thoracic or dorsal vertebræ; 5 are in the lumbar region; 5 are fused together to form the sacrum, the rear portion of the pelvis; the lower 4 are only partially developed and form the coccyx. The spinal column is flexible above the sacrum, upon which the flexible portion rests. Each vertebra bears the weight of all parts of the body above it, and since the lower ones have to bear much more weight than the upper ones the former are much the larger. The flexibility of the column makes it possible to balance the weight upon the vertebræ in sitting and standing.

Each vertebra has a dozen or more parts or points of interest to be observed. The body is the largest portion and the most important, since the weight is transmitted through it; passing to the rear are the two pedicles, then the two laminæ, the five enclosing the spinal foramen. A spinous process extends to the rear and a transverse process from each side; four articular processes, two above and two below, have articulations with the next vertebræ; beneath each pedicle is an intervertebral notch, leaving a place for nerves to leave the spinal cord. Besides these points, to be found on all vertebræ, the thoracic vertebræ also have four articular processes or facets for the attachment of the ribs.

The skeleton of the chest or thorax includes the sternum and twelve pairs of ribs, a pair for each thoracic vertebra. The ten upper ribs are attached to the sternum by the costal cartilages, the lower two being attached only to the vertebræ.

The vertebræ are separated by elastic disks of cartilage called the intervertebral disks, which are firmly joined to the bodies of the vertebræ and which permit movement of the column because of their elasticity. Besides the union through the disks the vertebræ are joined by ligaments; the bodies by an anterior and a

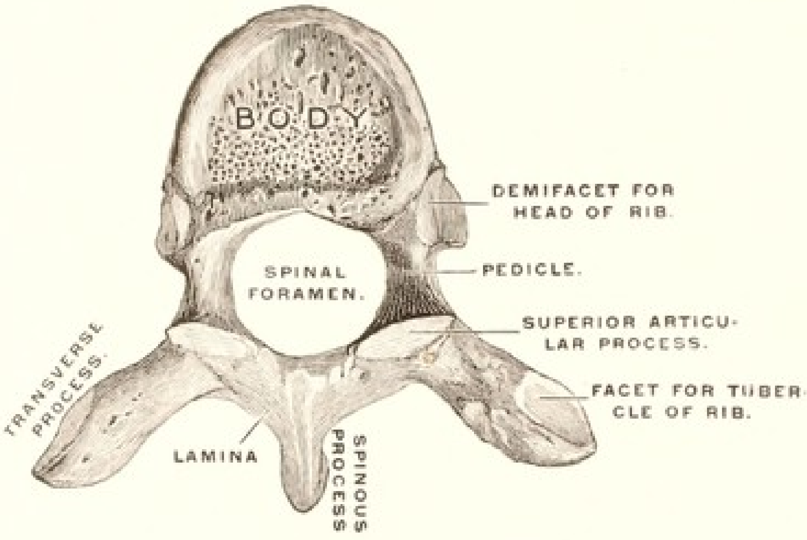


FIG. 120.—A thoracic vertebra seen from above. (Gerrish.)

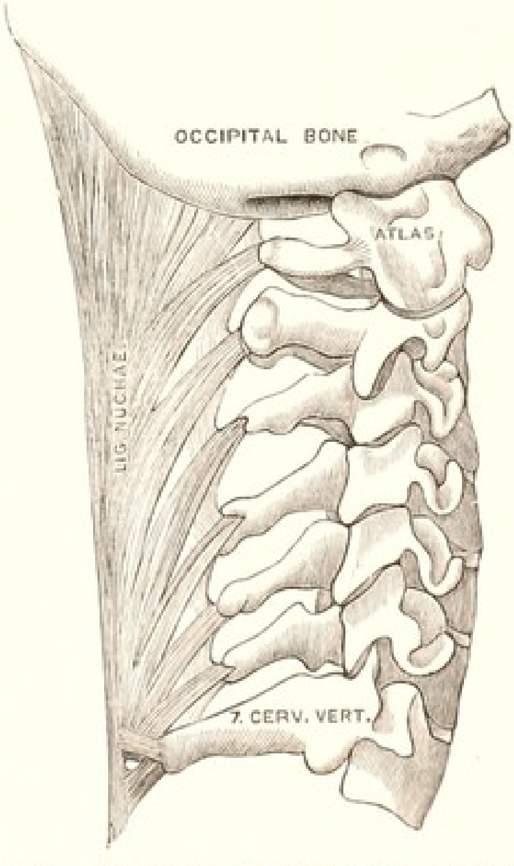


FIG. 121.—The ligament of the neck. (Gerrish.)

posterior common ligament extending from the skull to the sacrum along their front and rear surfaces and by short lateral ligaments joining the bodies of adjacent vertebræ; the laminæ are joined by the subflava ligaments, which enclose the spinal canal, and the spinous processes by the interspinous ligaments. In the cervical region these processes are short and the interspinous ligaments are replaced by a single strong elastic ligament, the ligamentum nuchæ or ligament of the neck. In quadrupeds this ligament has to support the weight of the head and is much larger than in man.

The normal spinal column is approximately straight when viewed from the front or rear; it has a slight curve to right in the thoracic region, supposed by some to be due to the pressure of the aorta and by others to the pull of the right trapezius and rhomboid, which are used more than the muscles of the left side by right-handed individuals. This deviation from a straight line is too slight to be observed in the normal living subject.

When the spinal column is viewed from the side it presents four so-called normal curves: cervical and lumbar curves, concave to the rear, and thoracic and sacral curves, convex to the rear. These curves merge gradually into one another, the only approach to an angle being where the last lumbar vertebra joins the sacrum; the sharp bend here is due to the fact that the top of the sacrum slants forward about 45 degrees with the horizontal, giving the sacral angle (Fig. 122).

The thoracic curve exists before birth, and is chiefly due to the shape of the bodies of the vertebræ, which in this region are slightly thinner at their front edges (see Fig. 122). The cervical and lumbar curves are not present in the young child, which has a single curve convex to rear through the entire extent of the spine. The cervical curve is formed by the action of the child's muscles when he begins to sit up and hold his head erect, and later to a more marked extent when he raises his head to look forward while creeping. The lumbar curve is formed in a similar way when he first stands on his feet. Up to this time the child's hip-joints are kept flexed to a considerable extent; even when he lies on his back he seldom extends the hips fully. When he begins to stand on his feet the iliofemoral band is put on a stretch for the first time, holding the pelvis tilted forward; to rise to erect position he has to fully extend the spine in the lumbar region, which gives the normal curve. Until he develops more strength in his legs and in the lumbar region and perfects the coördination, his position is somewhat stooped. The cervical and lumbar curves are due to the shape of the disks rather than to the shape of the vertebræ.

Movements of the spinal column take place by compression and traction of the elastic disks and by gliding of the articular surfaces upon each other. Bending the trunk forward, bringing the face toward the pubes, is called flexion; the opposite movement as far as the normal position is called extension; backward movement beyond a normal posture is overextension; bending sidewise is called lateral flexion and rotation on a vertical axis is called rotation or torsion.

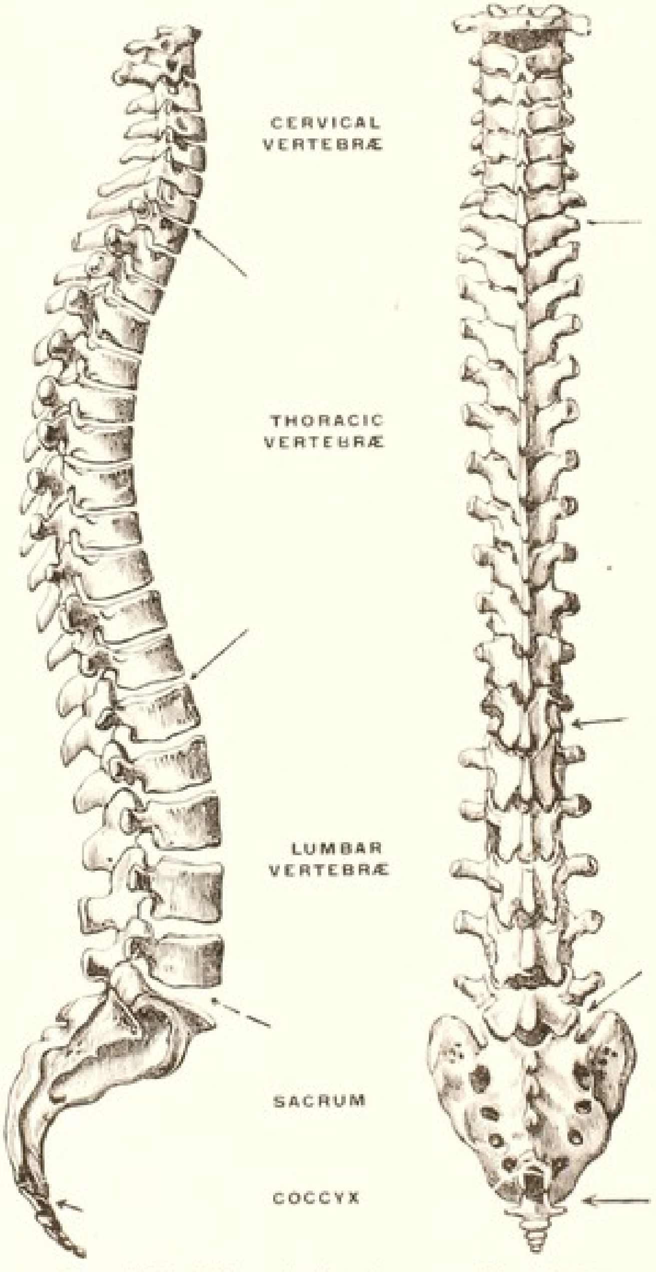


FIG. 122.—The spinal column. (Gerrish.)

Flexion takes place in all regions of the spine but is most free in the lumbar region. The lumbar and cervical curves can usually be obliterated by voluntary flexion in young subjects and the thoracic curve considerably increased. The shape of the articular processes in the lumbar region is calculated to permit flexion and extension while preventing other movements. The total amount of flexion possible in the spine is apt to be overestimated because the movements in the hip and in the joint between the head and the spine are easily mistaken through superficial observation for actual flexion of the trunk.

Extension is free in normal subjects; overextension is possible to a slight extent in the cervical and thoracic regions and to a much greater extent in the lumbar region and in the lower two thoracic segments. The fully overextended spine, as Dr. Lovett observed, is shaped like a hockey stick, with the chief bend at the lower end.

Lateral flexion is possible to a slight degree at all levels but is most free at the junction of the thoracic and lumbar regions. The ribs prevent much lateral movement in the region of the chest and the interlocking processes prevent it in the lumbar region. Considerable lateral movement is possible in the neck but is less important.

Rotation is most free in the upper parts of the spine and less free as we pass downward, being prevented in the lumbar region by the processes. The shape of the articular processes permits rotation above, the limitation in the chest region being due to the ribs. Rotation is said to be to right or left according to the way it would turn the face.

Lateral flexion and rotation of the spine are usually described separately by authors on anatomy although, as Dr. Lovett has pointed out, the two movements never occur separately. To state the same thing in other words, lateral flexion of the trunk always involves rotation at the same time, and rotation of the trunk always involves lateral flexion. This fact is illustrated by Fig. 123, which shows a normal subject sitting on a slanting seat; the seat compels her to flex the trunk sidewise to keep her balance; the cardboard pointers, glued to the skin, indicate the direction of the spinous processes and show a rotation of the vertebræ, especially marked in the lower thoracic region, where most of the lateral flexion occurs. The subject is bending forward so as to simplify the conditions, the lumbar curve acting to complicate matters unless removed by flexion forward.

The presence of rotation, such as this figure shows, accompanying all lateral flexion of the trunk, is explained by an unfamiliar law of mechanics to the effect that if a flexible rod is bent first in one plane and then, while it is in this bent position, it is bent again in a plane at right angles to the first, it always rotates on its longitudinal axis at the same time. To see why this is true think of the conditions existing in the case shown above. When the subject bends forward, giving a condition always present in the thoracic region, it puts a tension on the ligaments at the rear (subflava and interspinous) that makes them resist lateral flexion more than usual, while the weight, bearing down on the front edges of the bodies, aids in the lateral bending. The result is that the bodies of the vertebræ go farther away from the vertical than do the spinous processes during lateral flexion, and this is the rotation shown by the pointers. The general principle, which is self-evident and which helps one to remember in which direction the rotation will be, is that the concave side of the normal curve, being under pressure, turns to the convex side of the lateral curve. It follows that in the thoracic region a lateral bend rotates the spinous processes to the concave side and in the lumbar region to the convex side.

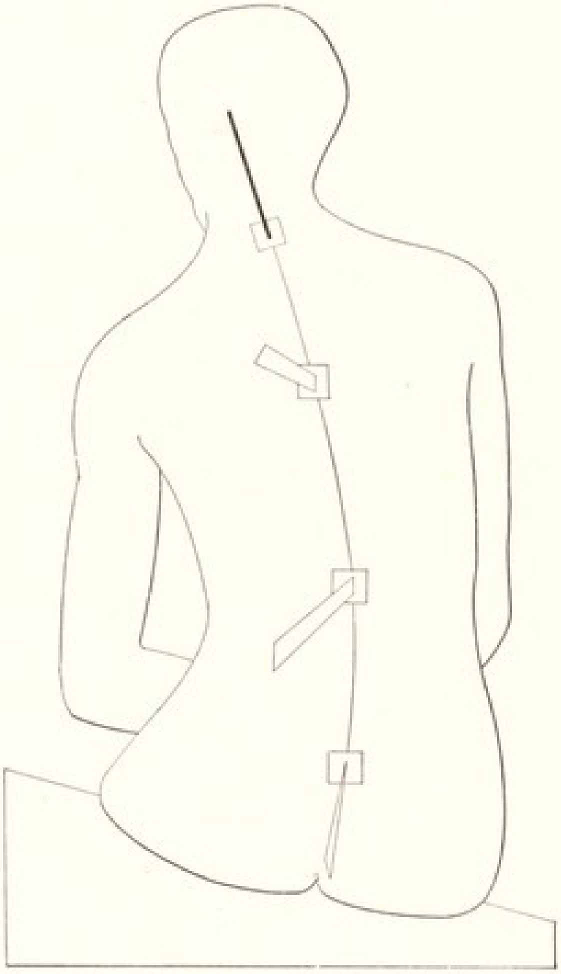


Fig. 123.—The rotation of the vertebra that accompanies lateral flexion of the trunk. The pointers attached to the back show the direction of the spinous processes. (Lovett.)

The principal muscles flexing the spine are the psoas, rectus abdominis, and external and internal oblique. These muscles, excepting the psoas, which has been previously described, are in the front and side walls of the abdomen and, along with transversalis, which lies beneath them are commonly called the abdominal muscles.

RECTUS ABDOMINIS.

A rather slender muscle extending vertically across the front of the abdominal wall. The right and left recti are separated by a tendinous strip about an inch wide called the *linea alba* (white line).

Origin.—The crest of the pubes.

Insertion.—The cartilages of the 5th, 6th, and 7th ribs.

Structure.—Parallel fibers, crossed by three tendinous bands. The lower end of the rectus passes through a slit in the transversalis and lies beneath it.

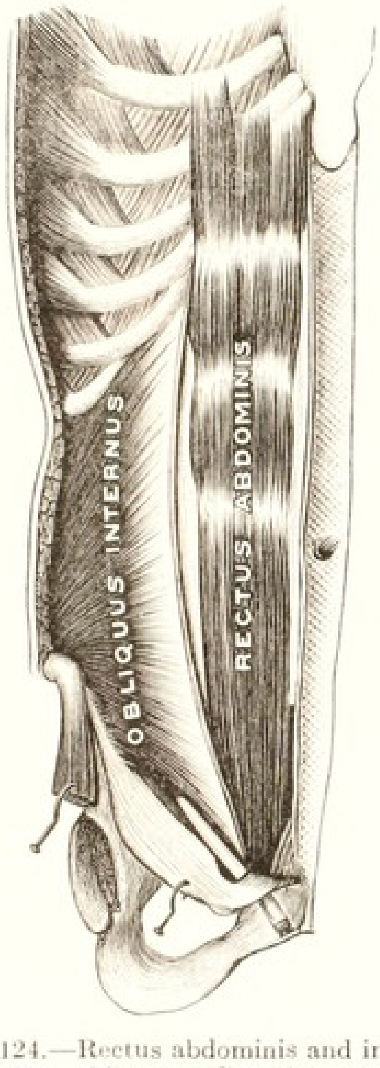


FIG. 124.—Rectus abdominis and internal oblique. (Gerrish.)

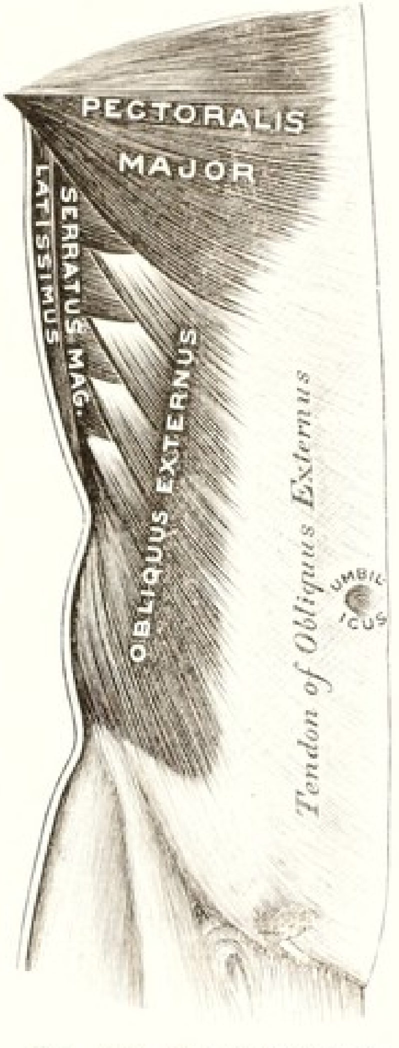


FIG. 125.—External oblique. (Gerrish.)

Action.—In standing position, with the pelvis as the fixed point, the rectus will pull downward on the front of the chest, exerting its force on two sets of joints: those of the ribs and those of the spinal column. If the ribs are free to move, they will be depressed; if they do not move or after they have moved as far as they can move it will flex the trunk. Unlike most muscles previously studied, the rectus abdominis usually follows a curved line when at rest and the first effect of its action will be to flatten the abdominal wall so as to bring it into a straight line.

Isolated action of the rectus causes flattening of the front abdominal wall followed by depression of the ribs and flexion of the spinal column.

EXTERNAL OBLIQUE.

This muscle covers the front and side of the abdomen from the rectus abdominis to the latissimus (Figs. 48 and 125).

Origin.—The front half of the crest of the ilium, the upper edge of the fascia of the thigh, the crest of the pubes and the linea alba.

Insertion.—By saw-tooth attachments to the lower eight ribs, in alternation with those of the serratus magnus and latissimus.

Structure.—A sheet of parallel fibers extending diagonally sideward and upward from the origin, the fibers of the pair forming a letter V on the front of the abdomen.

Action.—The line of pull is too nearly coincident with the line of the rib it joins to give it much power to depress the chest. If the muscle of one side acts alone it will pull the insertion forward and downward, causing a combination of flexion, lateral flexion, and rotation to the opposite side; if both muscles of the pair act at once the lateral pull is neutralized, giving pure flexion of the spinal column. The external oblique will tend to flatten the abdomen even more than the rectus because of its curved position around the side and front of it.

INTERNAL OBLIQUE.

Situated beneath the externus, with fibers running across those of the outer muscle (Fig. 124).

Origin.—The lumbar fascia, the anterior two-thirds of the crest of the ilium, and the upper edge of the fascia of the thigh.

Insertion.—The cartilages of the 8th, 9th, and 10th ribs and the linea alba.

Structure.—A sheet of slightly radiating fibers forming with the opposite muscle a letter A on the front of the abdomen.

Action.—Pulling downward and sideward on the front of the chest and abdomen, the internal oblique of one side will flatten the abdomen, rotate to the same side, and flex the trunk; working with its fellow it will cause pure flexion.

The rectus and the two oblique muscles of the abdomen act together in all movements of vigorous flexion of the trunk, as in rising to erect sitting position when lying on the back. Notice that when the movement begins slowly, the head being lifted first, the rectus acts alone, the obliques joining in when the shoulders begin to rise. In lateral flexion the abdominal muscles of one side act; in rotation, the external of the opposite side acts with the internal oblique of the same side.

Paralysis of the abdominal muscles gives rise to an excessive lumbar curve, produced by the unopposed action of the extensors.

The chief extensors of the spinal column are the splenius, the erector spinæ and its branches, and the oblique extensors, which are usually named as several distinct muscles. It will also be remembered that the latissimus acts indirectly to extend the spine. These muscles of the back are best understood by studying them in regular layers, beginning at the surface.

First layer, trapezius and latissimus (Fig. 30).

Second layer, levator and rhomboid (Fig. 35).

Third layer, serratus posticus superior and inferior and splenius (Fig. 126).

Fourth layer, erector spinæ and its upper divisions (Fig. 127).

Fifth layer, the oblique extensors (Fig. 128).

SPLENIUS.

Situated on the back of the neck and upper part of the chest.

Origin.—The lower two-thirds of the ligamentum nuchæ, and the spinous processes of the seventh cervical and the upper five thoracic vertebræ.

Insertion.—The base of the skull and the transverse processes of the upper cervical vertebræ.

Structure.—For surgical purposes the splenius includes two distinct muscles, but the division is unnecessary here. Like all the muscles acting on the vertebræ at the back it has a series of origins and insertions through its entire length, the fibers from a certain origin being inserted four to eight vertebræ above, so as to act on all the joints of the spinal column within its range.

Action.—The pull of a single strand of the splenius is mainly downward but slightly backward and toward the median line, so that when one side acts alone it will rotate the upper vertebræ. When both muscles of the pair act together the rotary effects neutralize each other, giving pure extension of the head and neck. The splenius is especially important for maintaining erect position of the head and neck. When it is weak or elongated the head and neck droop forward, causing the worst feature of round shoulders.

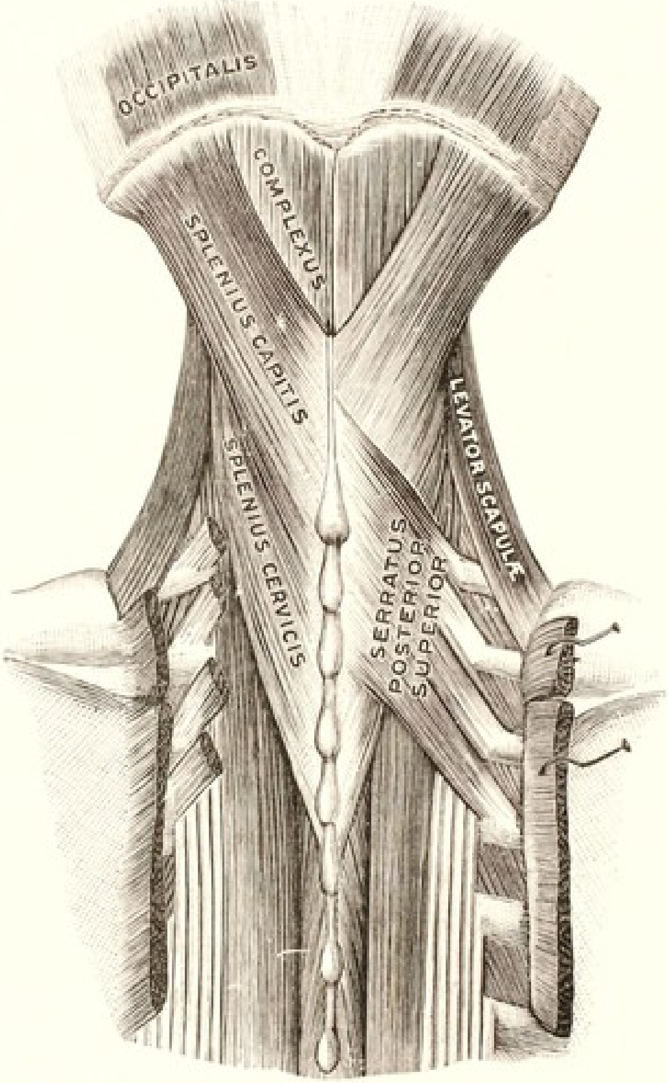


Fig. 126.—The splenius and the serratus superior. (Gerrish.)

ERECTOR SPINÆ.

A very large and thick mass of vertically directed fibers that lie on each side of the median line through the whole extent of the back (Fig. 127).

Origin.—The posterior one-fifth of the crest of the ilium, the back of the sacrum, the spinous processes of the lumbar and the last three thoracic vertebræ, and the transverse processes of all the thoracic vertebræ.

Insertion.—The transverse and spinous processes of the vertebræ, the angles of the ribs, and the base of the skull.

Structure.—Beginning as a thick muscle arising directly from the pelvis, the erector spinæ has joining it as it passes upward fibers arising from the processes of the vertebræ; as it reaches the level of the last rib it divides into three parts. The inner part passes up close to the median line of the trunk, having a continuous series of origins and insertions from the sacrum up to the level of the scapulæ, and is usually called the spinalis dorsi. The middle part, which is the largest of the three divisions and called the longissimus dorsi, passes upward along the line of the transverse processes as far as the head, the higher divisions being called the transversalis cervicis and the trachelomastoid; like the inner division, it has origins and insertions all the way up. The outer division follows the line of the angles of the ribs and is named from its attachments the iliocostalis; it is continued as the accessorius and the cervicalis ascendens as far as the middle of the neck. The muscle is more strongly developed in the lumbar and cervical regions than in the thoracic, where it tends to become more and more tendinous as age advances. The following diagram indicates the relations of the two erector spinæ and their parts.

Hip Left	Iliocostalis	Accessorius	Cervicalis	Ascendens
Erector spinæ	longissimus	transversalis	cervicis	trachelomastoid
		Spinalis dorsi		
Sacrum———	———	—Median line—	———	———Head
		Spinalis dorsi		
Erector spinæ	Longissimus	Transversalis	Cervicis	Trachelomastoid
Hip Right	iliocostalis	accessorius	cervicalis	ascendens

Action.—The contraction of a single strand of the erector spinæ will draw the processes of two vertebræ closer together, and since the axis or fulcrum for each vertebra is at the middle of its body, the leverage is fairly good; the combined action of several strands will evidently extend the spinal column. The structure of the muscle, with its continuous series of origins and insertions, makes it possible to extend one part of the trunk while permitting flexion of other parts. The pull of one erector spinæ without its fellow will produce some lateral flexion along with the extension, and the attachment of the iliocostalis and its extensions so far to the side makes the lateral pull considerable. The external division of the erector spinæ will also have power to depress the ribs.

The latissimus is tendinous for some distance from its origin, and its tendon is so thin a sheet that the erector spinæ is readily felt through it. By placing the fingers well back toward the median line a little below the level of the waist one can feel the erector spinæ contract and relax in alternate bending forward and backward, the muscle being hard when the trunk is being raised from a stooping position, but as soon as the erect position is reached it relaxes. The alternate action of its two halves can be felt while walking; notice that it is the erector on the side of the lifted foot that acts and that it relaxes when the weight is placed on that foot.

THE OBLIQUE EXTENSORS.

This group includes the muscles known surgically as the complexus, in the region of the neck, the semispinales, extending through the cervical and thoracic regions, the multifidus, the whole length of the spine, and the rotators, in the chest region. They lie beneath the erector spinæ in the hollow seen on each side of the median line (Fig. 129).

Fig. 127.—The erector spinæ. (Gerrish.)

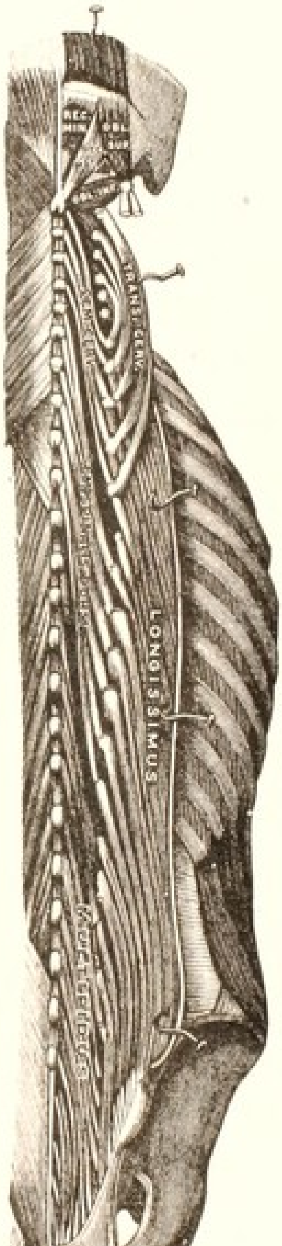


Fig. 128.—The oblique extensors. (Gerrish.)

Origin.—The transverse processes of the vertebræ.

Insertion.—The spinous processes of the vertebræ a little above the origin.

Structure.—The fibers pass obliquely upward and inward from the origin to a spinous process, usually four or five vertebræ above.

Action.—The pull is downward and to a less extent sidewise, making the main action extension with some rotary effect when the muscles of one side act alone. Like the erector, the fibers of different levels can act separately, localizing the movement in a certain region.

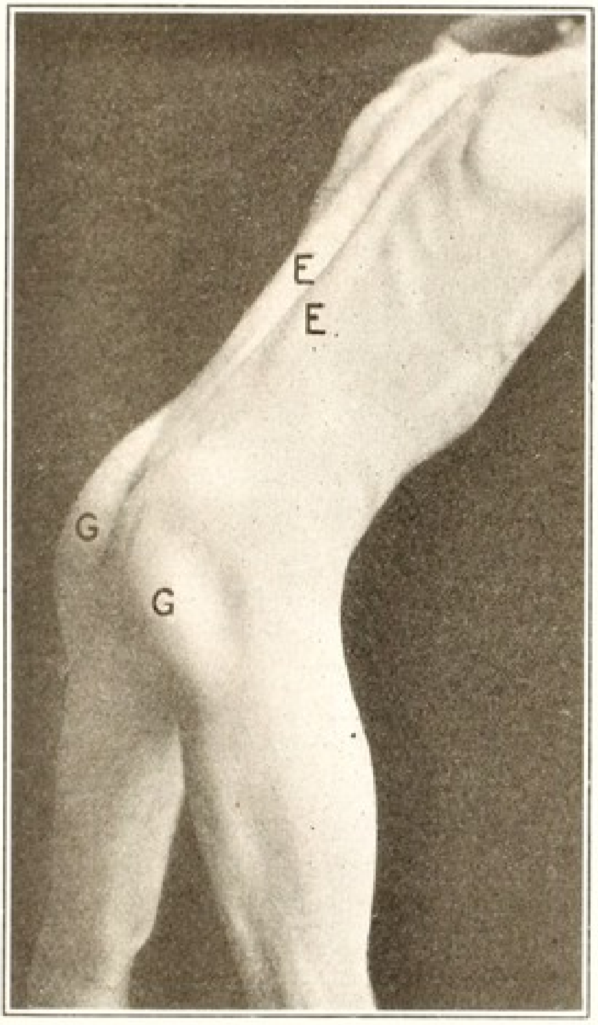


Fig. 129.—Inclining trunk forward, showing the erector spinæ and the gluteus maximus in action: *E*, erector spinæ: *G*, gluteus.

QUADRATUS LUMBORUM.

The "four-sided muscle of the loins" is a flat sheet of fibers on each side of the spinal column beneath the iliocostalis.

Origin.—The crest of the ilium, the iliosacral ligament, and the transverse processes of the lower four lumbar vertebræ.

Insertion.—The transverse processes of the upper two lumbar vertebræ and the lower border of the last rib.

Structure.—A flat sheet of fibers directed mainly in a vertical direction.

Action.—The downward pull tends to depress the twelfth rib, and when one muscle acts alone, to flex the trunk laterally. It will also tend to extend the spinal column, since the attachments are behind the axes of movement of the several vertebral joints. It is too deeply placed to admit of study on the living body.

FUNDAMENTAL MOVEMENTS.

Erect Position.—The ordinary erect position of the trunk in standing is maintained by a combined action of the flexors and extensors of the spine and the extensors of the hip. The weight is poised on the hip-joints, and as soon as the hips are slightly flexed the hamstrings and the erector spinæ can be felt in action to support the weight, which would otherwise cause a fall; if the weight is thrown back to a certain extent these muscles relax and the abdominal muscles come into action. So slight a change of balance as that produced by raising the arm forward is enough to bring the hamstrings and erector spinæ into action, and this can be felt plainly if the arm is raised quickly; a quick depression of the raised arm brings the abdominal group into action in turn. The iliofemoral band prevents overextension of the hip and makes it unnecessary for the flexors of the hip to act in such cases, but whenever the movement throws much strain on it the flexors act to help it stand the strain.

Bending Forward.—Bending forward as in Fig. 129 is accomplished by a lengthening contraction of the extensors of the hip and spine so as to allow the weight to flex those joints and yet with enough contraction to prevent the flexion from going too fast or too far; the ankles are extended passively during this movement, in order to carry the hips back and prevent the weight of the trunk from causing a fall. Rising to an erect position again requires stronger use of the same muscles to extend the hips and trunk; incidentally, this pulls the tibia to erect position.

In case it is desired to bring the trunk farther down, as in picking up an object from the floor, the knees are flexed to give the hamstring muscles more slack. To make it easier to avoid falling forward, one foot is usually placed in advance of the other so as to make the base wider in the direction of the movement.

The trunk can be inclined forward from sitting position until the chest comes in contact with the thighs. The mechanism of the movement is the same as when taken from standing, except that in

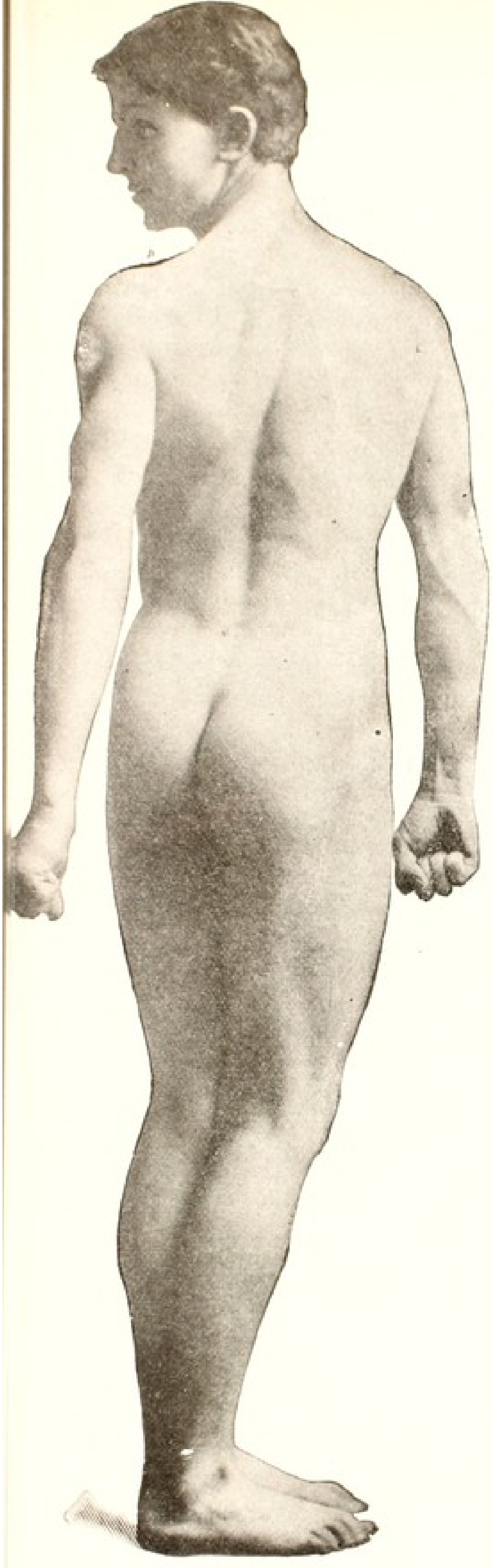


Fig. 130

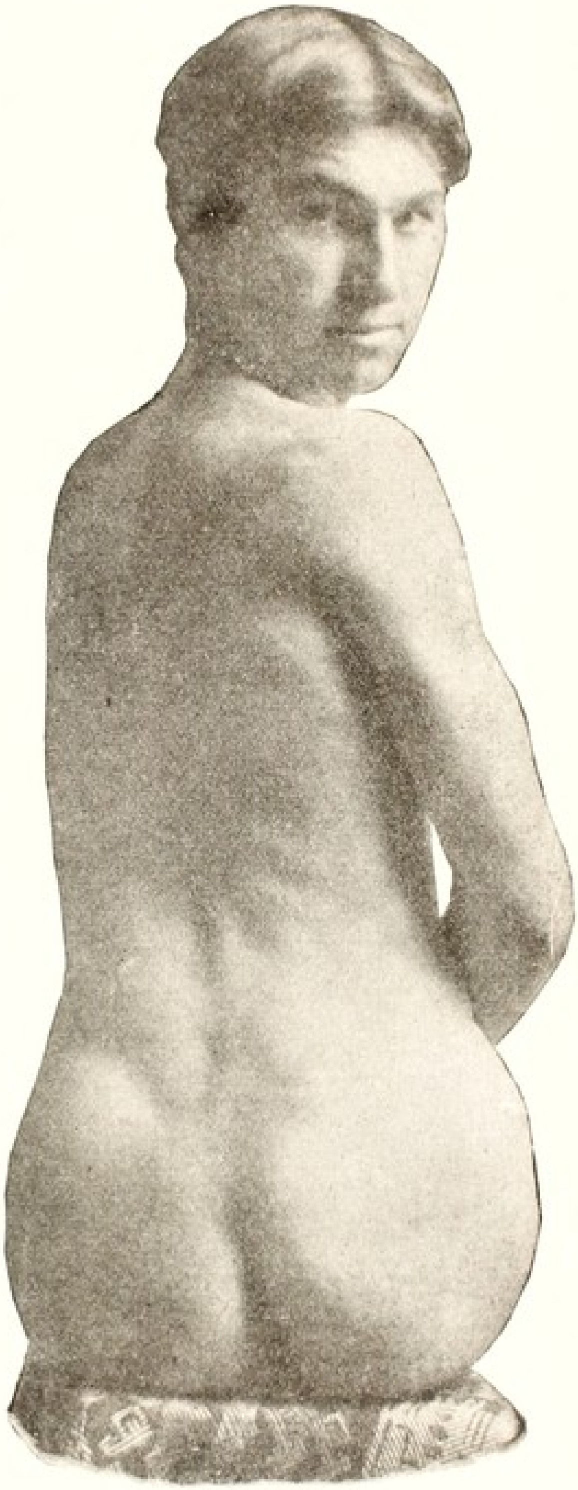


Fig 131

Fig. 130.—This figure and the next one are designed to show the capacity of the body for rotation. The feet point in one direction, the face exactly opposite. This was accomplished without previous practice. (Gerrish.)

Fig. 131.—To be compared with Fig. 130. The thighs and feet are held pointing away from the spectator, and the sitter has turned to face the camera as squarely as possible. If the effect obtained by this method be subtracted from that in Fig. 130, the amount of rotation below the movable vertebræ will be ascertained. (Gerrish.)

sitting the hamstrings, being slackened by flexion of the knees, do not check the movement so soon.

Bending Backward.—Bending backward as in looking at an object directly overhead, is accomplished by a lengthening of the abdominal muscles, allowing the lumbar portion of the spinal column to be overextended by the weight of the trunk. If the lumbar vertebræ do not permit as much movement as is desired the knees are flexed to add to the inclination; the flexors of the hip work strongly in this position to supplement the iliofemoral ligament. Standing with feet wide apart adds slightly to the tilt of the pelvis, as it slackens the ligament somewhat. The psoas muscle is in a position to help the abdominal muscles sustain the weight in the extreme inclination backward, but the abdominal muscles have better leverage.

Bending Sideward.—Bending sideward is accomplished by relaxation of the flexors and extensors and the quadratus lumborum of the opposite side, allowing the weight to bend the spine laterally. If the movement is slow these muscles relax gradually; if it is to be made quickly, to the right, for example, the flexors and extensors of the right side must contract to hasten it; if it is desired to bend farther than the weight will carry the trunk against the resistance of the opposing muscles and ligaments, the muscles of the right side must pull to complete the movement. Those of the left side must act to lift the trunk to erect position again. Sir Arthur Keith calls attention to the fact that the intercostal muscles are in a position to help in movements of this kind and in holding the trunk in perfect balance.

Twisting.—Twisting, so as to turn the face to the right, will take place mainly in the hip-joints unless movement there is prevented; if it takes place it will be mainly inward rotation of the right hip by the gluteus medius and minimus and outward rotation of the left by the group of outward rotators. Rotation of the spinal column, which may take place far enough to turn the shoulders about 45 degrees in most cases, is caused (to the right) by the right splenius and internal oblique acting with the left external oblique and the left oblique extensors. Some authors include the serratus magnus and rhomboid among the rotators of the trunk, looking upon the right internal oblique, left external oblique, and the left serratus and rhomboid as a continuous spiral band of muscle connecting the right hip with the left side of the spinous processes in the upper chest region.

Creeping.—Creeping, a form of progression on the hands and knees used by nearly all children before they learn to stand, is essentially the same as regards position of the trunk as the natural position of quadrupeds. Here the trunk is supported at its two extremities and its weight tends to make it sag in the middle, which would be an extension or an overextension of the spine. The abdominal muscles, as the flexors of the spine, have to prevent this movement and hold the trunk partly flexed. As a result the young child, like the quadrupeds, is apt to have strong abdominal muscles, while they are often weak in the adult through disuse.

GYMNASTIC MOVEMENTS.

Since exercise for the flexors of the trunk is so generally lacking in common occupations, and especially so in school and college life, graded work for this group of muscles is especially important in gymnastics. The impossibility of over-extending the hip joints makes it necessary to choose other than standing positions for these exercises. Sitting, leaning, lying and hanging positions can be used to advantage.

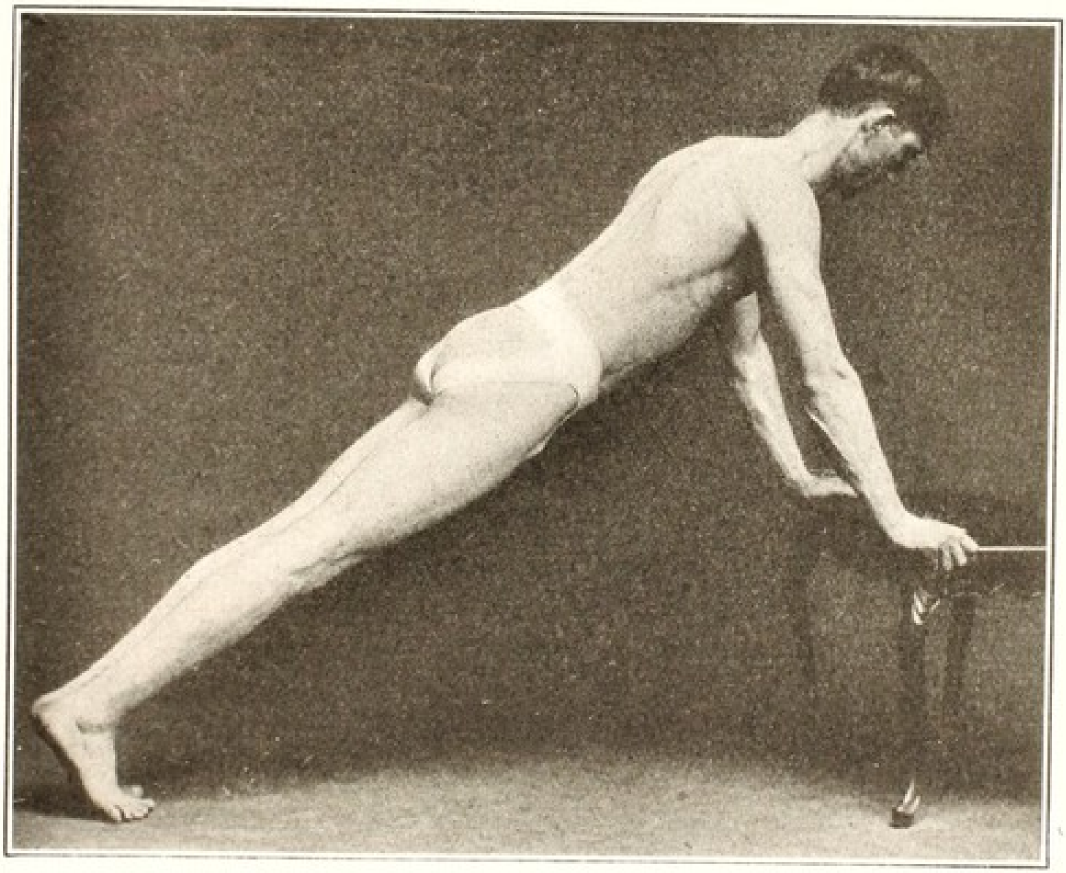


Fig. 132.—The leaning position, used for the abdominal exercise it gives.

Leaning Forward.—Leaning forward with the weight supported by the hands placed upon something at the height of the chest is a mild exercise of the quadruped type, and one that can be gradually varied toward the quadruped position by lowering the object of support. The schoolroom affords opportunity for four stages of the progression: hands on the wall, hands on the desks, hands on the seats, and hands on the floor. Flexing and extending the arms in leaning position, with the hands at either of the heights, adds to the severity of the work and affords variation to sustain the interest of the pupil. (See Fig. 148). It is usual to keep the hips extended in leaning positions, as shown in Fig. 132.

Inclining Backward.—Inclining backward from sitting position (Fig. 133) is a convenient way to exercise the abdominal muscles and the flexors of the hip, but it requires a bench and some means of holding the feet down to prevent falling backward. It differs from the backward bend while standing, in that the iliofemoral band is lax and will permit the hip to extend through 90 degrees. This exercise permits one to grade the severity of the strain on the abdominal muscles, since the force required to sustain the weight increases slowly at first and later more rapidly, the weight acting on the lever with full force only when the horizontal position has been reached. Raising the arms forward lessens the strain somewhat in the first stages of the movement by moving the center of gravity forward; holding the arms in higher positions increases the strain by moving the center of gravity up away from the axis. The average person unused to gymnastic work can usually incline backward through 30 degrees safely; the horizontal position, especially if the arms are held high, is severe enough for the most vigorous athlete. To avoid cultivation of bad postures, the erect sitting position should first be taken and then the inclination made in the hip-joints only.

Lifting the Knees.—Lifting the knees while hanging by the hands is another excellent movement for development of the flexors of the hip and spine, but it requires apparatus to support the weight and is unsuited to subjects with very weak arms. The strain on the abdominal muscles can be graded as finely as desired, since it is possible to raise one or both limbs, raise them through any angle up to 150 degrees, and the weight arm of the lever can be varied considerably by flexion or extension of the knees. The function of the abdominal muscles here is to hold up the front edge of the pelvic basin, which would otherwise be depressed by the pull of the flexors of the hip, and in case of lifting the knees above the level of the hip to raise the front edge of the pelvis through flexion of the spinal column.

Lifting one knee while standing on the opposite foot is often used as an abdominal exercise, but it brings the abdominal muscles into action too mildly to be of use, the pelvis being held in normal position by the hamstring muscles of the supporting limb; it gives instead strong work for the gluteus medius and minimus of the supporting side. If the limb is raised to horizontal with knee straight there is a mild action of the abdominal group, to about the same degree as in walking. Teachers of gymnastics and athletic trainers have greatly overestimated the effect of this exercise to develop the abdominal muscles, overlooking the action of the hamstring group to hold up the pelvis when standing on one foot. By throwing the knee up violently, especially when the supporting knee is allowed to bend and the pelvis is flexed, the abdominal muscles come into action, but the posture is bad.

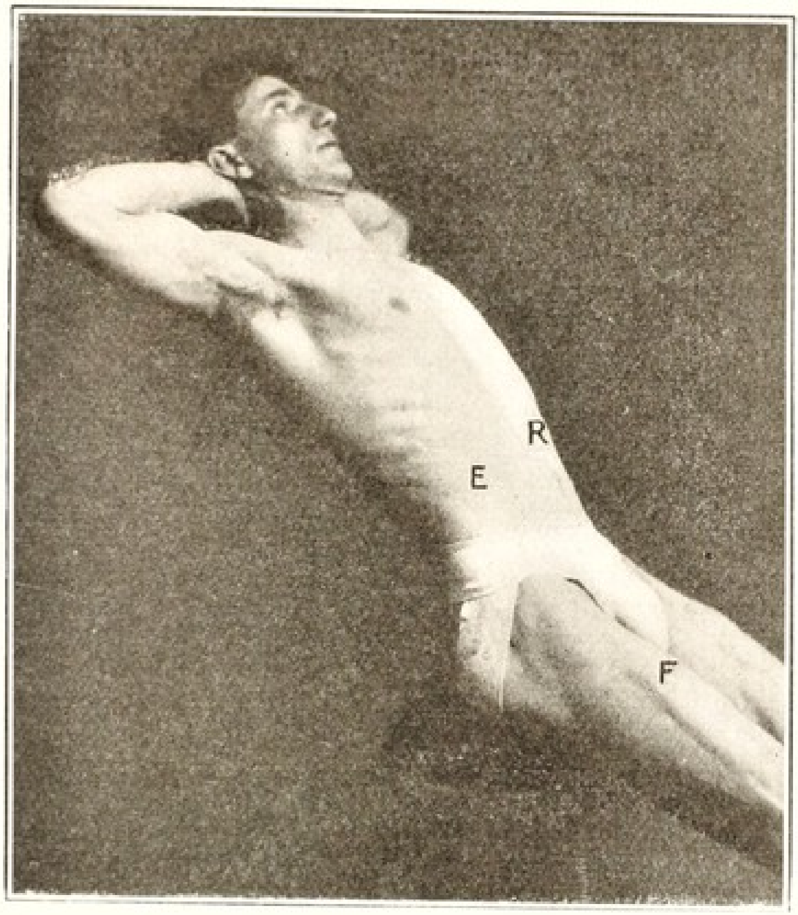


FIG. 133.—Inclining backward from erect sitting position: *R*, rectus abdominis; *E*, external oblique; *F*, flexors of hip.

Lifting the Feet.—Lifting the feet while lying on the back is accomplished by the same muscles as the preceding exercises but is less suitable for beginners and weak subjects because the movement begins at the point where the work is greatest. The weight of the limb, pulling at right angles to the weight arm when the muscles are at rest, requires the most force to lift it through the first few inches, the strain gradually diminishing as the limb is raised toward the vertical, where it becomes nothing. The amount of work can be graded by varying the length of the weight arm by flexion of the knee. When the knees are allowed to separate widely as they flex the feet can be drawn up toward the hips without using the abdominal muscles; then by lifting the flexed limbs the latter are used moderately. When the knees are kept close together as they are flexed the abdominal muscles act in both the knee flexion and the elevation of the limbs. When the flexed limbs have been lifted the movement may be made a little stronger by extending the knees and then lowering the limbs slowly to the floor.

Lifting one Limb.—Lifting one limb while lying on the back is often used as an exercise for the abdominal muscles with the thought that it is just like lifting both limbs but milder, leading up to and preparing for the stronger exercise. It is evident that raising one limb is as vigorous work for the flexors of the hip as lifting both, since the muscles of each side have to lift the limb of that side in either case. One would suppose on first thought that lifting one limb will bring the abdominal muscles into mild action as in hanging position, having to support one limb instead of two, but feeling of the front wall of the abdomen while one foot is slowly lifted from the floor shows that these muscles do not act at all in this case. The explanation is that the duty of the abdominal muscles, to hold the front edge of the pelvis up against the pull of the hip flexors, can while one limb is lifted be more easily done by the hamstring muscles of the other limb, which are very much stronger than the abdominal group and are here in a position to act, since the floor prevents the femur from moving backward. When, however, the feet are separated widely on the floor the raising of either limb requires a mild use of the abdominal muscles, the hamstring muscles of the opposite limb contracting but not in a position to hold the pelvis firmly in place.

Rising to Erect Sitting Posture.—Rising to erect sitting posture from horizontal position on the back brings the flexors of the hip and spine into strong action, but the movement is not suitable for any but the strongest subjects because, like raising the feet from the same position, it begins at the point of greatest strain and because, unlike lifting the feet, it cannot be graded in severity by a preliminary movement. It is made slightly less vigorous by raising the head first as high as possible, but to do this the rectus contracts strongly while the obliques are relaxed, pressing the abdominal organs against the lax side wall of the abdomen with danger of causing hernia in weak subjects.

Exercises on Chest Pulleys.—Exercises on chest pulleys with the back toward the machine give work for the abdominal muscles varied in force by the weights used and by the kind of movement employed. Starting with arms at front horizontal the elbows may be flexed and extended, bringing hands to shoulders and thrusting

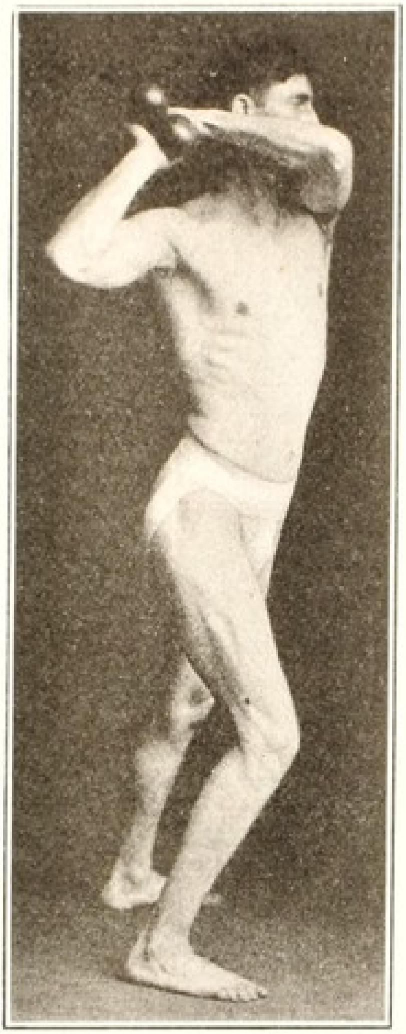


FIG. 134.—The Roberts "chopping" exercise for development of the extensors of the hip and spinal column. Starting position.

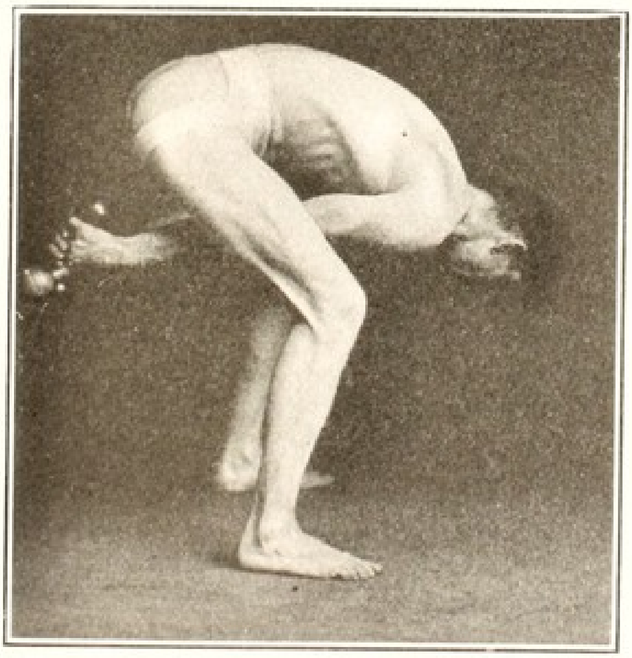


FIG. 135.—The Roberts "chopping" exercise for development of the extensors of the hip and spinal column. The finish.

them forward in rhythm; the arms may be swung downward, sideward, or upward and back to front horizontal; combinations of different ones of these with right and left arms may be used. To make the balance problem easier it is best to stand with one foot advanced.

Exercises on the chest pulleys with face to the machine, often used for development of the trapezius, rhomboid, teres major and latissimus, at the same time give strong work for the extensors of the hip and spine, to hold the trunk firmly erect as a basis for the action of the arm muscles. The same is true of the familiar "chopping" movements of the Roberts dumb-bell drill, in which the bells, first raised over one or the other shoulder, are swung far down beside or between the knees, which completely stretches the extensors, and then the body is raised to full height again, which brings them into strong contraction. Another familiar gymnastic movement with similar effect is the "leaning hang," with the body inclined backward, perfectly straight from head to heel, and kept from falling by the arms through grasping bars or rings. (See Fig. 177.)

QUESTIONS AND EXERCISES.

1. Pick out from a set of unmounted vertebræ a cervical, a thoracic and a lumbar vertebra. Point out their special differences and show from their shapes why rotation of the spine diminishes as we pass downward.

2. Study the action of the trunk in rowing, and state which muscles work in each movement.

3. Study upon yourself the action of the gluteus medius and the erector spinæ in walking, by placing the hands so as to feel their contraction. Does the gluteus medius act with the erector of the same or the opposite side?

4. What muscles of the trunk are most used by waiters in carrying a heavy tray of dishes in front of the chest? Why do they lean back? Explain advantage and disadvantage of holding it overhead.

5. Two men pull a heavy roller, both walking forward, one pulling on a handle in front of the roller with arms behind him and the other pushing against the rear of the frame. What muscles will each man rest when they change work?

6. Study the action of the trunk muscles in exercises on pulley machines, (*a*) with face to the machine, (*b*) with back to the machine, (*c*) with side to the machine. Tell what muscles of the trunk act in each position and also what muscles of the hip-joint act in these same movements.

7. What trunk muscles are usually brought into action in pushing and striking? In lifting? Is boxing better exercise for balanced development for a baggage man or for one whose work is mowing and rolling a lawn?

8. Watch twenty different persons walk, standing behind them, and make a note of how many drop the free hip at every step, how many lift it, and how many bend the trunk sidewise. Report.

9. A light stick three feet or more in length held against the back of the hips by the hands while walking makes it easy to detect any rotation of the hips, since the stick magnifies the extent of the swing. Try this on yourself and on several others, and find how many do not swing the hips. Try the effect of length of stride. Strap such a stick to the hips and another to the shoulders and see them move when the arms swing freely during the walk.

10. Study the association of arm and leg movements in the common breast stroke in swimming, and tell just how it is done. What are the main groups of muscles used in propelling the body through the water?

CHAPTER XII.

BREATHING.

BREATHING is a rhythmic expansion and contraction of the chest, causing air to flow into and out of the lungs. How and why these movements of the chest cause the flow of air is the first question that presents itself.

The chest is an air-tight box having the ribs as its sides and the diaphragm as its base, and containing within it the heart and lungs. The lungs are elastic air sacs able to contain, in the average adult, about 350 cubic inches of air. The elasticity of the lungs, due to elastic tissue and to involuntary muscle fibers in the walls of the bronchial tubes, is sufficient to expel most of the air they contain. This is well illustrated by inflating a pair of lungs removed from the body of an animal and then releasing the pressure; they quickly collapse as the air escapes through the trachea. Under normal conditions the lungs fill all the chest room not occupied by the other organs; they do not collapse like the isolated lungs, although they are freely open to the outer air through the trachea. The explanation of this is that the isolated lungs receive the pressure of the atmosphere both on their inner and outer surfaces, so that it has no effect, and the elasticity of the lungs acts unopposed, while in the normal lung the atmospheric pressure on the outer surface is prevented by the resistance of the chest wall, with the result that the atmospheric pressure within the lungs inflates them. The correctness of this explanation is shown by the fact that the lungs collapse if the chest wall is punctured.

As long as the chest is without movement the air-pressure within the lungs is the same as that outside, but as soon as the chest cavity is enlarged the pressure within is diminished and the constant pressure of the outer air forces more in through the trachea until the pressures balance again. When the chest becomes smaller the opposite flow of air occurs. The flow of air to and from the lungs is seen therefore to be controlled by one constant force—the atmospheric pressure—and two varying forces—the elasticity of the lungs, which varies with the extent of inflation, and the size of the chest cavity, which varies with muscular action.

The next question that presents itself here is how the size of the chest cavity is altered in breathing. The change takes place by two separate movements—the lateral expansion of the chest wall and the depression of its base. To explain the first we must observe the manner of movement of the chest wall.

The framework of the chest consists of the thoracic vertebræ, the twelve pairs of ribs, the costal cartilages, and the sternum. The costal cartilages join the ribs to the sternum; at the ends of the ribs are arthrodial joints, permitting a slight movement at the junction with the cartilages and somewhat more at the junction with the spinal column. The movement is mainly an elevation and depression of the ribs on their spinal joints as axes, with some rotation of each rib on the axis passing through its two extremities. In the resting position the ribs slant downward at an angle of 15 to 20 degrees from the horizontal, and, as a consequence, their elevation carries the sternum and the whole front of the chest away from the spinal column, as shown in Fig. 137. This enlarges the chest from front to rear; since the ribs slant downward and sideward where they join the spinal column, this elevation will increase the lateral diameter of the chest as well. In order to expand the chest, therefore, there must be muscular action that will lift the ribs.

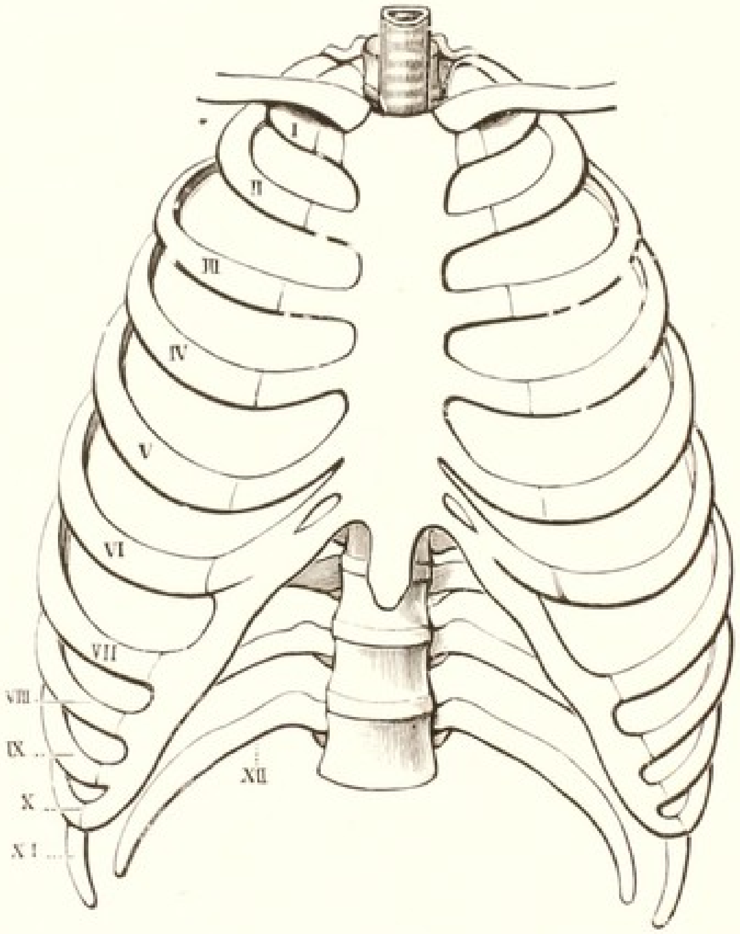


Fig. 136.—Position of the lungs in the chest. (Gerrish.)

The muscles acting to raise the ribs in quiet normal breathing are the external intercostals, the diaphragm, and probably the internal intercostals.

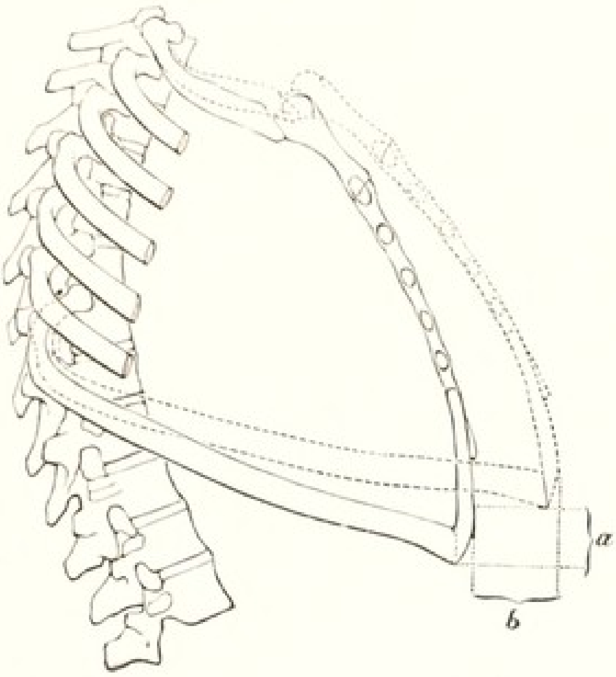


Fig. 137.—Enlargement of the chest by elevation of the ribs. (Gerrish.)

EXTERNAL INTERCOSTALS.

Eleven sheets of muscular fibers located in the spaces between the ribs (Fig. 138).

Origin.—The lower borders of the first eleven ribs.

Insertion.—The upper borders of the last eleven ribs.

Structure.—Short parallel fibers extending diagonally forward and downward, in the direction of the external oblique. It extends from the spinal column forward to the costal cartilages, being absent next to the sternum.

Action.—The pull is evidently calculated to draw the ribs closer together. Duchenne reports that stimulation of the external intercostal muscles causes a lift of the rib below, without depressing the rib above. Although the action has been in dispute it is now generally agreed that the external intercostals act to lift the ribs in inspiration.

INTERNAL INTERCOSTALS.

Eleven muscular sheets just beneath the external intercostals.

Structure.—Fibers extending downward and backward, like the internal oblique. The muscle extends from the sternum backward as far as the angles of the ribs, being absent next to the spinal column. The layer of muscular fibers is about half as thick as the external intercostal.

ACTION OF THE INTERCOSTALS.

The origin, insertion and action of the internal intercostals is still an unsettled question.

Few topics of anatomy have been so long and bitterly disputed as the action of the intercostal muscles. Disagreement is not surprising, for the question is important and difficult. These muscles are too deeply covered by other muscles to permit of study on the normal living subject, and the mechanical problems are complicated and confusing. The first one to make a practical study of the matter was Galen, physician to the Roman emperor in the second century. He discovered by experiments made on living animals that the intercostals and the diaphragm are breathing muscles, and he taught that the upper intercostals, external and internal, lift the ribs and that the lower ones depress them. His view was accepted by all scholars for more than twelve centuries. In the sixteenth century Vesalius, a Belgian, trained in the univer-

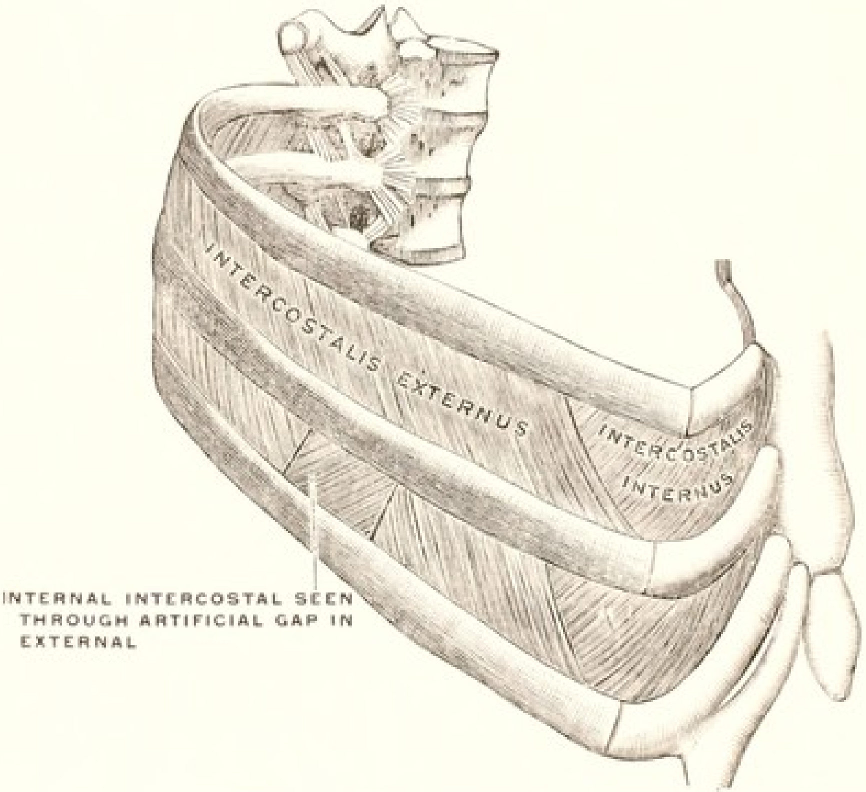


Fig. 138.—The intercostal muscles. (Gerrish.)

sities of Louvain and Paris, and chosen professor of anatomy at the three leading universities of Italy in succession, taught that the intercostals are both depressors of the ribs and muscles of expiration. Aranzi, who followed him shortly in the university of Bologna, taught that the intercostals have nothing to do with breathing, except as passive portions of the chest wall, and von Helmont, a famous scholar of Amsterdam, held the same opinion. Magendie and Cruveilhier, well-known French anatomists, said that the intercostals are at the same time elevators and depressors of the ribs, acting in both inspiration and expiration. The Bartholins, father and son, professors of anatomy in Copenhagen during the seventeenth century, taught that the two sets of intercostals are antagonists, the internals being elevators of the ribs and the externals depressors. None of these views are now held, but they are interesting as showing how wide a range of conclusions have been reached by leading scholars.

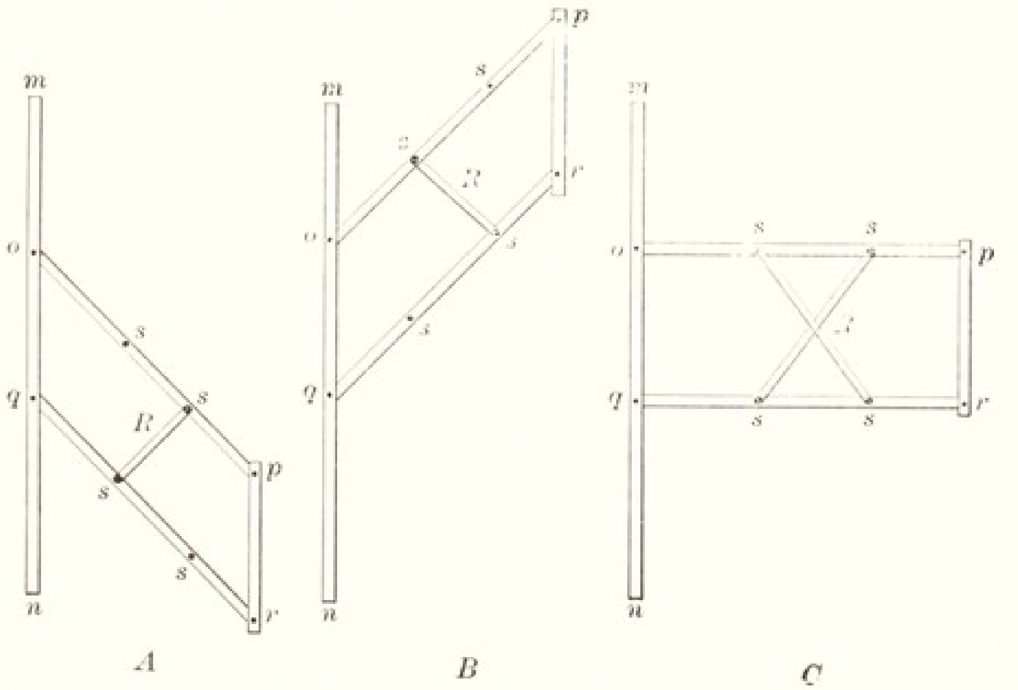


FIG. 139.—Hamberger's model to show intercostal action. The bar *mn* represents the spinal column; *op* and *qr*, ribs; *pr*, the sternum. In *A* the rubber band *R* slants like the internal intercostals and in *B* like the external intercostals; in *C* both are acting; *s*, pegs to hold rubber bands.

Two opposing theories of intercostal action still hold the field, each having many supporters. One of these, attributed to Hamberger, of the university of Jena in the first half of the eighteenth century, is the exact opposite of the view of the Bartholins, namely, that the external intercostals lift the ribs and the internals depress them. The main argument for this view is mathematical, and is best explained by means of a model used by Hamberger, later described by Huxley, and now frequently seen in class-rooms where physiology is taught. It consists of four straight pieces of wood so hinged together as to illustrate the positions of the spinal column, the sternum, and two adjacent ribs, and the movements of the latter (Fig. 139). Pegs are driven into the ribs so that one can attach to them cords or rubber bands to represent either set of intercostal fibers. When a rubber band is attached in the position of the external intercostals it lifts the two ribs and the sternum; when it is placed in the position of the internal intercostal fibers it depresses them. The action of this model is so convincing that a large number of authors accept it as a complete demonstration of the Hamberger theory. This theory has found further support in results obtained by Martin and Hartwell, well-known American writers. They found by observing the action in cats and dogs that the external intercostals act in unison with the diaphragm, while the internal intercostals act in alternation with it, from which they conclude, as Hamberger did, that the former are muscles of inspiration and the latter of expiration.

The other theory claims that both sets of intercostal muscles are elevators of the ribs, acting in unison in inspiration. It was taught in the eighteenth century by Borelli, an Italian physiologist, Haller, a German physiologist, Cuvier, a famous French naturalist, and Winslow, a French anatomist, all authorities in their respective fields. Haller claimed to have seen the opposite of what Martin and Hartwell report, namely, that the internal intercostals contract in inspiration, and as early as 1747 he argued that Hamberger's model does not prove anything because it does not accurately represent the conditions of the chest; he attached cords to the ribs of a real chest, fresh from the dissecting-room, and showed that contraction of the internal intercostals will lift the ribs. Winslow argued that since both sets of fibers between two ribs tend to draw them together, and since the upper ribs are less movable than the lower ones, both will help in lifting the ribs. He also pointed out the presence of each set of fibers at the end of the space where it must act to lift the rib below, and their absence at the end of the space where they would do the opposite. If the internals are expiratory, why are they omitted near the spinal column, where they would pull directly from the vertebræ to lower the ribs?

The second theory received still stronger support through the work of Duchenne, who began in 1850 a long series of observations and experiments upon living human subjects, patients in the hospitals of Paris. He found cases who had lost all of the muscles ever supposed to lift the ribs, excepting the intercostals, and in such subjects he saw the chest rise and fall in normal rhythm in quiet breathing; he saw and felt the external group, at the sides, and the internal group, at the front, where the externals are absent, both acting in unison with the movement of the chest wall. Again he stimulated the intercostal muscles, in patients who had lost the pectoralis major and serratus magnus, and found that isolated action of either group lifts the rib below it, without depressing the rib above. Then he stimulated the nerve which supplies fibers to both groups and saw the same elevation of the rib—which should not take place if the two sets are antagonists. He claimed that isolated action of either set causes distortion of the chest, one set pulling the ribs back and the other set pulling them forward; therefore both sets must be used in unison in normal chest expansion. Duchenne is an ardent supporter of Haller and Winslow and attacks the Hamberger theory at every point.

Present-day text-books of anatomy are about equally divided on the question of the action of the intercostals, Gray and Spalteholtz agreeing with Hamberger that the internal intercostals depress the ribs, Morris, Cunningham and Piersol agreeing with Duchenne that they act with the externals to lift the ribs, while Gerrish and Sobotta say it is undecided, and Quain states both views. Everybody seems agreed that the external intercostals lift the ribs, and the fact that the internal set is of only half the thickness in the average subject makes the difference of less importance than it might be. The arguments have been stated here in full because they are good examples of scientific reasoning, and especially fitting in a book like this, where the problems of muscular action are the main subjects of study.

THE DIAPHRAGM.

A dome-shaped sheet, partly muscular and partly tendinous, forming a partition between the thoracic and abdominal cavities. The tendon is at the summit of the dome and the muscle fibers along the sides (Fig. 140).

Origin.—An approximately circular line passing entirely around the inner surface of the body wall. It is attached at the back to the upper two lumbar vertebræ and the lumbar fascia; on the sides for a variable distance, to the lower two ribs; at the front, to the six lower costal cartilages and to the sternum.

Insertion.—The central tendon, which is an oblong sheet forming the summit of the dome.

Structure.—The fibers pass vertically upward for some distance from the origin, and then turn inward to their insertion. The fibers of the sternal portion are shortest; the lateral portion has saw-toothed attachments to the ribs and cartilages in alternation with those of the transversalis, which is a muscle of expiration.

Action.—Contraction of the fibers of the diaphragm will evidently pull down on the central tendon and up on the ribs and sternum. Observation shows that it lifts the ribs slightly but depressses its own central tendon as its principal movement. Observation also shows that it acts in unconscious breathing in unison with the intercostals or nearly so. As it descends it flattens and leaves more room in the chest, thus aiding the intercostals in enlarging the chest. Duchenne considers it the most important of the breathing muscles, since he found it to be the only muscle that can maintain without much effort a sufficient flow of air to supply the tissues when all other muscles of inspiration have been lost.

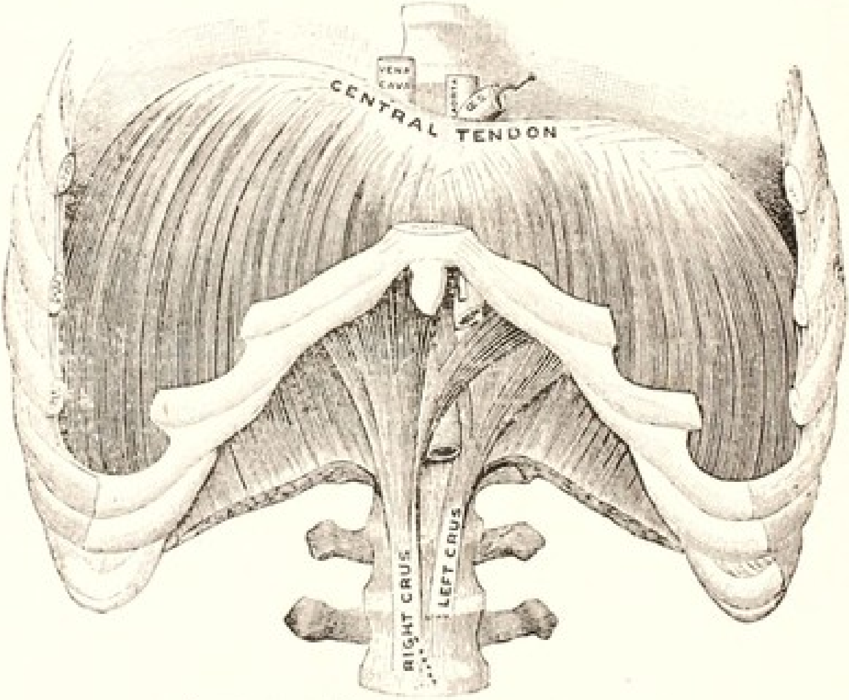


Fig. 140.—The diaphragm. (Gerrish.)

The relation of the diaphragm to the abdomen is important, as well as its relation to the chest. When it descends it must of course take from the abdomen just as much room as it gives to the chest. It pushes the stomach, liver, and other abdominal organs before it, and since these organs are soft and pliable but not easily compressible, they crowd out against the abdominal wall. The soft and flexible abdominal wall gives way, expanding on the front and somewhat at the side to make the needed room. If the abdominal wall is thick and strong it offers considerable resistance to the descent of the diaphragm, and this will increase the upward pull of the latter on the ribs. The diaphragm always has to force out the abdominal wall against the pressure of the atmosphere, which is considerable, but the breathing is more efficient when the abdominal walls are strong and well muscled.

Simultaneous contraction of the intercostals and diaphragm expands the chest in all directions and thus produces inhalation; in quiet breathing this is the only muscular action taking place with the exception of the muscles in the walls of the bronchial tubes, which are not of the same variety and not usually included in studies of the muscular system. When the muscles of inspiration relax, the air is expelled by the elasticity of the lungs, the weight of the chest, and by the elasticity of the abdominal wall, the latter forcing the diaphragm up to its resting position. In more vigorous inhalation the intercostals and the diaphragm are assisted by the sternocleidomastoid, scaleni, serratus posticus superior, pectoralis minor, and sometimes by the upper trapezius.

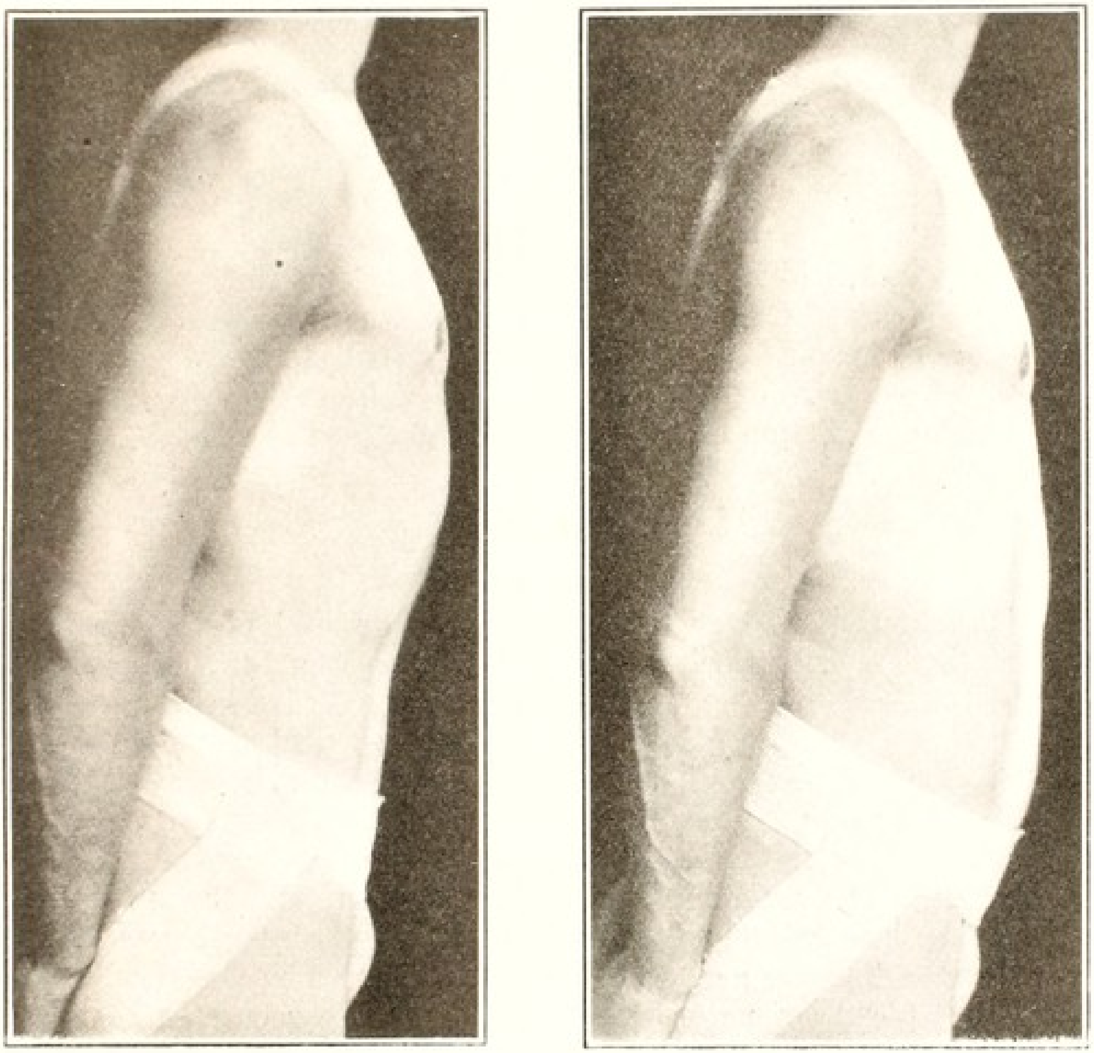


Fig. 141 Fig. 142

Figs. 141 and 142.—Expansion of the abdomen by contraction of the diaphragm. Fig. 141 shows the position of the abdominal wall in quiet expiration. Fig. 142 shows how it is protruded when the diaphragm contracts in taking a full breath.

STERNOCLEIDOMASTOID.

A pair of muscles forming a letter V down the front and sides of the neck.

Origin.—The mastoid process of the skull.

Insertion.—The front of the sternum and the inner fourth of the posterior border of the clavicle.

Structure.—Parallel fibers, dividing into two parts below its middle.

Action.—As a breathing muscle, it lifts the sternum, both muscles of the pair acting together while the head is held erect; when the lower end is the origin, the two acting together will flex the neck and either alone will rotate the face to the opposite side.

The sternocleidomastoid is an important muscle of respiration, acting in labored breathing in such exercises as running or in making a deep inhalation for any purpose. It is able to assist greatly in cases where some of the other muscles of breathing are lost.

The lower portion of this muscle is shown well in Fig. 48.

SCALENI.

Three muscles named the anterior, middle, and posterior scaleni from their relative positions and their triangular form as a group (Fig. 143).

Origin.—The transverse processes of the cervical vertebræ.

Insertion.—The anterior and middle scaleni, on the upper surface of the first rib; the posterior on the second rib.

Structure.—Longitudinal fibers, tendinous at each end.

Action.—The scaleni are in a position to support the upper ribs when the intercostals contract and to lift them by strong contraction, providing the neck is held firmly erect. The presence of the brachial plexus of nerves makes it difficult to secure satisfactory isolated action of the scaleni, but under the mild stimulus that can be given them, the elevation of the first ribs and sternum has been seen. The inability of the scaleni to sustain and lift the chest when the neck is not held up is the most serious result of mild cases of round shoulders.

SERRATUS POSTICUS SUPERIOR.

A flat rhomboidal sheet of muscular fibers lying beneath the upper half of the scapula. It is shown in Fig. 126.

Origin.—The ligament of the neck and the spinous processes of the seventh cervical and the first three thoracic vertebræ.

Insertion.—The second to the fifth ribs inclusive, beyond their angles.

Structure.—Longitudinal arrangement with the ends tendinous.

Action.—The serratus posticus superior lies so deep beneath the scapula and the trapezius and rhomboid that its action has not been observed. Its position and attachments are such that all agree that it is able to lift the ribs.

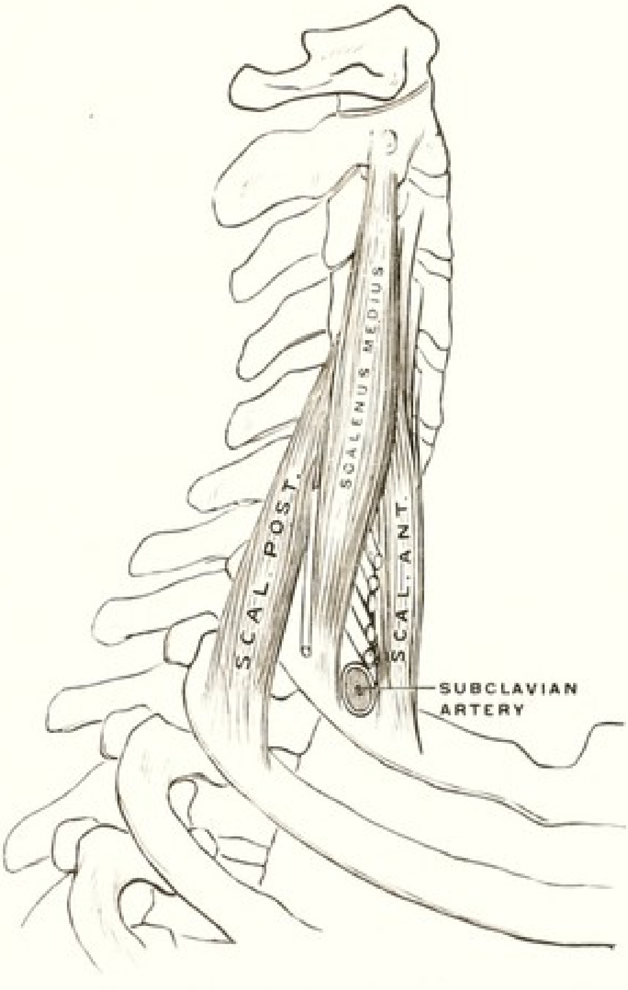


FIG. 143.—The scaleni. (Gray.)

TRANSVERSALIS.

This muscle forms the third layer of the abdominal wall next to its inner surface.

Origin.—The lower six ribs, the lumbar fascia, anterior two-thirds of the crest of the ilium, and the upper edge of the fascia of the thigh.

Insertion.—It meets its fellow of the opposite side at the linea alba.

Structure.—A thick sheet of parallel fibers crossing the abdomen horizontally. Its middle part is thickest and also has the longest fibers. Like the internal and external oblique, its muscular fibers are placed chiefly at the sides of the abdomen. The front tendons of the three fuse to form a single tendon which is slit down the center to form a sheath for the rectus abdominis.

Action.—The shortening of the transversalis presses upon the abdominal organs and acts through them to push the diaphragm upward, the four abdominal muscles working together in this movement. Its upper part also pulls the lower ribs forward toward the median line.

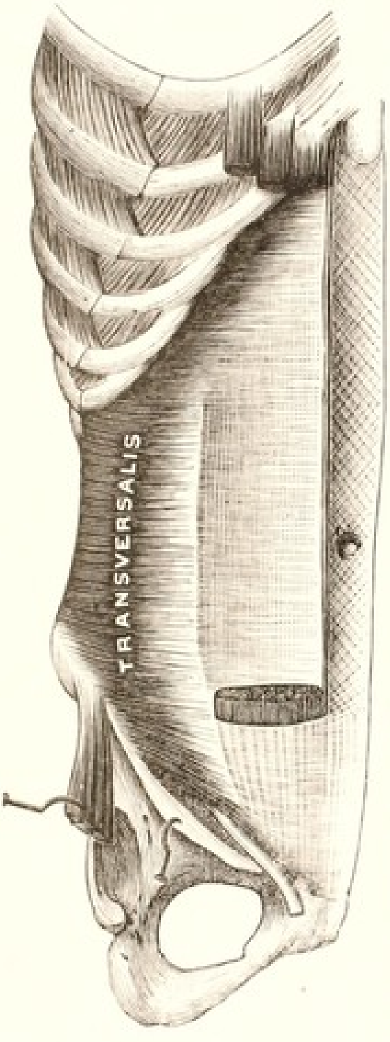


Fig. 144.—The transversalis. (Gerrish.)

SERRATUS POSTICUS INFERIOR.

Named from its position and its saw-toothed insertion (Fig. 35).

Origin.—The spines of the last two thoracic and first two lumbar vertebræ.

Insertion.—The last four or five ribs, beyond their angles.

Structure.—The inner half is a tendinous sheet blended with the tendons of the latissimus and erector spinæ. The muscular fibers are inserted directly into the ribs.

Action.—The fibers of the serratus posticus inferior are in a position to depress the ribs and the angle of pull is large. As it will act in this case in unison with the latissimus, at least in some instances, its action is not easily observed on the living subject.

BREATHING MOVEMENTS.

The act of breathing is one of the most interesting movements to study on the living subject. In quiet breathing we can easily see the expansion of the chest caused by the intercostals and the expansion of the abdomen caused by action of the diaphragm, although the muscles doing the work are hidden from view. With a deep, full inspiration the sternocleidomastoid springs into view and the scaleni can be felt behind it on the sides of the neck. The pectoralis minor can usually be felt and sometimes seen, bulging up beneath the major. The upper trapezius can be tested as described in Chapter IV. These muscles show best when the subject takes the deepest possible breath or makes sudden inspiratory effort, as in sniffing.

Besides the regular breathing muscles just mentioned, the trapezius acts in deep breathing to sustain the scapula as a firm base for the pectoralis minor, and the extensors of the head and neck act to hold these parts firmly erect to support the action of the sternocleidomastoid and scaleni. The cervicalis ascendens and the serratus posticus superior are in a position to lift on the ribs, but their action cannot be seen or felt.

The list of *inspiratory muscles* usually given by authors of textbooks includes the muscles just studied and also the serratus magnus, latissimus, and lower pectoralis major, but observation of the living body does not justify it. All three of these muscles seem to swell out in inspiration, but careful observation shows that it is passive as far as they are concerned, the expansion of the chest giving an appearance of contraction. No contraction of the serratus magnus can usually be seen or felt unless the arms are raised, and then it acts as an elevator of the arm rather than as an elevator of the ribs. Duchenne says that on stimulation of the serratus and rhomboid at the same time the scapula is first raised considerably and then the ribs are lifted, but nothing like this occurs in ordinary breathing. By placing the hand on the tendons of the latissimus and pectoralis major at the armpit any action of these muscles can be felt; I have never been able to detect any action of the pectoralis major in breathing, and only rarely any action of the latissimus. An occasional subject brings into action in strong effort all the muscles in the vicinity of the desired movement, whether they can help in the performance of it or not, but that is not normal coördination, and such subjects are not useful for studying normal muscular action.

Normal *quiet expiration* seems to be performed without any muscular action, but as soon as it becomes vigorous certain muscles are contracted to expel the breath. This is also true in coughing and sneezing, which are sudden expirations to expel something from the air tubes, in the production of the voice, as in talking, singing, and shouting, and in laughing, crying and blowing wind instruments. The muscles of expiration are the rectus abdominis, external and internal oblique, transversalis, serratus posticus inferior, latissimus, and perhaps the iliocostalis and the quadratus lumborum.

In *vigorous expiration*, such as we have in coughing, sneezing, singing, shouting, and blowing a wind instrument, the four abdominal muscles can be felt in action and also the latissimus, which is tested by feeling its tendon at the rear of the armpit. The iliocostalis and quadratus lumborum are not so surely felt to contract, although they bulge out in the movement; the sudden pressure on the abdomen produced by the action of the abdominal group makes the wall suddenly tense everywhere, and it is not easy to tell whether the muscles near the spinal column actually contract or not. Most subjects move the scapula in coughing, but there seems to be no uniform manner of moving it, some lifting it, some adducting the lower angle, and some adducting the whole scapula. The trapezius acts in some cases and the rhomboid in others; it looks more like a diffuse spread of impulses than a coördinated action. In expiration with gradually increasing force the rectus abdominis can be felt to act first, the others joining as the force increases.

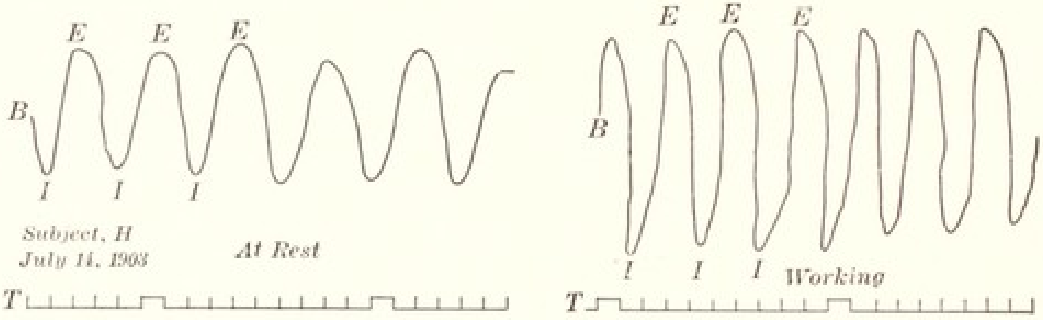


Fig. 145.—Graphic record of breathing movements: *B*, curve of breathing; *T*, time in seconds; *I*, inspiration completed; *E*, expiration completed.

In normal breathing the lungs are protected from injury that might be produced through sudden and great changes in air-pressure by the manner in which the movements are performed. As may be seen in the record shown in Fig. 145, the ribs are raised slowly at first, gradually coming to the most rapid inhalation, and then gradually slowing down, the inspiration ceasing when there is only the slightest movement being made. Although expiration in quiet breathing is said to be without muscular action, yet it is controlled, as the record shows, in the same way, and this must be done by gradual changes in the relaxation of the inspiratory muscles, which act through the entire cycle of breathing, contracting in inspiration and relaxing in the same manner in expiration. The nerve center controls the two movements and the change from one to the other much as a motorman stops and starts his car, so as to avoid sudden jolts and still secure results promptly. We see the difference when we notice how a sigh is produced, simply by suddenly and completely relaxing the muscles of inspiration when the lungs are full; the characteristic sound is made by the sudden rush of air out through the nose when the elastic forces that empty the lungs are suddenly released, in marked contrast with the almost noiseless manner of normal breathing. Yawning is similar in this way to sighing, being a full inspiration followed by a sudden relaxation of the inspiratory muscles. Here the elastic cartilages and ligaments of the chest, the ribs themselves, and the abdominal wall are drawn tense as a bowstring by the full inspiration and suddenly let go, discharging the air through the open mouth. The same tendency to fail to control expiration is seen during fatigue and in fever.

In all physical examinations the *size* and *mobility* of the chest are items of the greatest importance. The size of the chest is important because upon it depends the amount of air the lungs will contain, and the more air there is in the lungs the more of the capillary area is exposed to the air and the greater is the gaseous exchange. The size of the chest depends in part upon the length of the bones that form its framework and in part upon the habitual posture of the chest—the chest that is held high containing more air than the one that is depressed. The size of the chest is usually measured with the tape, although its depth and breadth are also taken by some examiners by means of calipers. The girth of chest of the average college man, as shown in Seaver's chart of Yale students, is the same as the height sitting; in case of college women, as shown by Miss Hill's chart of Wellesley students, it is only 86 per cent. of the height sitting; in Mrs. Clapp's measurements of Nebraska women it is slightly above 86 per cent. Actual size of the chest cavity, as measured with the tape, is subject to considerable error due to different degrees of development of the muscles on the outside of the thorax, and this is especially important in subjects who contract during deep inspiration muscles not usually employed.

Mobility of the chest, quite as much as size, is a measure of the efficiency of the lungs, indicating the extent to which the ribs can be raised and the lungs filled. With a mobile chest the muscles can more easily move the amount of air needed in quiet breathing and the subject does not so soon reach his limit in exercise that demands great increase of respiration. Many examiners still measure mobility of chest with the tape, although the method is liable to even greater errors than in determining its size. For example, it is possible to still farther expand the chest after a complete inspiration by closing the glottis and then contracting the abdominal muscles; this forces the diaphragm upward and since the air cannot escape through the trachea all the force of the abdominal muscles is exerted upon the inner surface of the chest wall to force it outward. The result is an increase in the measurement shown by the tape, although no air is inhaled and the chest is not really enlarged; the subject has by a trick enlarged the chest at the exact place where the examiner is measuring it; many a man with a poor chest has passed his examination for life insurance by deceiving the examiner in this way. The best test of lung efficiency is that made by means of the spirometer. The subject fills his lungs as completely as possible and then exhales as completely as possible into the mouth-piece of the spirometer and the amount of expired air is read directly on the scale. Since the movement of the chest is of value only as it causes movement of air, the spirometer test is the best that can be made; it also shows the effect produced by depression of the diaphragm as well as by elevation of the ribs.

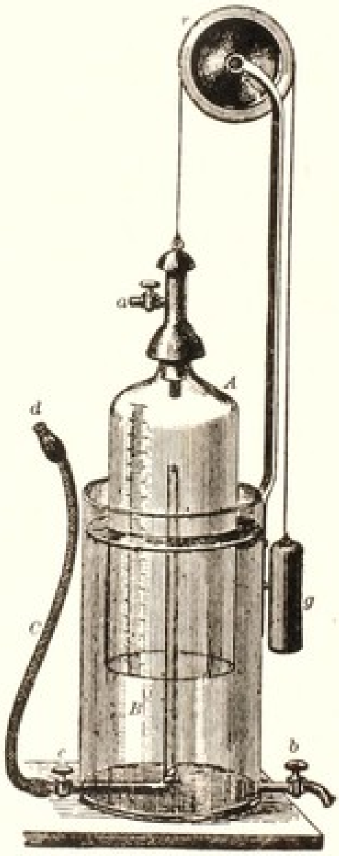


Fig. 146.—The spirometer: *A*, air tank; *B*, retainer partly filled with water; *C*, breathing tube; *d*, mouth-piece; *a*, *b*, *c*, stop-cocks; *g*, counterweight. (Reichert.)

The spirometer test is really a test of strength, since the best record can be made only by the greatest possible action of the inspiratory muscles followed by the greatest possible action of the expiratory muscles. Practice in using the spirometer will increase ability to breathe effectively by increasing the strength of the muscles and increasing the mobility of the chest. Hutchinson, who first used the spirometer for scientific purposes, pointed out that the average individual in quiet breathing moves in and out from 25 to 30 cubic inches of air (tidal air); he can inhale about

100 cubic inches more than is taken in quiet inspiration (complemental air) and can exhale about 100 cubic inches more than is exhaled in quiet expiration (reserve air); after the most complete expiration about 100 cubic inches of air (residual air) still remains in the lungs. Some objection has been raised to the use of the spirometer because of the inability of subjects to make the same record repeatedly at first; this is always a difficulty with strength tests, and disappears after a few careful trials, if the subject takes pains to make complete inspirations and expirations, without hastening during the expiration; air is often lost around the mouthpiece and through the nostrils if too much force is used. The breathing capacity of the average college man, according to Seaver, is 253 cubic inches; that of the average college woman, according to Miss Hall, is 150.3 cubic inches. These figures are about 5 per cent. too low because the spirometer is usually at a temperature 20° below that of the body and the air blown into it is cooled and thereby shrinks before the reading is made.

The chest is relatively deep and narrow in infancy and becomes broader and flatter as age advances. This change is more rapid in some cases than in others, so that in the examination of high school and college students both types are seen—the broad, flat chest and the deeper and narrower type. McKenzie has found that in college men the deep-chested type has greater breathing capacity than the broad and flat type; he also finds that the chests of ancient Greek athletes, as shown by classic statuary, are of the deeper and narrower type. On the other hand, Woods Hutchinson and others claim that the broad and flat chest is the normal adult type and that the narrow and deep chest is a case of arrested development and a menace to health.

The nervous mechanism that controls the breathing muscles works automatically, regulating the amount of movement to suit the needs of the body during sleeping and waking, rest and exercise, without any attention being directed to it. Nevertheless, these movements are subject to the will and may at any time be modified, as to rate, depth, and even as to form by the will. This makes the breathing subject to educational influence and enables one to change his habitual coördination, just as he can in throwing, walking, or talking, by persistent practice of a different style. Singers often change their habitual method of breathing, first by a conscious effort and later unconsciously, developing a form of inhalation and exhalation that some teacher considers best suited to the production of the voice. For example, singers are taught to hold the chest high habitually and to habitually take the next inspiration before the chest is fully depressed, since the expanded chest acts as a sounding box for the voice and gives a better tone. Some teachers of voice culture train their pupils to keep the abdominal muscles contracted in inspiration so as to prevent the use of the diaphragm and emphasize costal breathing; others teach them to hold the chest expanded and use the diaphragm as much as possible in taking the breath. The extent to which it is possible to gain control of the individual muscles of breathing so as to inhale and exhale in a variety of ways, is surprising. Athletes also learn to breathe in ways that will accord with the movement that is being made, as it economizes nervous and muscular force to do so.

One consequence of our ability to change the coördination of our breathing muscles by practice is the variety of habitual methods of breathing we find when we observe many individuals, as we have occasion to do in physical examinations. In quiet breathing many subjects use the chest movement exclusively while others use only the diaphragm, and in taking deeper breaths they begin in the same way, bringing in the other movements in later stages. This gives what are called the costal and the abdominal types of breathing. Investigations have shown that men tend to use the diaphragm chiefly and women the chest, and it was formerly believed that something in the structure of the female led to her using costal breathing. More study of the questions shows that it is mainly a change of habitual coördination produced by habits of dress, the constricted waist producing costal breathing by preventing movement of the abdominal wall. The two types are not universally found in the two sexes, however, some women who have not worn corsets breathing like men and some men who have worn belts breathing like women. Children generally breathe by a combined costal and abdominal movement, as do many adults. For purposes of health it is usually considered of no consequence how one takes the breath so long as he gets air enough; still there are some who favor particular types of breathing on the ground that certain parts of the lung are especially liable to disease and for that reason those parts need to be aërated frequently.

In taking the deepest possible breath, as in making a test with a spirometer, the costal and abdominal types of breathing are noticeable. Some subjects expand the chest and the abdomen through the entire movement, while others begin to constrict the abdomen as soon as they reach the point where considerable effort is used. This has always seemed to me to be a faulty coördination, the contraction of the abdominal muscles preventing the taking of a full breath. Some writers believe that a certain amount of contraction of the abdominal muscles is needed to enable the diaphragm to lift the lower ribs, making this form of breathing as efficient as the former. Campbell says that the lungs are filled before the chest is completely lifted, and that the stronger chest muscles overcome the diaphragm and suck it upward and the abdominal wall inward; this view does not seem to me justified, since if the lungs were so small we would not so easily get the rapid increase of breathing capacity that readily follows practice in deep breathing.

Two kinds of exercises for the development of the lungs are recognized in physical education: voluntary deep breathing and the securing of increased respiration by running and similar exercises. Each method has its advocates and its advantages.

Voluntary deep breathing can be taken by those who cannot endure vigorous exercise and under conditions that make the latter impossible; this makes it a practical method to use at all ages and as a regular routine when varying conditions break up habits of general exercise. The practice aërates the rarely used portions of the lungs, gives work to the muscles, and increases the mobility of the chest. The Swedish system wisely directs that voluntary breathing exercises be given at the end of the exercise period, when the need of air has been increased by the exercise. The Swedes arranged an elaborate series of arm movements to accompany breathing exercises and make them more efficient, but recent studies have shown that all such movements hinder rather than help the most complete filling of the lungs, so that they are useful only to give variety and make pupils think they are doing something different.

QUESTIONS AND EXERCISES.

1. What is the advantage gained by raising the head and shoulders to full height when one wishes to take a full breath? Test with a spirometer whether you can actually take in more air when you do this, and if so, how much more.

2. Explain how increased mobility of the ribs can make one able to run better. Will it be more useful in sprinting or long distance running?

3. Explain how tight clothing may result in strengthening the breathing muscles. Will it have most effect on inspiratory or expiratory muscles? What objection to this method of developing these muscles?

4. Explain how the lower serratus can help in taking a full breath; the splenius; the upper trapezius; the middle trapezius.

5. Study upon yourself the action of the abdominal muscles and find what part of the muscular wall is contracted in the ordinary use of the voice in speaking; in loud talking; in whistling; in singing; in blowing, as in inflating a ball. Is the muscular contraction distributed evenly over the abdominal wall or is it localized? Is it the same or different in the different exercises?

6. Test the effect of compressing the waist with a strap on your ability to take a full breath, as shown by the spirometer. How many inches can it be compressed before an effect is produced on the record you can make? Has this any relation to the advisability of wearing belts or tight clothing about the waist?

7. What measurements must be made with the tape line to test a person's breathing ability as a spirometer tests it? Why cannot the test with the tape be as good as the spirometer test?

8. A pneumatometer is an instrument to test the force of exhalation. Why is this test less valuable in a physical examination than the spirometer test? Why is it more liable to injure the lungs?

9. How can you explain the fact that long distance runners are often unable to make a high record on the spirometer? Would it help them to practice deep breathing exercises? What good would it do them?

10. The Kellogg dynamometer (Fig. 7) tests the strength of separate muscle groups. By placing a strap around the waist and attaching it to the dynamometer one can exert a force of 150 pounds, the abdominal wall pressing out on the strap to give the force. What muscles are used here? Is there any chance of injury in suing this test? How and upon what tissues?

PART V.

GENERAL KINESIOLOGY.

CHAPTER XIII.

TEAM WORK AMONG MUSCLES.

In a former chapter we have seen how the nervous system controls muscles, bringing them into action in groups, stimulating some and inhibiting others, so as to accomplish useful work. We are now in a position to inquire further into the association of the muscles, to see more fully what they gain by such association and how it is accomplished.

It is well to notice first of all that the muscle fiber is the unit of action rather than the muscle, for, as we have seen, many of the muscles are masses of fibers grouped together and named without regard to their action. The trapezius, for example, consists of at least four separate muscles as far as action is concerned, the deltoid of three, the pectoralis major of two, while the rhomboid major and minor and the infraspinatus and teres minor are examples of muscles usually named and described separately but having no separate action. Duchenne has shown by electrical stimulation that the deltoid consists of a great number of muscular units with different actions. Beevor has shown that the upper part of the pectoralis major is an associate of the anterior deltoid and the lower part an associate of the latissimus. We have seen how the upper part of the serratus magnus can be brought into action by the will in any position of the arm, while the lower part never works unless the humerus is raised to at least an angle of 45 degrees with the body. Some muscles, on the other hand, like the brachioradialis and the levator, have no use in parts and always act as a single unit.

W. C. Mackenzie denies all this in a recent book (reference on page 341) and insists that all the parts of a muscle must act together. Such a view is a direct denial of the results obtained by Duchenne, Beevor and other writers.

Students of the complex problems of coördination are agreed that the objects accomplished by the association of muscles in a kind of "team work" are strength, speed, and skill, with some influence also on endurance. Grace and ease of movement are often mentioned as objects to be sought through exercise, but when we think of it we see that if the muscles work together economically and accurately so as to secure the highest degree of strength, speed, and skill that an occasion demands, grace and ease of movement will result naturally. Grace and ease of movement are therefore rather indications of a high degree of coördination in the direction of strength, speed and skill than separate qualities to be sought by other methods.

The simplest form of muscular association to secure strength or power of movement is the same as that seen in a team of horses hitched to a wagon or two locomotives coupled to a train of cars. Any two muscle fibers lying side by side, pulling at the same time in the same direction on the same bony lever join forces in this way. It is well illustrated by the action of the three parts of the triceps in extending the elbow. If the long head pulls with a force of 50 pounds, the outer head with a force of 100 pounds, and the inner head with a force of 200 pounds, their combined pull on the olecranon is found by simply adding the separate forces. If we want to find how much force they exert at the hand we have to make one simple computation based on the length of the lever arms, using the sine of the angle of pull when this is other than at a right angle.

It is not possible to have all the muscles that need to be used together so placed that they will join forces in the simple way we have just considered. In most cases the muscles associated to move a lever are attached to it at different points and pull at different angles. We see a good example of this in the four flexors of the elbow, or in the action of the deltoid and the supraspinatus in elevating the arm. Each one does its part in its place and in its own way and the strength of the movement is aided by each, perhaps more effectively than it would if all had to work in exactly the same manner. When we wish to find out the total strength exerted by the combined pull of the four elbow flexors we must work out the effective pull of each separately, taking into account leverage and angle of pull, and then add the results. The following table illustrates fully the plan to be pursued in such computations. F is the force of contraction, which must be estimated roughly for each muscle, considering its size, structure, and condition of training; l is the power arm of the lever and L the weight arm, measured on a skeleton, and s is the sine of this angle, found in the table on p. 39; E is the effective pull or lift at the hand, 12 inches from the elbow, computed according to the formula given on page 36.

Muscles.	F		L	A	s	E
Biceps	400	1.5	12	85	0 99619	49.8
Brachialis	200	1	12	80	0.98481	16.4
Brach. rad.	150	9	12	20	0.24202	38.4
Pron. teres	75	5	12	10	0.17365	5.4
Total effective pull at hand						110.0

If one is trying to find practically and accurately the strength of any group of muscles it can be done directly with a suitable dynamometer. The object of a computation like the above is rather to get acquainted with the manner of association of the muscles composing a group. It is evident from the table that if we judge of the effect of a muscle by its size alone, as one is apt to do, we are likely to be wide of the mark, for the effective pull depends not only on the direct power of the muscle but equally upon its leverage and angle of pull. The brachioradialis, for example, while relatively small, has the advantage of an exceptionally long power arm, and its origin up the condyloid ridge gives it a considerable angle of pull, with the result that it is very effective as regards power of movement.

A third kind of association among muscles for the purpose of securing strength of movement is the use of one muscle to prevent one of the two movements another muscle can produce, in order that its force shall all be utilized in the desired direction. A good example of this kind is the action of the trapezius and lower serratus in taking a deep breath. The pectoralis minor is the muscle whose pull is needed in deep breathing, but its action will rotate the scapula downward rather than lift the ribs unless that bone is held firm by other muscles. The serratus and trapezius hold it immovable or even rotate it upward, thus giving the pectoralis minor the best possible chance to aid in the breathing. Another example of this kind is the action of the upper serratus and pectoralis minor when the triceps is contracted to strike a blow with the fist. When the fist strikes, the action of the triceps will push the scapula back and the blow will have little force unless support is given; the two abductors of the scapula hold that bone firmly forward and then the whole force of the triceps is utilized for the blow. Still another example is the action of the triceps in all efforts at strong supination of the forearm; its use is to prevent the elbow from being flexed by the contraction of the biceps, so that the full force of the latter muscle can be utilized by supination.

This kind of association among muscles is exceedingly common, in fact, every contraction that is made with any considerable vigor needs to be supported in this way by the action of other muscles, because every muscle pulls as strongly upon its origin as it does upon its insertion, and the bone that serves as origin must be held firmly in place if the force is to be utilized to do what is intended. This has led to a classification of acting muscles into moving muscles and supporting muscles, the former producing the movement and the latter affording the former a solid point of origin. The fulcrum on which the lever turns must also be made firm if the movement is to be effective, and the need in both cases increases with the force of contraction of the moving muscles. A good example to show this mode of action is seen in opening a table drawer. One hooks his fingers into the handle of the drawer and if it opens easily enough the contraction of the flexors of the fingers is sufficient. If it works a little harder the flexors of the elbow contract to hold the bones of the forearm up so that the flexors of the fingers may have a firm origin. If still more force is needed the latissimus and teres major spring into action to support the humerus and the rhomboid to hold the scapula. To make a strong pull one pushes against the table with the other arm and brings the extensors of the trunk into action, and finally, if this does not suffice, the legs are braced and the whole body is converted by muscular action into a single solid piece in order that the flexors of the fingers may exert all their power to open the drawer. Another interesting example of this kind is seen in the suppression of the breathing in all movements made with greatest force. In many movements of the upper and lower limbs so much force is required that the trunk must be made a single solid piece in order to permit the moving muscles to act upon it with all their power. To accomplish this we take a deep breath, close the glottis, thus imprisoning the air in the chest; then when the abdominal muscles are contracted the solidity of the trunk is increased. This habit of using the air impris-

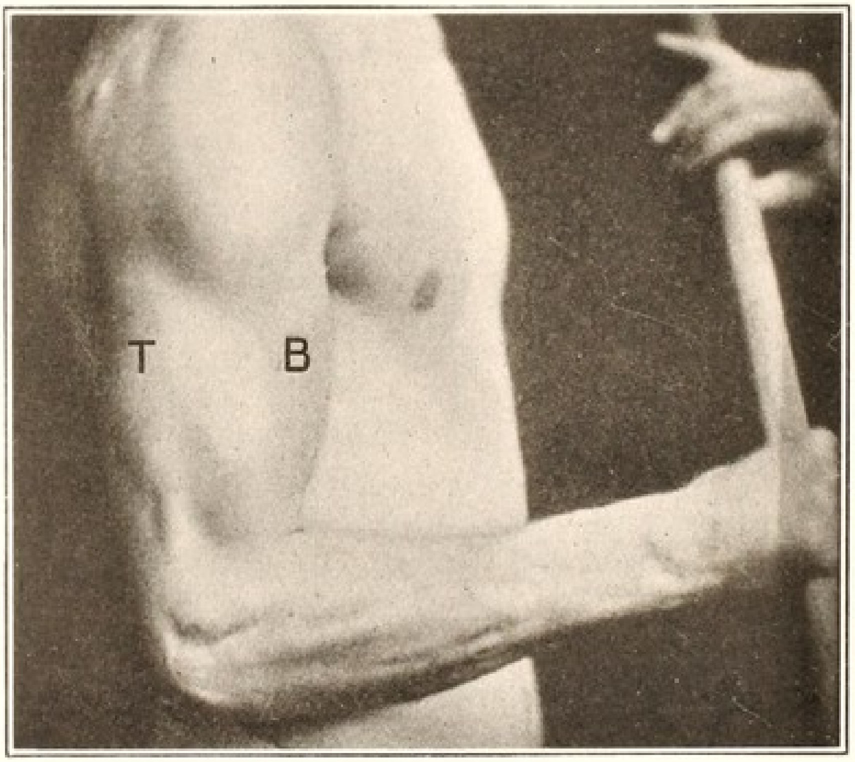


Fig. 147.—Combined action of the biceps and triceps in supination.

oned in the lungs as a means of making the chest more rigid for the arm muscles to work upon is a natural one and the coördination is inherited. It may be a source of danger to persons with weak lungs, making it advisable for them to avoid severe effort.

The action of the so-called "supporting muscles" differs from that of the moving muscles in being largely static; they perform no external work although they consume tissue and give off waste products just as moving muscles do. Although they help to fatigue the system and are necessary to the work, the force of these contractions cannot be added to that of the moving muscles to find the total force of pull. The whole body working in this way can pull upon the table drawer no more strongly than the flexors of the fingers can do; they simply enable the flexors of the fingers to do their utmost. Grace and ease of movement depend much on the accurate coördination of the supporting muscles; unskilled performers are apt to hold the body more rigid than is necessary, making the movement appear stiff and awkward. Only a great amount of practice can give this needed coördination and made the movement easy and graceful. For this reason those who stand, walk, and dance much are apt to be considered graceful persons, although in movements which they do not perform in public, such as swimming, throwing, or running, they may be very awkward.

There are many movements in which the arm, lower limb, or even the whole body may take part as a system of levers instead of a series of separate levers, and such conditions enable distant muscles to help and to transfer their force to levers upon which they usually have no effect. The act of pushing against a wall with the arms half-flexed will serve as an example. To make it more definite, assume the position with the elbows pointing horizontally sideward. Here the upper arm and forearm, instead of acting as separate levers, as they often do, are changed by the fixed position of the hand into a lever system acting in unison. Any force that extends the elbow also moves the humerus forward, and any force that moves the humerus forward necessarily acts upon the elbow to extend it. When, therefore, the pectoralis major contracts in this exercise it acts for the time as an extensor of the elbow, and when the triceps extends the elbow it also acts to swing the humerus forward and extend the wrist. In the pull in rowing we have another example of the same kind. The elbow of the rower cannot be flexed without depressing the humerus and the humerus cannot be depressed without flexing the elbow; the latissimus and the teres major could produce flexion of the elbow in this position even if the flexors of that joint were paralyzed; normally they assist the flexors in this movement while the flexors assist them. The lower limb works in this way in climbing, jumping, bicycling, and in many other cases, and the arm in pushing, pulling, climbing, rowing, and in all similar movements. The only condition needed to convert the arm into such a system of levers and joints is to have the hand on a fixed object. See Fig. 148.

Speed can be secured through association of muscles in two ways. When the resistance to be overcome in the movement is so great in relation to the size and strength of the muscle that it will diminish the rapidity of the muscle's contraction, then any of the kinds of association for securing greater strength of contraction will add to the speed. In putting the shot, for example, the object to be gained is to make the shot move with enough speed while in the hand so that its momentum will carry it a long distance. The main difficulty in securing the desired speed of movement is the great weight of the shot, whose inertia cannot be overcome quickly enough. Here it is evident that all that is needed to get more speed is to add to the strength of the movement, both by bringing into action all the moving muscles that can be made to work to advantage and by supporting the origins of these muscles effectively.

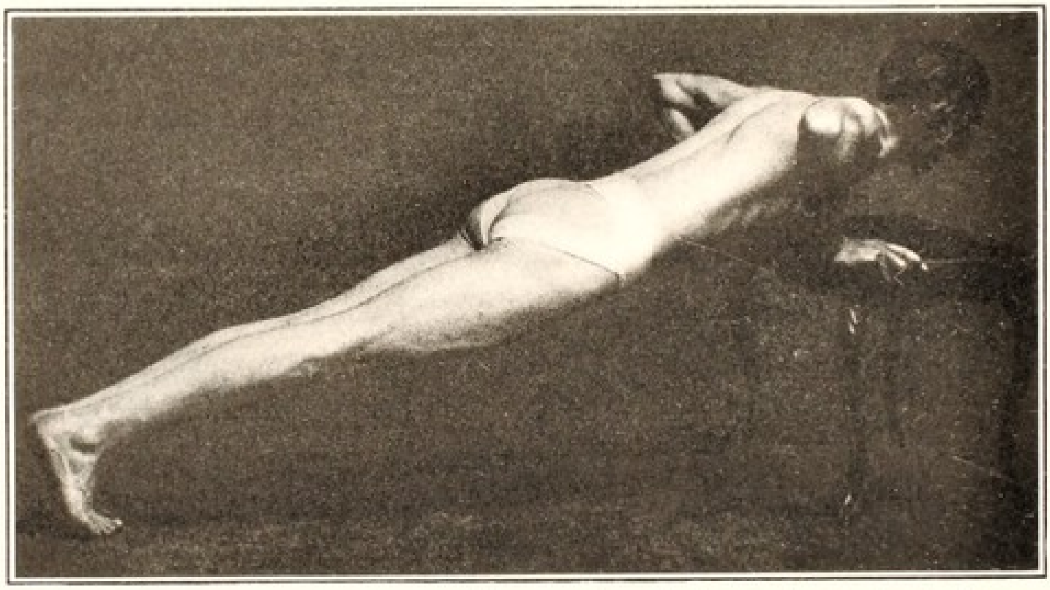


Fig. 148.—The arm as a system of levers. Arm flexion and extension in the leaning position.

In such movements as throwing a ball, on the other hand, it is not the weight of the ball that limits us, but rather the inability of the moving muscles to contract rapidly enough. We need to add in some way to the speed with which even an unloaded muscle will contract. This is done by an association of levers and muscles such as we see in driving nails with a hammer. The extension of the elbow by the triceps swings the hammer through a certain distance in a certain time; depression of the arm by the latissimus and teres major can swing it through the same distance in about the same time; by using both at once the hammer can be swung through twice the distance in the time, nearly doubling the speed and momentum of the hammer. The body acts to add to the speed of the arm in throwing in a similar way. While the arm is being carried far back in preparation for the throw the body also inclines far backward, and as the arm swings forward the body swings forward too, so that the hand carrying the ball travels six or seven feet in the time it could move through four feet if the arm had to act alone. The same increase of speed is gained by the united action of the deltoid and the lower serratus in raising the arm, and that of the triceps, upper serratus, and pectoralis major in striking a blow with the fist.

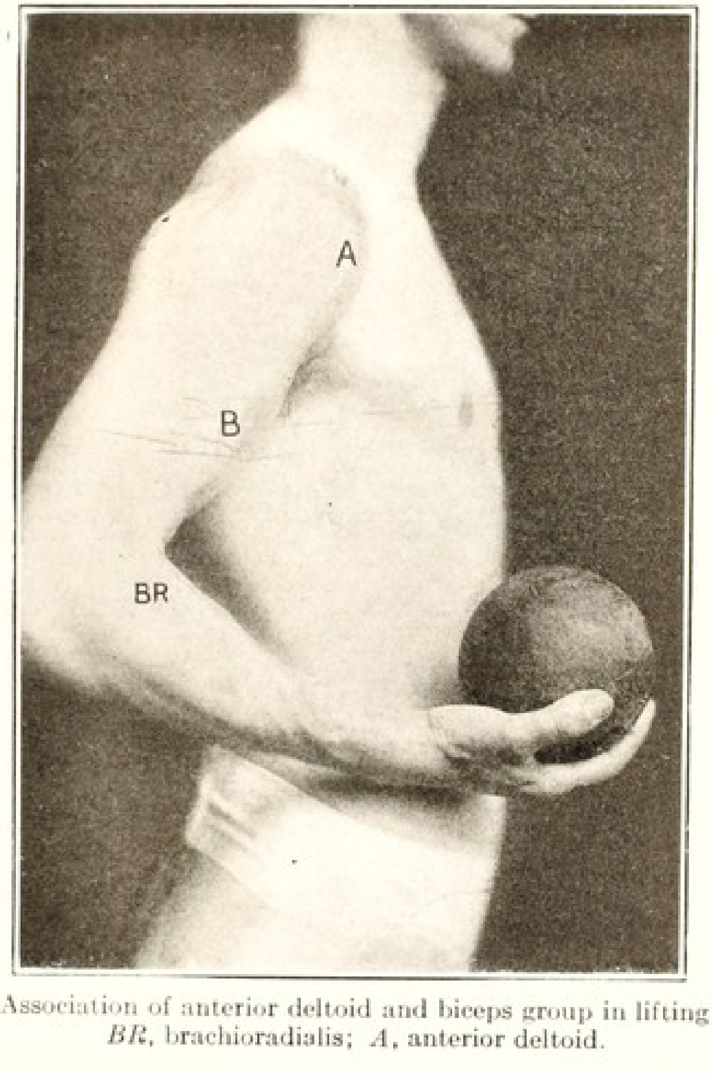


FIG. 149.—Association of anterior deltoid and biceps group in lifting; *B*, biceps; *BR*, brachioradialis; *A*, anterior deltoid.

There is an interesting relation between the action of supporting muscles, discussed above, and the case we are considering now. The upper serratus supports the scapula in striking a blow with the fist so that the action of the triceps may not lose force by a loose origin; the serratus, assisted by the rotators of the trunk, can push the scapula forward and thus increase the range and speed of the blow. The anterior deltoid can hold the humerus from swinging backward while the biceps group flexes the elbow in lifting, but if the deltoid shortens while the elbow flexes the speed of the lift is doubled. See Fig. 149.

Unlike strength and speed, skill depends entirely on muscular control. Skill implies accuracy of movement, which is the suiting of the movement to a purpose, and also economy of force, which involves the use of the right muscles at the right time with the right amount of energy. When we say that an exercise was skilfully done we mean that it did what it was intended to do with the least possible muscular expenditure. From the aesthetic standpoint such an exercise is graceful.

The first essential in performing a movement skilfully is to use the right muscles, those that can do the work required most effectively and easily. The selection of the muscles for many of the most common movements is an inherited instinct, all persons invariably using the same muscles for coughing, sneezing, walking, running, jumping and all the so-called "natural movements." In the case of racially new movements the coördination is developed by practice, and in old movements it may be changed by practice of a variation.

The next essential in skill is the use of these muscles with the right amount of force. Everything depends upon the utmost accuracy in this control of relative forces. When one undertakes, for example, to drink a glass of water, too strong use of the deltoid will toss the water above the head, too strong use of the pronators will empty it on the floor, too strong use of the elbow flexors will strike the glass against the face, etc. By varying the strength of the stimulus that the nervous system sends to each muscle it may be made to act with any desired force, from its maximum strength to zero. Every one is familiar with this fact by practical experience. We habitually grip a door-knob with a force of several pounds but we just as readily handle eggs with a much milder hold. The way in which the nervous system controls the force of muscular action is now explained according to the "All or none" principle, which means that each muscle fiber contracts with all its force or not at all.

Heart muscle has been known for many years to act in this way and now physiologists believe that the principle is also true of voluntary muscle fibers and of neurones. Our ability to vary the strength of muscular contractions at will is explained by the fact that some fibers are able to respond to a slight stimulus while others require a stronger one. We explain the increase of contraction that results from an increased stimulus by saying that with a slight stimulus only a few of the fibers of the muscle respond, these few contracting with all their force while the others are idle; with each increase in stimulus more muscle fibers are brought into action, giving the increased force. For example, we might suppose that in flexion of the elbow all the four flexors act all the time, no matter how strong the movement or how mild, but this is not the case. The biceps, as stated by Beevor, begins to act when there is a resistance of 4 ounces if the arm is in supination, but in a position of complete pronation it does not act until the resistance is at least 4 pounds. In many cases it is not difficult to observe that the moving muscles and still more emphatically the supporting muscles come into action one after another as the force of the movement is increased.

The correct timing of the action of the various muscles taking part in an exercise is another essential for skilful movement, for even if accuracy could be secured without paying attention to the time that the different muscles begin and end their action it would unquestionably be economical to have their action accurately timed. Awkwardness in the performance of new movements usually consists of a failure to rightly control the force and time of the action. The manner in which the nervous system controls the muscles so as to bring each one into action with exactly the right force and at exactly the right time has been explained in Chapter III.

Stated again briefly, to apply especially to the point in mind, every contraction of a muscle stimulates sensory nerve endings in that muscle, giving rise to nervous impulses that go to the central nervous system and there do one or both of two things: they give us a sensation of the state of action of the muscles, or they serve as a signal for other muscles to begin, change the force of contraction, or stop. Usually in practising new movements all of this takes place rapidly, although the sensations are not very definite, but soon all sense of details is lost and the incoming impulses from the muscles and joints merely serve to guide the action of the muscles, giving what we call a reflex movement.

The skilful performance of a movement often requires the use of muscles to guide the direction of it, besides those that move it and support it. Such additional muscles are called guiding or steadying muscles. They are especially needed in such exercises as throwing, shooting, fencing, kicking a football, and others of similar kind. These muscles must also be selected, stimulated in just the right degree, and accurately timed by the controlling mechanisms of the nervous system.

Skilful action often requires also the use of antagonistic muscles. When a class of pupils is commanded "Fling arms sideward" it is expected of them that they will move their arms rapidly to horizontal position and stop them in exact position. In certain strokes used in tennis, croquet, and other games it is necessary to make a quick and strong movement and then stop or recoil. In all of these cases, unless the muscles antagonistic to the movement were brought into action at a certain time the momentum of the movement would be too great to permit of its being rightly performed. Two sets of muscles standing in the relation of the antagonists of one another are usually what we have for guiding muscles, as in shooting.

Coördination may favor endurance by shifting different muscles into action in alternation. In sitting or standing, fatigue is lessened and endurance increased by varying the attitude. Walking and other exercise can often be modified in a similar way so as to bring the strongest work on different muscles in turn.

In all slow movements where accuracy and steadiness is needed, as in writing, playing a musical instrument, and similar cases, the antagonists contract along with the principal movers. If there is strong resistance or if the movement is to be made quickly the antagonists do not contract and in many cases are inhibited, as shown by the investigations of Sherrington and Demeney. The moving muscles may make a quick contraction and then relax allowing the momentum of the moving part to continue the movement.

QUESTIONS AND EXERCISES.

1. Mention three instances in which two or more muscles aid each other by pulling on the same lever at practically the same point of insertion, like the separate parts of the triceps.
2. Mention an exercise in which the deltoid acts as a supporting muscle and another in which it acts as a "mover;" the same for the serratus; the biceps; the latissimus.
3. Mention three other instances in which the arm acts as a system of levers, as in rowing and pushing, rather than as separate levers.
4. Give three examples of movements in which a muscle works with the deltoid to secure speed rather than power; three where a muscle works with the deltoid to secure power rather than speed.
5. Mention muscles used in throwing that do not act all at once, and give the order in which they act.
6. Study the action of wringing a cloth. What muscles act in each arm? Does the amount of force you can exert in this way depend on the direction of the twist? Explain why the average person can wring it most effectively when he turns the right arm over from the body.
7. From the standpoint of this chapter, what is gained when the method of throwing of the child is abandoned for that of the baseball player?
8. Name the muscles used to guide the movement in striking forward with a tennis racket against a ball that is over the head; sidewise at the level of the shoulders; just to the right of the right knee.
9. Mention two exercises in which the infraspinatus assists the deltoid; the biceps; the latissimus; the subscapularis.
10. By the use of a hand dynamometer, find how much more you can grip when the chest is held rigid than when you continue to breath during the test.

CHAPTER XIV.

ERECT POSTURE.

In preceding chapters we have studied individual muscles and groups of muscles, with special attention to their actions on the joint mechanism to which they are attached and to their use in performing certain movements of the body. Our attention has been directed almost exclusively to the conditions existing within a limited region. Later we are to study these actions in relation to the body as a whole and the part played in their control by the entire neuromuscular mechanism. It is suitable at this time, therefore, to take up the study of the erect posture, which is man's habitual posture in action.

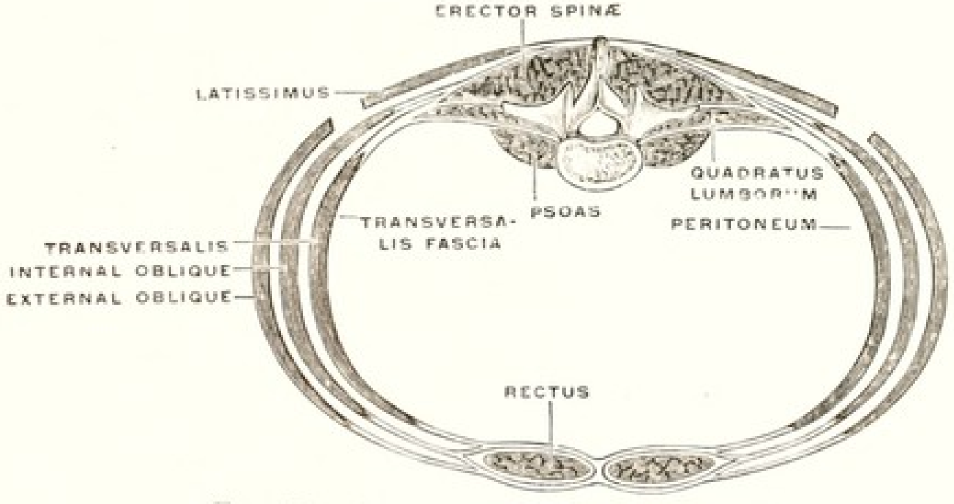


Fig. 150.—A cross-section of the trunk. (Gerrish.)

Vertebrate Structure.—Man's erect posture is peculiarly his own, so that he appears to the casual observer to be built upon an entirely different plan from that seen in other vertebrate animals, but comparative study readily shows that this is not the case. The general plan of structure in man is the same as that of all vertebrates. The trunk consists of a body wall, roughly cylindrical in shape, surrounding a body cavity which contains the vital organs and which is divided near its middle into the thoracic and abdominal cavities by the diaphragm. It has a cross-section like that shown in Fig. 150, with the segmented spinal column placed in one side of the body wall.

Quadrupedal Posture.—In all lower vertebrates, including the familiar quadrupeds, this common type of trunk is placed in horizontal position, with the spinal column at the top; in the quadrupeds it is held up from the ground by the limbs, which support it at four points.

The mechanics of this position is illustrated by the skeleton of the horse (Fig. 151). The spinal column is supported in a stable manner near its extremities by the four limbs, and the part between has the form of a flat arch; the abdominal muscles, rectus and obliques, joining the lower edge of the pelvis to the ribs and sternum, hold the arch up against the weight of the trunk, which is tending constantly to flatten it. The degree of curvature of the spinal arch differs considerably in different species.

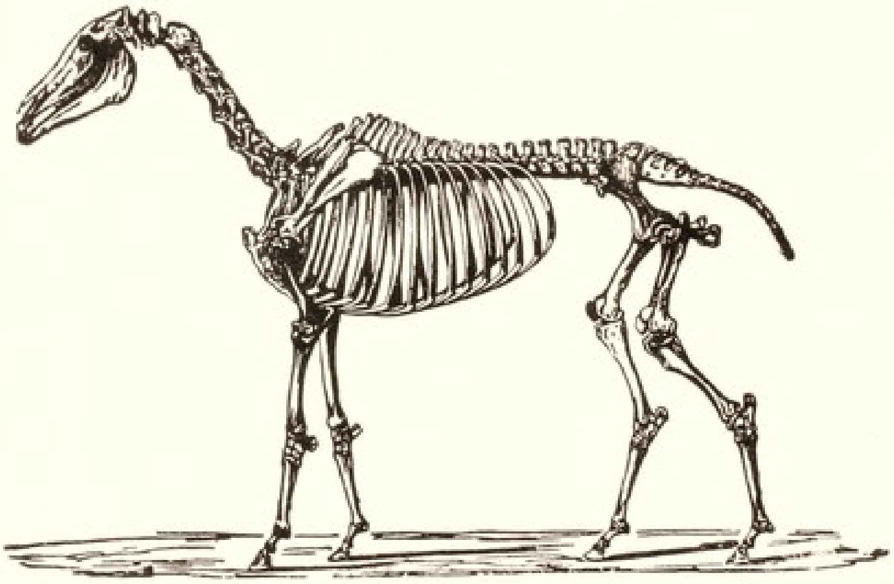


Fig. 151.—Skeleton of the horse. (Chauveau.)

The Gibbon.—The earliest vertebrates to assume an upright posture habitually were the hylobates or "wood-folk," a tree-dwelling genus of monkeys that is represented in present time by the white-handed gibbon of southeastern Asia. The hylobates are shown by fossil remains to have lived at remote ages of geological history, long before the appearance of man. The gibbon has fore-limbs longer and more powerful than his hind-limbs; his locomotion is mainly through the tree-tops rather than on the ground, and his progress through the trees is largely by use of his fore-limbs. His trunk assumes the upright position by suspension rather than by support from below; in fact, his hind-limbs are not strong enough to support his weight alone for any considerable length of time. In standing and sitting, as well as in locomotion, he leans heavily on his fore-limbs. Although habitually upright, the trunk of the gibbon is essentially of the same shape as the quadrupeds that live in a horizontal position.

The Apes.—The first appearance of the anthropoid apes and man is now placed by geologists in the Oligocene period, roughly estimated at three million years ago. There are three species of ape that resemble man more in structure and posture than does the gibbon; these are the orang-utang of the Malay peninsula and the neighboring islands of Sumatra and Borneo, and the chimpanzee and gorilla, both of west central Africa.

While the apes have four hands and live largely in trees, they show progress from the quadruped type toward that of man, not only in maintaining an upright position habitually but also in greater development of the hind-limbs and in more extensive use of these limbs in locomotion on the ground. They fall short of the erect posture of man in several ways, but especially in retaining the single arch of the spine seen in the horse and other quadrupeds, and in using the hands more or less to help support the trunk in standing, sitting and walking. The spinal column of the apes, like that of the gibbon, lack both the lumbar curve and the sacral angle that are characteristic of the posture of man (Figs. 122, 151 and 154).

Posture of the Infant.—"The spine of the human baby, as regards the proportion of its parts and its curvatures, is in an anthropoid phase of evolution. We have only to watch an infant trying to support its body erect when learning to walk, to see reproduced the orthograde posture of a great anthropoid ape. The lower limbs are seen to be imperfectly extended, the body plainly inclines forward, and the arms stretch out to clutch at neighboring objects for support. In the second year of life, growth changes in the lumbar vertebræ make further extension of the body a permanent possibility; it is then that the loins elongate and the lumbar curve, seen only in the human species, makes its appearance."[1]

Effects of Erect Posture.—When we think of man's form and posture as the result of evolution from lower vertebrate types, it is natural to inquire what changes in conditions and functions have come along with it. It is apparent that several results are sure to follow whenever a child or a species changes from a quadruped posture to an erect one: (1) changes in muscular development, (2) changes in coördination, (3) changes in the work of breathing, (4) changes in the mechanics of the circulation, and (5) increased tendency to displacement of the internal organs.

Muscular Development.—Erect posture, with the weight borne by the lower limbs, must result in vastly greater size and strength of the extensor muscles of those limbs and of the lower portions of the

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[1] Quoted from Sir Arthur Keith: Man's Erect Posture, British Medical Journal, 1923.

trunk; greater power in bones and vertebræ is also a necessity. The flexors of the trunk, relieved of much of the strain they have to bear in the quadruped position, have a tendency to deteriorate.

Coördination.—Greatly increased difficulty in poise and balance in the erect posture leads to a corresponding development of nervous reflexes to maintain exact balance under all conditions, while the release of the fore-limbs from heavy and monotonous labor leads to their employment in skilled occupations under the guidance of the eyes, developing many new coördinations for their control.

Breathing.—In the quadrupedal position the ribs hang down below the spinal column and swing back and forth in breathing like a pendulum, requiring very little muscular expenditure; when this mechanism is shifted to the upright position the entire weight of the chest wall must be lifted with each inspiration and must be held up to proper level continuously. So great is the pull of gravity on the chest, neck and spine that the ribs gradually sink as age increases, and the internal organs sink along with them.

Circulation.—In the horizontal position the blood returning to the heart along the inferior and superior vena cava, the two great veins of the body cavity, flows easily and evenly from the anterior and posterior portions of the body, but when the erect posture is assumed the flow from the head is hastened while that from the lower parts is held back by its weight until there is force enough behind it to overcome gravity. This distends the lower vena cava and checks the blood flow to a marked degree.

Position of Internal Organs.—In horizontal position the internal organs, while attached to the spine by their mesenteries, are supported mainly by the muscles of the body wall, which are kept in constant tension to maintain the arch of the spine. There is little or no tendency to displacement of the organs. When the erect position is assumed, the weight of each organ tends to pull it downward toward the pelvis, lengthwise of the cavity; heavy organs, like the liver and the full stomach, pull strongly on their mesenteries, tending to stretch them and to crowd the organs that lie below. To hold these organs up in place calls for a considerable tension of the abdominal wall, but the muscles are no longer kept in contraction to hold up the arch of the spine and therefore tend to relax.

Ideal Posture.—From a mechanical point of view, "the ideal posture is one in which the different segments of the body, head, neck, chest and abdomen, are balanced vertically one upon the other so that the weight is borne mainly by the bony framework, with a minimum of effort and strain on muscles and ligaments; this is when the long axis of its segments, seen in profile, form a vertical line instead of a zigzag."[1] In addition, the chest is held high, the

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[1] Quoted from the American Posture League.

scapulæ in moderate adduction, the pelvis tilted forward normally and the lower limbs in full extension, with the weight poised over the arch of the foot.

The muscles involved in maintaining ideal posture are the extensors of hip, knee and ankle; extensors and flexors of the trunk; the splenius, the middle half of the trapezius, and in some cases the latissimus. The adductors and abductors of the hips and the lateral flexors of the spine will act, but with less force. When there is a wrong habit of posture or some abnormal condition of the framework, stronger action of certain muscles will be required.

In sitting erect, without resting against a support, the trunk is poised upon the tuberosity of the ischium of each side by tension of the hamstrings and the flexors of the hips; the muscles of the trunk act the same as in standing. The hips being flexed to 90 degrees, the iliofemoral band cannot help, and so the flexors of the hips must act. The hamstrings are somewhat more elongated than in standing position, since the flexion of the hips is not fully compensated by flexion of the knees.

FIG. 152.—The ideal standing position. From a chart issued by the American Posture League.

FIG. 153.—Miss Bancroft's "window-pole test" for posture. (Photo by Ethel Perrin.)

Faults of Posture in the Apes.—The posture of the apes falls short of the ideal in several particulars. The head of the ape is far forward, his scapulæ are abducted, and his back is arched without any compensating lumbar curve; all this throws too much weight on the extensor muscles of the spine. Again, when he rises from horizontal to vertical position, the movement takes place in the hip-joints only, and this carries the sacrum far behind the hip-joints and forms a decided zigzag in the framework. Lacking the iliofemoral band and the sacral angle of the spine, the pelvis of the ape is much too flat in the upright position. Another zigzag is at the knees, which the ape does not hold fully extended. As the result of these faults the ape does not stand with his trunk fully erect and needs to use his hands to help in maintaining an upright poise.

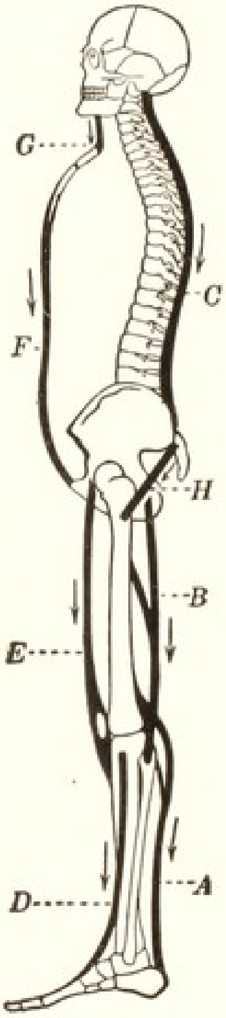

Fig. 154.—Diagram showing the action of antagonistic muscles which keep the body erect. (After Huxley.) Arrows indicate the direction of the pull, the feet serving as a fixed basis of support. The muscles *A*, *B*, *H* and *C* keep the body from falling forward; *D*, *E*, *F* and *G* keep it from falling backward. (Hough and Sedgwick.)

The Pelvic Angle.—Studies have been made to find what degree of obliquity is best. For purpose of discussion the line between the two hip-joints is called the principal diameter of the pelvis, and a line from the top of the sacrum to the crest of the pubes is called its conjugate diameter. Dr. Lovett concludes from the results of various studies that the best position of the pelvis is when the principal diameter is level and the conjugate diameter at an angle of about 60 degrees with the horizontal.

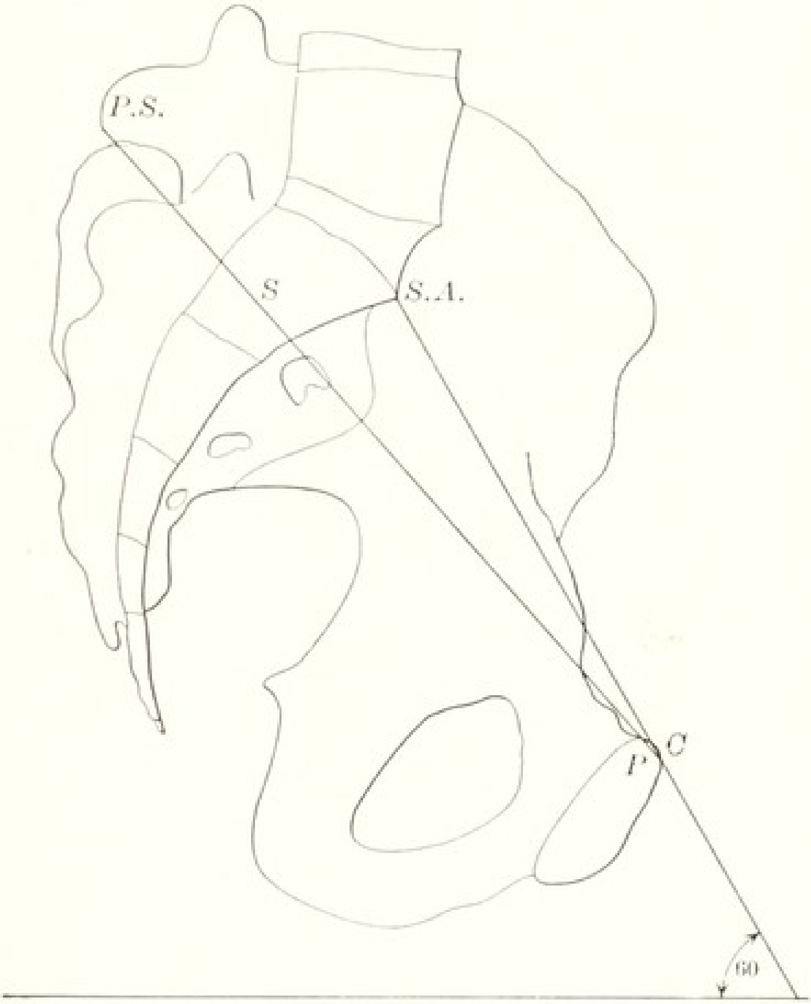

FIG. 155.—Median section through the pelvis: *P*, pubes; *C*, pubic crest; *S*, sacrum; *S.A.*, sacral angle; *P.S.*, posterior spine. (Spalteholz.)

When the pelvis is inclined forward 60 degrees, the lumbar curve and the sacral angle give the trunk a bend that tends to separate the long body cavity into two parts, causing the organs of the upper part to rest upon the crest and rami of the pubes instead of upon the organs within the pelvis.

The oblique position of the pelvis brings the pelvic organs far to the rear, where they are beneath the sacrum and protected somewhat by it from the weight of the organs above; it also brings the lower lumbar vertebræ far enough forward to be practically over the hip-joints, so that little force is required to maintain poise.

The Chest.—The best functioning of the internal organs calls for a vigorously erect position of the chest and neck. The best posture for breathing is one in which the ribs are held habitually in a position midway between full inspiration and full expiration. The higher the position of head, neck and chest, the more room is there for heart, stomach, liver, and other organs. Notice the difference in capacity of the body cavity by comparing figures 156 and 157.

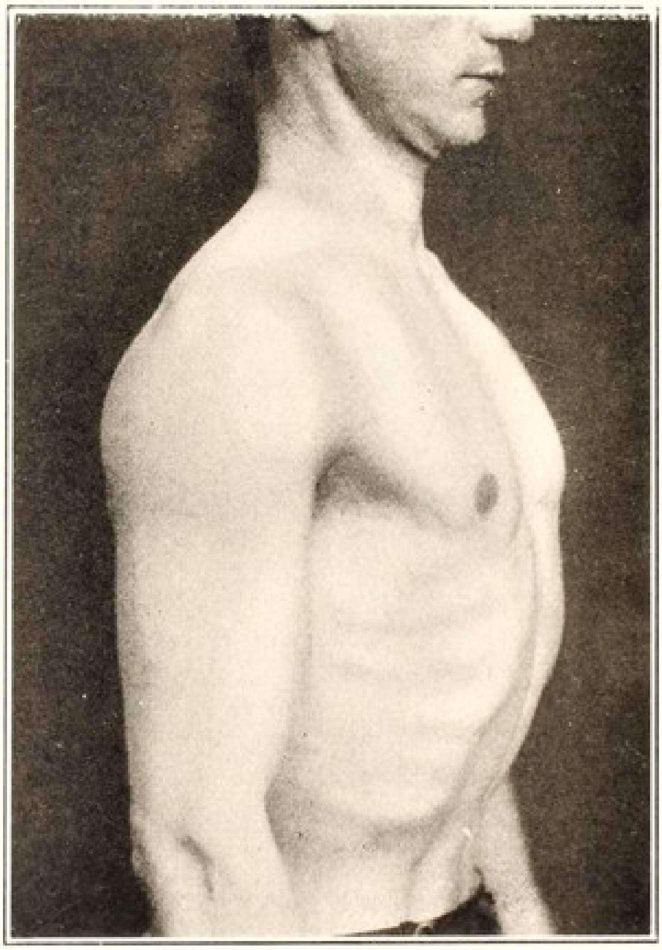

FIG. 156.—The expanded chest seen in the vigorously erect posture.

Posture Reflexes.—The perfect balance of every segment of the body that an ideal posture involves can be secured only by a perfect balance of tension between all the opposing muscle groups. The tension necessary in the hip adductors and abductors and in the quadratus lumborum of each side when the poise is perfect is so slight that one may not be able to detect any contraction by the feeling of his muscles, yet, no matter how slight the tension may be, it must be perfectly balanced and controlled at every instant.

Three kinds of sensory stimuli act upon the motor neurones of all these muscles to regulate their tension; (1) stimuli from the semicircular canals, which respond to every deviation from a perfect poise of the head; (2) stimuli from the eyes, which often give us first intimation that we are losing our balance; (3) stimuli from the muscles themselves, in response to every change of tension.

We can notice the working of these postural reflexes by getting two objects in line when standing or sitting and observing that we never remain perfectly still; we unconsciously sway a little from the place of balance and then, when the deviation is sufficient to arouse the proper stimulus, the muscles change tension so as to bring it back.

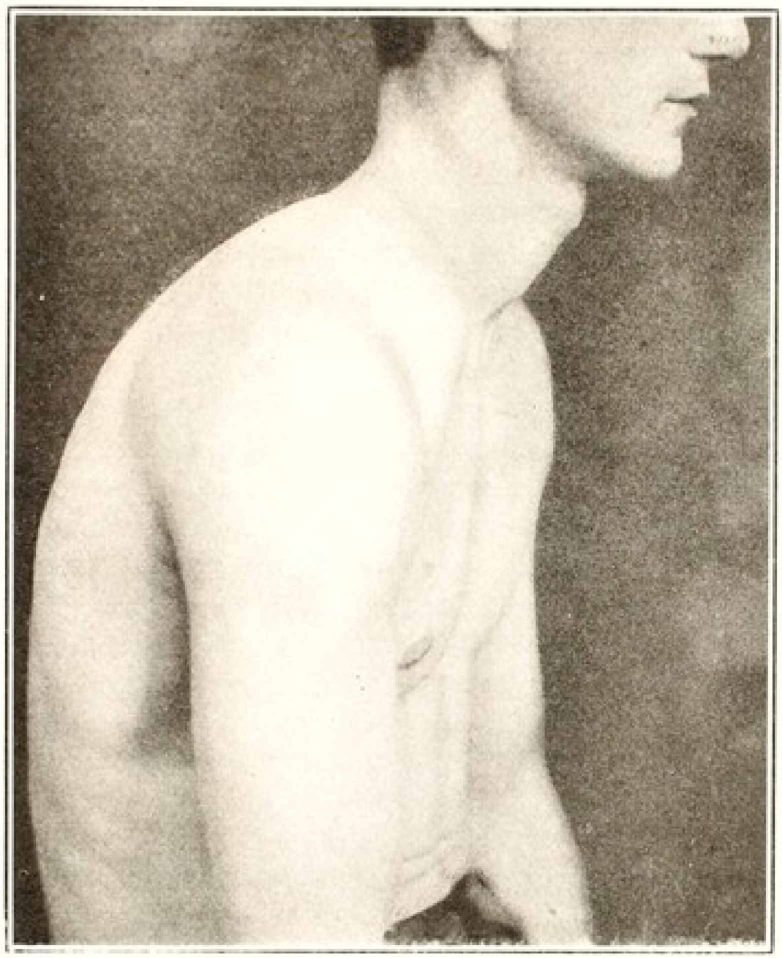

FIG. 157.—The flattened chest seen in kyphosis.

Each child, as he practises various postures and exercises, gradually perfects his postural control, and even before he reaches school age he is apt to have a habitual posture that is very close to the ideal.

Causes of Bad Posture.—Defects of posture may result from (1) injury, (2) disease, (3) habit, (4) muscular or nervous weakness, or (5) mental attitude.

Injury.—When a bone, ligament or muscle is injured it is apt to weaken the support at that point and throw the framework out of balance. As long as this condition is present, perfect posture is impossible; after the injury has been fully repaired a habit set up may persist and the faulty posture continue for a long time. Since minor injuries, like a sprained ankle, often occur, and since there is seldom any effort made to reëducate the reflexes of the wrong habit, we frequently see defects of posture that arose in this way.

Disease.—Diseases that weaken bones or muscles or cause joints to lose their strength or their freedom of action upset the control of posture as badly as injuries. Rickets, due to faulty nutrition of bone, and tubercular disease of joints or vertebræ are examples of this kind. Infantile paralysis, by weakening or destroying the motor nerve cells in the spinal cord, causes partial or complete loss of function in certain muscle groups. This loss of power in the muscles upsets the control as in the former instances and also causes another kind of defect; the uninjured group that is the natural antagonist of the paralyzed one, not having its normal opposition, becomes gradually shortened and holds the joint out of normal position. For example, one with a paralyzed gastrocnemius gradually develops a flexed ankle which he cannot extend.

The treatment of cases involving severe injury or disease often requires surgical measures, such as cutting a muscle or tendon, removing or grafting bone, transplanting of tendons to make good muscles do the work of absent ones, and the making of braces to support the weight when the natural support is lacking.

Habit.—Habits of posture, whether good or bad, are acquired in the same way as habits of speech or habits of walking, namely, by practising a certain coördination so many times that the reflex finally becomes habitual and unconscious and is performed whenever the appropriate situation presents itself. In a very large percentage of the cases of faulty posture found among school children and college students, the bones, joints, ligaments and muscles are in normal condition; the fault is a wrong habit of coördination. Segments of the body have been held out of line so long, with some parts bearing too much weight and others too little, some muscles elongated and their antagonists shortened, that the wrong posture feels natural and a correct position seems strange.

Wrong habits of posture are caused by injury and disease and by occupation and environment as well. A boy who sprains his left ankle has to stand on his right foot, and during the period of lameness he forms the habit of standing on that foot and is likely to keep on doing so for years. A boy who has carried a heavy sack of papers on one shoulder every day for a year or two is apt to hold that shoulder low for the rest of his life. Thus bookkeepers are known by their peculiar habit of holding the head and cowboys by their bow-legged gait. Seats, shoes and clothing produce similar effects when they have the wrong size or shape, so that they hold one in a faulty position; defects of vision and hearing, and resting positions on rocking chair, lounge, hammock or bed may induce such habits also.

On the other hand, those who are strongly impressed with the advantages of good posture, so that they study their own postures and try to improve them, just as thoroughly as they study to improve their complexions and the appearance of their clothes, are apt to have correct habits of posture, in spite of occupation and environment.

Weakness.—The erect posture cannot be maintained without the expenditure of energy, and therefore requires strength and endurance. Posture is a sensitive indicator, showing to one who can read it not only our habits but also the level of our store of energy. A boxer who has been struck a hard blow over his solar plexus collapses to the floor, simply because the muscular tensions that have been holding him erect have been suddenly withdrawn. A college student with an "A" posture returns after a week's illness unable to test better than "C" or "D." Maintaining erect position is a type of exertion that brings fatigue quickly, because it blocks the circulation, and the never-ending force of gravitation then causes a slump. This is the reason why games and plays are so good an antidote for faults of posture; they build up neuromuscular power.

Mental Attitude.—Feelings of elation, confidence and satisfaction help in the maintenance of erect posture; humility and depression hinder it. Those who are modest or timid are especially liable to relaxed postures, such as round shoulders, while the overconfident and bold more often have hollow back.

CORRECTING FAULTS OF POSTURE.

The General Problem.—Whenever faulty posture is due to disease, the disease must be cured before anything else is attempted; if it is due to an injury, the injury must be healed. In general, the cause must be removed before any measures for improvement are apt to be effective; a posture due to wearing high heels will not be much improved as long as the high heels are worn; an hour in the gymnasium will not cure bad postures while many hours are spent in the environment that caused them.

Teaching Better Habits.—To correct any bad habit, a better one must be formed in its place. This is much like teaching new and better form in an athletic event, such as running, jumping or throwing. The coach has to give the athlete a clear idea of what to do and must develop an interest in doing it that will stimulate him to persistent practice, long and thorough enough to establish a new coördination.

The work of teaching better posture differs from the coaching of athletes in that everybody must be taught, instead of a few especially capable and willing athletes, and in that the training in posture must be more thorough; whereas the athlete must acquire the coordination well enough to excel in competition during a few weeks

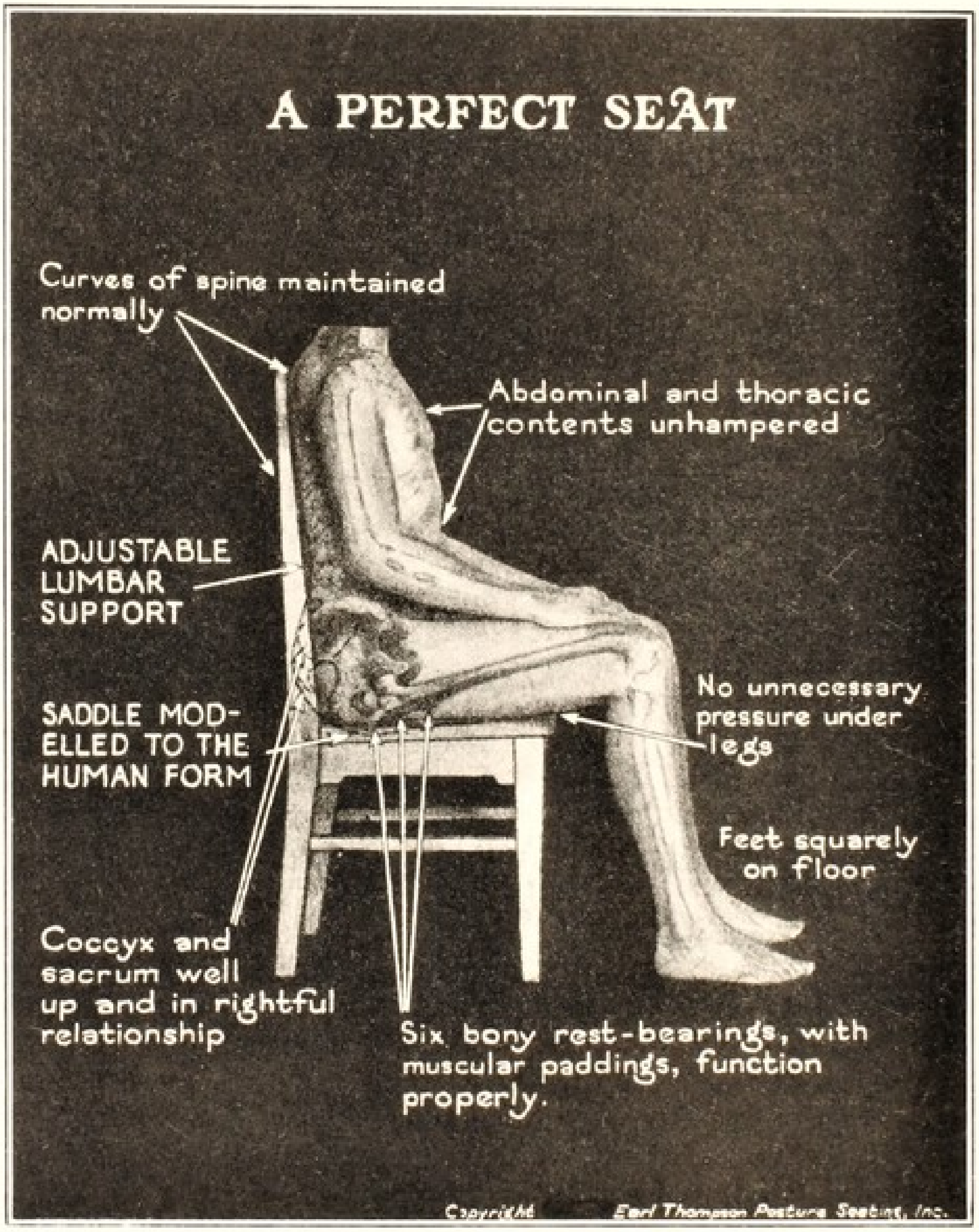

FIG. 158.—The good points of a perfect seat. (By permission of Earl Thompson, Posture Seating, Inc.)

or months, the student of posture must acquire a perfect coördination and then make it a fixed habit; he must know the form too well and must prize his skill in posture too highly to let any occupation or environment get him into a wrong habit.

To create a vivid and lasting impression of what an ideal posture is, there must be plenty of pictures, diagrams and living models for its demonstration. The charts published by the American Posture League are helpful here. The advantages of good posture should be discussed fully but not at tedious length, for there is danger of the pupil's becoming bored and disgusted with the whole matter. Each subject should see his own posture and have its good points and its faults pointed out to him while he is looking at it; this can best be done by the use of a triple mirror, like those in use in clothing stores. In a triple mirror one can see his own posture in profile and from the back, as well as the view seen in a common mirror. It is very helpful in teaching posture, for one can see in it exactly how successful he is in his attempts to assume ideal posture and exactly where he fails to achieve it.

The coach relies upon competition and trophies to stimulate sustained effort among his athletes, and the schools rely upon tests, marking and grading to stimulate scholastic work; the teacher of posture should use both of these devices. Nagging and punishment and other slave-driving tactics are to be avoided because they kill enthusiasm and enthusiasm we must have.

Special Posture Classes.—Many will be found who are not strong enough and skilful enough to assume and maintain correct posture without more personal attention than can be given the average pupil. For these, special classes of small size should be conducted. More complete study of each case and of its causes and its difficulties is possible here; the triple mirror can be used daily, and special exercises suited to the particular defect can be practised under the eye of the instructor. As soon as the pupil can assume a correct posture and hold it without help, he is promoted to regular activities that are more inspiring. Such cases, however, are especially liable to relapse into the old habits, so that it is best to have them report once a week to the instructor and practise often before the triple mirror, to be sure the right coördination is being practised.

Resistant Cases.—When a bad habit of posture has continued too long, muscles, ligaments and finally bones have their structure altered, so that they can no longer be brought into normal position by muscular action; such cases are called resistant. Instructors who have been sufficiently trained in orthopedic practice can handle mild cases of this type in the special class, helping the subject to stretch the shortened tissues and to form a correct coördination in place of the wrong one he has had. Severe cases are more success-fully treated in an orthopedic hospital, where more complete equipment, more highly trained experts, and even surgical assistance can be given.

ROUND SHOULDERS.

This fault, in its early stages, consists merely of a forward drooping of the head and neck. The chest is flattened, because the lowering of the origins of the sternocleidomastoid and scaleni muscles permits the ribs and sternum to fall. When this position has been assumed the head is no longer poised evenly at the summit of the spinal column but pulls forward on the extensors of the upper spine; as fatigue comes on, these extensors elongate, thus increasing the normal convexity of the thoracic curve. When the stooping has progressed thus far, the weight of the arms and shoulders puts extra tension on the middle trapezius; as this elongates, the scapulæ are abducted. The effect of all this on the size and shape of the chest is shown by a comparison of Figs. 156 and 157. When round shoulders has become resistant and the subject can no longer assume the erect position it is called *kyphosis*.

FIG. 159.—Correcting posture of shoulders with assistance of the instructor. (Drew.)

Causes and Frequency.—Round shoulders is the most common fault of posture, and when we think of all the occupations that cause the head to droop forward it seems surprising that it is not universal among men, as it is among apes. Nearly all school occupations, including reading, writing, drawing, solving problems in mathematics, library work and laboratory work, keep the head bent forward so that the eyes can be used to direct the work of the hands or to read the printed page. Fortunately, there are other school occupations, such as working at the blackboard, reading from charts, looking at illustrative apparatus or at one who is speaking, in which the head is held erect. On the other hand, many home occupations are just as conducive to round shoulders as any; sewing, sweeping, ironing, playing with blocks and with cards are examples.

Among the generation now in school and college, reading is the occupation most commonly practised and the one in which most hours are spent. It is for this reason the most important single cause of the habit of round shoulders. The reason is easy to see; holding the book up before the eyes tires the arm muscles, and so the book is allowed to drop to the table or the lap, and the head droops to bring the eyes within range. Newspapers, being lighter, are usually held up.

Preventives.—Stronger arms would hold the book up more easily, but a mechanical contrivance to hold it in position without effort is probably a more practical plan. Whoever invents a book-holder so satisfactory and so cheap that it will come into universal use, will improve the posture and the health of the race, for habitual round shoulders decreases respiration and thus lowers vitality and favors various forms of deformity and disease.

Corrective Exercises.—Exercises devised for the prevention and correction of round shoulders are illustrated in Figs. 41, 42, 60 and 62. Persistent practice of these exercises will help to elongate the shortened muscles and to correct the faulty reflex that has allowed the back muscles to keep habitually in too great a degree of elongation. For weaker persons and those whose power of coördination is poor, they can be practised to advantage while sitting in a good chair whose back is just high enough to support the chest. For those who need more vigorous exercises, the same ones can be practised while lying on the face with the feet held down and with the chest raised up from the plinth or floor by the use of the extensors of the trunk.

As in all correction of posture, it is of course not enough to stretch the short tissues and make it possible to assume an erect posture; the habit of correct posture must be fixed by the subject himself, through education of his nervous reflexes by persistent practice.

HOLLOW BACK.

There are two types of hollow back, which in resistant stages is called *lordosis.* The simpler is merely an exaggeration of the normal lumbar curve; in the more complex type the pelvis is tilted forward.

The simpler type of hollow back is illustrated in Fig. 161 and in 166. It is assumed temporarily whenever one carries a weight in

FIG. 160.—The Adams bicycle exercise. (Drew.)

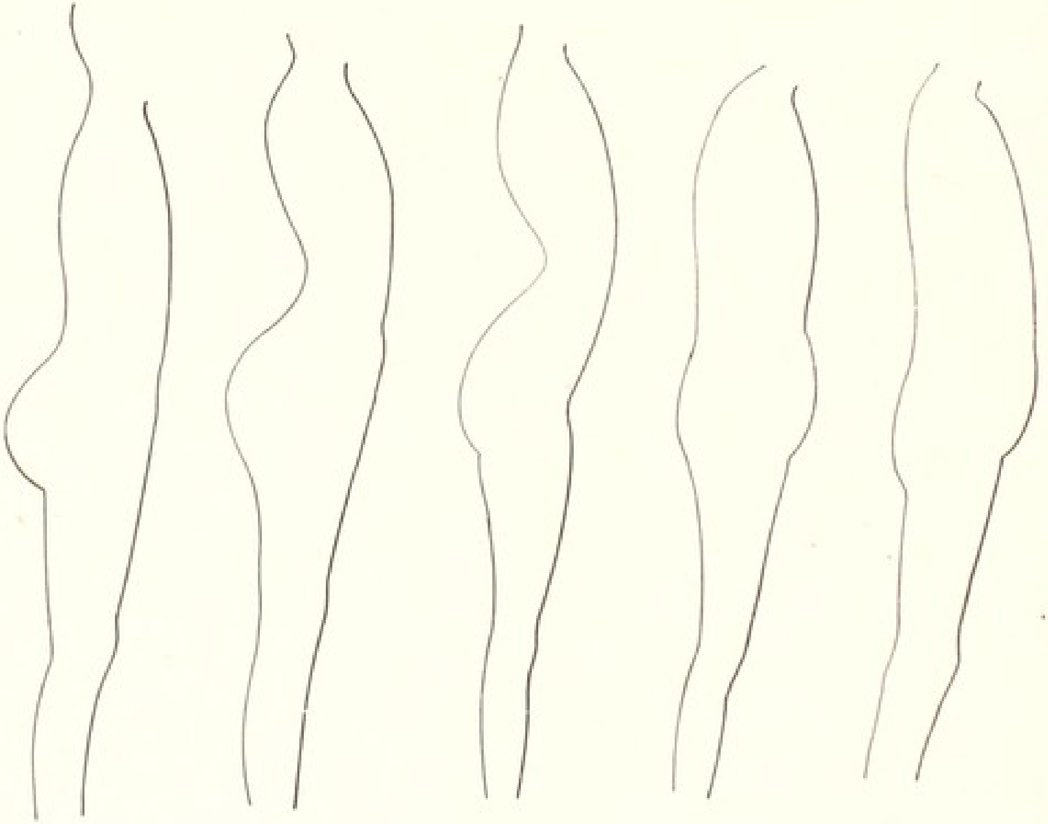

FIG. 161.—Tracings made with pantograph, showing normal posture, lordosis and flat back: *A*, normal; *B* and *C*, lordosis; *D* and *E*, flat back.

the arms held in front of him, as when a waiter carries a heavy tray of dishes. The muscles of the lower back are shortened and the abdominal muscles are elongated. When this position is assumed habitually, too much weight is thrown on the posterior edges of the bodies of the lumbar vertebræ, and there is a marked tendency to assume a position of round shoulders to compensate for the backward shifting of the body weight. In flexible cases the subject has only to acquire the ability to assume the right position of the spine and then to practice it until the habit is established. In cases that are slightly resistant there are two kinds of exercises that will help to elongate the back muscles and to shorten the abdominal group.

Sitting on a bench against a wall and pushing the trunk backward so as to make it touch the wall in the lumbar region is good; it is a little stronger if taken while sitting on the floor, with the knees straight, as this tilts the pelvis backward and so helps to straighten the lumbar spine.

An exercise described by Schatz and by Berggren and suitable for vigorous subjects is taken while lying on the back on the floor with the hips flexed until the feet are vertically over the face and 12 to 18 inches away from it; the hands or a pillow may be used to hold the hips off the floor. From this position move the feet in a circle as large as can be made conveniently. The back muscles are kept in a stretched position and the abdominal muscles used moderately in a shortened position. The so-called bicycle exercise of Adams is easier; here the hips are against the wall and the lower limbs extended upward along the wall; from this position one limb is flexed and extended in alternation with the other, as in bicycling.

When the pelvis is tilted too far forward we have not only a wrong coördination of the flexors and extensors of the trunk but also a wrong coördination of the flexors and extensors of the hips at the same time. Notice that in this case the back muscles and flexors of the hips are shortened, while the abdominal muscles and hamstrings are elongated; it will do no good to correct the coördination of trunk muscles alone or of hip muscles alone, but all four groups must be adjusted and controlled to keep the pelvis in its proper degree of inclination.

It will be readily seen that the exercises that have been described to correct the simple hollow back will not be of any use when the pelvis is inclined too far forward. None of these exercises will help to elongate the flexors of the hips, and the Schatz-Berggren exercise will stretch the hamstrings still more. In flexible cases having especially good powers of coördination, the subject will be able to correct the wrong tilt of the pelvis by some careful work with the help of the instructor; a few will learn to control the tilt of the pelvis at will, and then the right habit can be established with comparative case. Others can learn to keep the front of the pelvis up by rising carefully and slowly from the sitting position, contracting the abdominal muscles first and then the hamstrings, with as little tension as possible on the back muscles and the flexors of the hips. If the iliofemoral ligaments are short, they will tilt the pelvis forward in spite of all the muscles can do to prevent it.

When the flexors of the hips and iliofemoral ligaments are just a little short it may be possible to stretch them in the following manner: lying flat on the back on the floor, knees extended, try to press the lumbar part of the back close to the floor; possibly putting one hand there and trying to press the back against it will help in the coördination. The work has to be done by the hamstrings and abdominal muscles, against the resistance of the back muscles, flexors of the hips and iliofemoral ligaments. A variation that will sometimes help is this: flex the knees a few degrees, sliding the feet along the floor toward the hips; then press the back down against the floor; now, while holding the back down, slowly extend the knees. This uses the extensors of the knees, along with the hamstrings and abdominal muscles, to stretch the tissues on the front of the hips.

FLAT BACK.

Flat back is the absence of the normal lumbar curve. It is a reversion to the posture of the apes, whereas hollow back is too great a departure from it. Here the pelvis is held too flat, the hamstrings being short and the flexors of the hips and iliofemoral ligaments too long; it may be developed by a habit of sitting with the hips forward and the lumbar curve obliterated. As in the former case, when the condition is flexible a better coördination can be acquired and a new habit of holding it established; the right position may be acquired by rising slowly from sitting position with the trunk held well forward, fixing the position of the pelvis by contraction of the extensors and flexors of hips, finally coming to erect posture by extension of the lumbar spine.

A combination of flat back and round shoulders gives the "gorilla type" of posture; it is commonly seen in weak and fatigued cases.

LATERAL CURVATURE.

Lateral curvature, which in resistant stages is called *scoliosis*, is a sideward deviation of the spine. The presence of rotation, which has been explained in connection with movements of the trunk, is a feature causing much difficulty in the correction of scoliosis.

Lateral curvature lessens the ability of the spine to support the body weight, it distorts the cavities and crowds organs out of place, and in advanced cases causes pressure on the spinal nerves, where they pass out of vertebral canal.

This fault may be due to disease or injury, to unequal height of the two sides of the pelvis, lack of symmetry of the trunk muscles, or to a wrong coördination that has become a habit.

When the pelvis is not level laterally the top of the sacrum is not level and the spine deviates toward the lower side of the pelvis; to maintain balance, it must curve to the other side in its upper portions. The slant of the pelvis to one side may be due to unequal length of the lower limbs, to a flat foot, or to a habit of standing with one knee partly flexed. The short limb can be leveled up by a lift on the heel or on the heel and sole; the curvature is apt to disappear if the faults below are corrected.

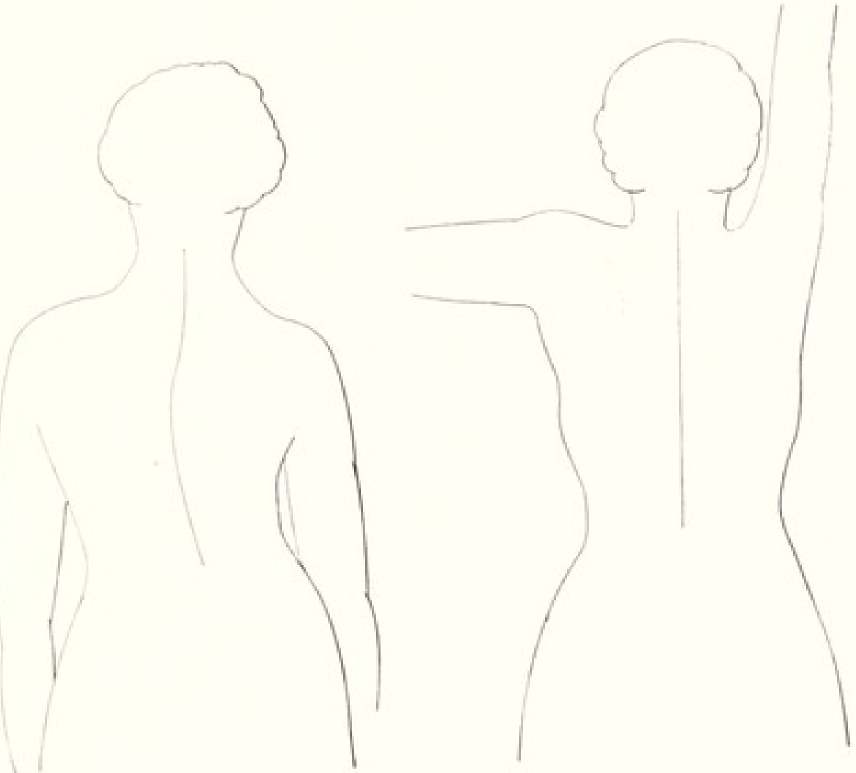

FIG. 162.—Straightening a lateral curve by use of a keynote position.

Key-note Positions.—Cases of lateral curvature are so varied and the complications are so many that correction is largely an individual matter. A plan suggested by Roth and called by him the use of "key-note positions" has been much used for the correction of flexible cases. The key-note position is a device to help the subject in assuming the correct position. When he tries to stand straight and shows a thoracic curve convex to left, raising the right arm to a certain height may bring muscles into action that will pull the spine straight; in some cases it may require raising both arms, but to different positions; when the curve is low it may require a sideward or diagonal position of one foot. When a position is found that brings the spine to a vertical and straight position, that is the key-note position for that case. The subject practises this position many times, and he takes pains in returning to fundamental position to hold his spine in the erect position if possible; in this way he gradually acquires ability to assume the erect position at will.

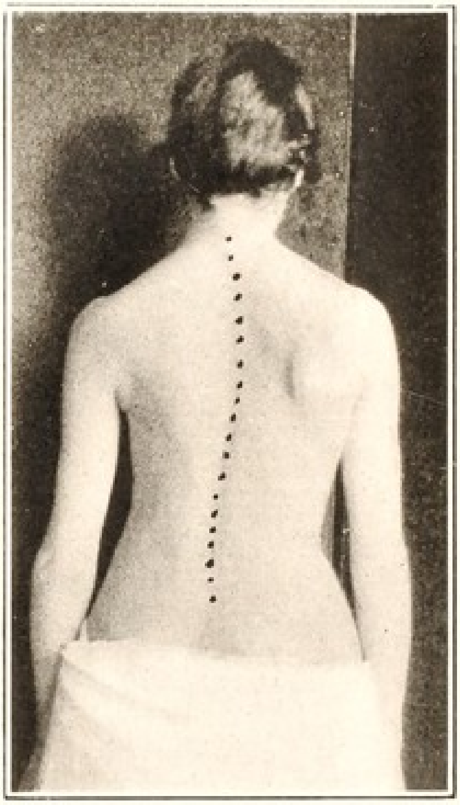

FIG. 163.—Scoliosis.

Scoliosis.—In resistant cases more than the subject's own muscular force is needed to straighten the curvature, and various devices are used to bring about flexibility. The subject's own weight is used in many ways for this purpose; hanging by the hands, suspension by a head-sling, lying on one side or the latter position with the upper trunk projecting over the end of the table or plinth. Straps and cushions and the strength of the instructor are also used. Muscular development must accompany the increase of flexibility unless a cast is used. A cast is formed by wrapping the subject's trunk, when he has been forcibly straightened, with cloth strips coated with plaster of Paris; when applied, dampened, and then allowed to dry, this forms a solid cast fitting the body snugly and holding it rigidly in position. When it has fully hardened the cast is cut in two at the front and back and laced up, so that it can be put on and off at will. To prevent degeneration of the muscles, the cast should be taken off and massage and exercise given at proper intervals, using the cast to keep the spine from going back to old habits.

FUNCTIONS OF THE ABDOMINAL WALL.

The four pairs of muscles in the abdominal wall—rectus, obliques and transversalis, are involved in two important reflexes that we have studied; those of posture and breathing. A third function of this group of muscles is to maintain a suitable pressure within the abdominal cavity, proportionate to the weight of the internal organs.

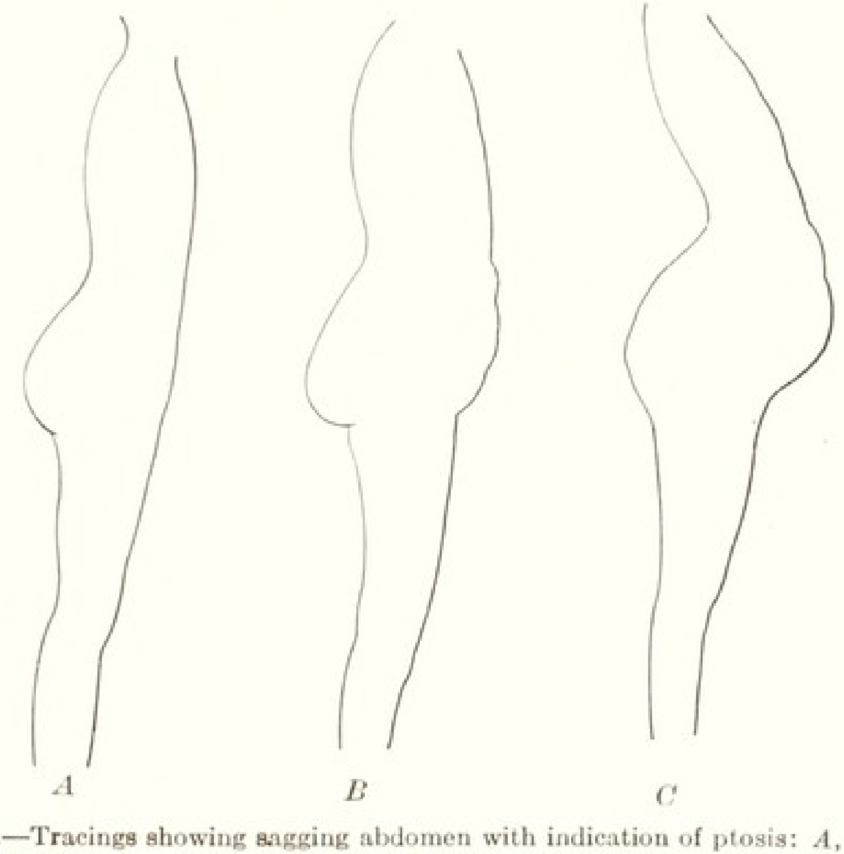

Fig. 164.—Tracings showing sagging abdomen with indication of ptosis: *A*, normal outline; *B* and *C*, weak abdominal walls with apparent sagging of the viscera.

Intra-abdominal Pressure.—The stomach, liver, colon and other organs completely fill the abdominal cavity, and each is attached to the posterior body wall. As long as the trunk is horizontal, the organs lie normally in place, even when the abdominal wall is fully relaxed, but as soon as the erect position is assumed their weight pulls them downward, lengthwise of the cavity; the mesenteries by which they are attached are not composed of strong fibrous tissue, like true ligaments, but are mere folds of the soft peritoneum, in which the arteries, veins and nerves going to the organs are enfolded. When the right amount of pressure is maintained by a coördinated action of the four pairs of abdominal muscles, the organs are held in proper position in upright postures, even when subjected to the jar of running and horseback riding.

Visceral Ptosis.—This is the medical term for the sagging of the organs and their downward drag upon their mesenteries that takes place when there is not sufficient tension of the abdominal wall to hold them up in place. The pull on vessels and nerves causes nervous irritation whose cause is not easy to find; if continued for a long time the organ sags to a lower place in the cavity, stretching the connecting vessels and crowding the organs below.

The lack of suitable muscular tension in the abdominal wall has another effect; it leads to dilatation of bloodvessels in the digestive organs, favoring inflammatory conditions and favoring also a rapid deposit of fat. The presence of more fat adds to the weight and hence to the tendency to sag and to the distention of the wall.

Hernia.—Hernia or rupture is a protrusion of some abdominal structure through an opening in the abdominal wall. The weakest point in the abdominal wall in the male is usually the inguinal canal, just above the groin and near the crest of the pubes; in the female it is usually the femoral canal, where the femoral artery crosses the rim of the pelvis; this is slightly lateral to the inguinal canal. The immediate cause of a hernia is usually some sudden and violent contraction of the abdominal muscles, due to a fall or other accident or to a violent fit of coughing; sometimes no definite cause can be assigned. The real cause is a weakness of the abdominal wall.

When a hernia has occurred once it is liable to occur again, since the protrusion stretches the ring of tissue and makes the opening larger. The recurrence can be prevented temporarily by wearing a truss; a cure is accomplished by a simple operation.

Preventive Measures.—Prevention of visceral ptosis and hernia is by maintaining the strength and thickness of the abdominal wall. Sedentary life predisposes to these troubles by lack of the bodily activity that is the natural means of its development. Quiet breathing scarcely employs the abdominal muscles at all; sitting, either when bending forward or leaning against a support, makes it unnecessary to use them in maintaining the posture. Walking, running and active games and sports bring them into action in the natural way, and so these activities are the best means of development and the best preventive measures. Special exercises in bending, twisting, raising and lowering the trunk and moving the lower limbs can help if carefully used, but they are apt to be used too violently and for too short a time.

CHAPTER XV.

GYMNASTIC MOVEMENTS.

A WOODEN-LEGGED sailor is quoted as saying that when he had two good legs he could strike a terrible blow with his fist. He had learned by his experience one of the basic principles of kinesiology—that the power of any muscle group depends very much in actual practice upon how good help it can get from its fellows.

In normal action the associated muscle groups are so controlled as to give the most effect with the least effort and muscular expenditure. We have studied the action of the muscle groups most directly concerned in the performance of many of the simplest gymnastic movements and have also noticed some of the ways in which muscles are able to help one another. We come now to the study of the relation of more distant muscle groups to these movements and how the whole body works as a unit to accomplish the end in view.

In studying any movement to discover its effect on the body we must recognize three elements or phases: The preliminary position, the movement taken from this position and the movement of recovery. Usually, it is the second of these parts that requires the most work and is, therefore, the main element to be considered; this is illustrated by such movements as raising arms forward while standing or raising the feet while lying on the back. Sometimes it is the preliminary position that is important, as in thrusting arms forward or sideward from neck firm or shoulders firm; sometimes it is the movement of recovery, as in case of trunk bending forward and of knee bending, from standing position. In some of the more vigorous exercises of gymnastics and sports, which may be illustrated by flexion of arms from prone falling position or putting the shot, it is necessary to analyze all three parts to get an adequate understanding of the movement and its effects.

Raising Arms Forward.—In raising arms forward all teachers have noticed that beginners invariably hollow the back and protrude the abdomen; if there are dumb-bells or other weights in the hands it is still more marked, requiring repeated corrections of the whole class and of individuals before all will execute this simplest of movements without losing good position. Waiters carrying trays of dishes exhibit the same position in an exaggerated form.

The explanation is a matter of balance. With the hands hanging freely at the sides the pupils take an upright position; raising the arm moves the center of gravity forward so that it is no longer vertically above the hip-joints. This requires an additional amount of contraction on the part of the extensor muscles, or a backward tilt of the trunk to bring its center of gravity over the support again. The latter way is more saving of energy and so everyone naturally does it that way. If we want the movement to train a sense of erect position rather than to get the work done in the easiest way, we insist that the pupils keep the erect posture.

When the movement is made slowly and without resistance other than the weight of the arms, we may not be able to feel any contraction of the lumbar extensors, but if weights are used or if it is made quickly the added contraction is plainly felt. With increased resistance the hamstring muscles and finally the extensors of the ankle come into action. When one arm is raised alone the action of the erector spinæ and extensors of the limbs is more marked on the opposite side.

Raising Arms Sideward.—In raising arms sideward the weights of the arms balance each other and little or no associated action of trunk muscles is needed, but if only one arm is raised the center of gravity is displaced just as much as in the forward movement. Here it is the muscles of the opposite side of the trunk that act—erector spinæ, quadratus lumborum, internal and external oblique—and if the resistance is considerable, the rectus abdominis and possible the intercostals. When the resistance to raising one arm is great and the arm is lifted with force the extensors of hip, knee and ankle of the lifting side also show increased contraction.

When one arm is raised at any other angle than forward or sideward the trunk muscles also contract and it is always those on the opposite side of the spinal column from the arm that act—erector spinæ when it is forward, lateral group when it is sideward, abdominal group when it is backward, and opposite intervening groups at any angle between.

When the arm bearing a weight is raised slowly from the side the action of the trunk muscles gradually increases up to horizontal because the angle at which the weight acts is increasing; as the arm is raised from horizontal to vertical upward the action of the trunk diminishes again, the weight having no effect to depress the arm when it is directly upward.

Persons who have short and inelastic pectoral muscles have great difficulty in raising arms upward and usually hollow the back by contraction of the erector spinæ whenever they try to take the position, but this is not a matter of gravitation and balance. The resistance of the opposing muscles keeps on increasing as the arms are lifted, and since it feels the same as in lifting a weight the subject involuntarily jumps at the conclusion that extension of the spine will help, although in fact it cannot possibly aid in complete elevation of the arm. In fact, overextension of the spine makes the arms point upward when they have been raised only part of the way, so that he appears to have done what was wanted.

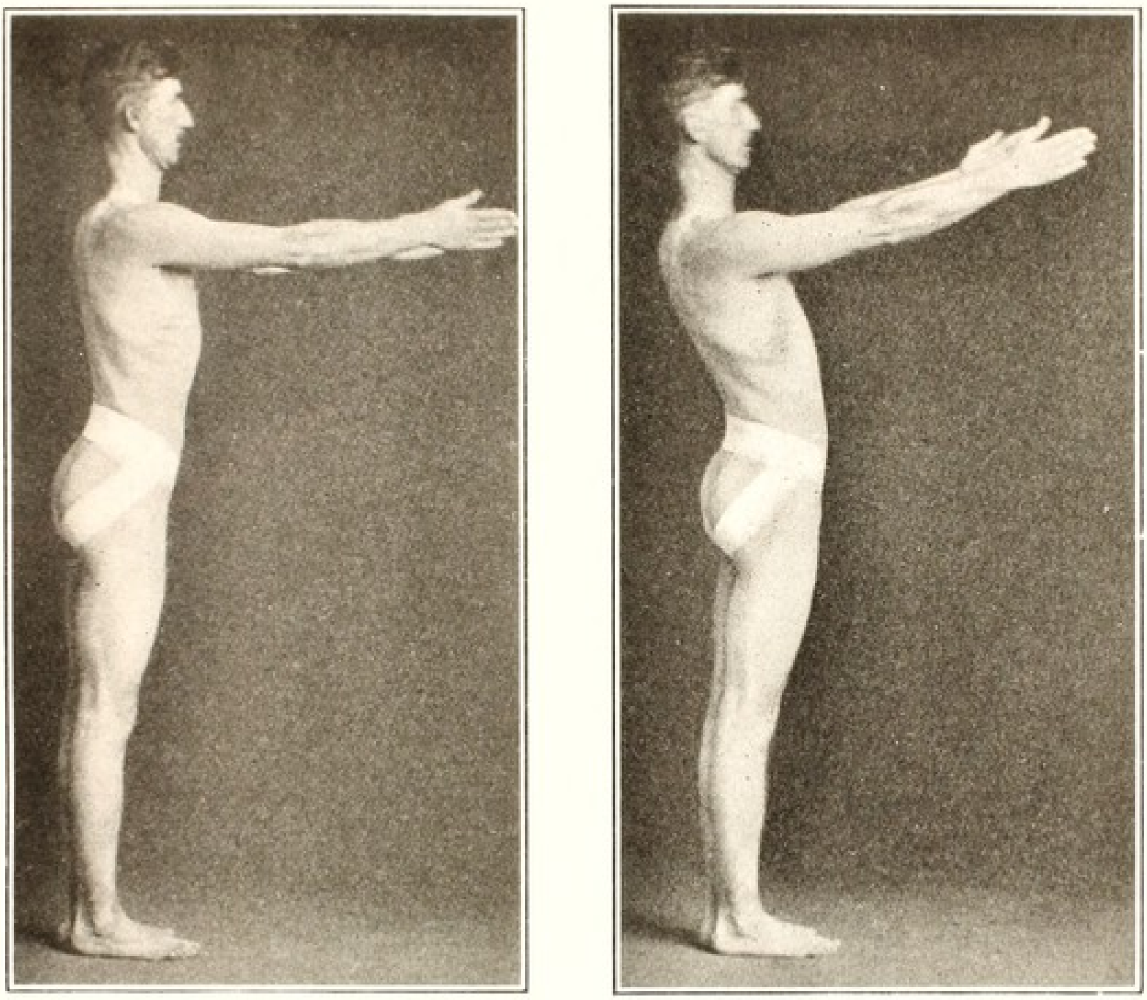

Fig. 165 Fig. 166

Figs. 165 and 166.—Action of trunk and limbs in raising arms forward. In Fig. 165 the extensors of trunk, hips and ankles are working; in Fig. 166 their work is lessened or entirely avoided by shifting the weight farther back.

Lifting.—The reinforcement of the muscles that raise the arm by those of the trunk and lower limbs is to be seen in all lifting movements, and the farther away from the body the arms are held and the heavier the lift, the stronger do these supporting muscles contract. Notice that the arm acts as a first-class lever, the vertebræ acting as fulcrum and the trunk muscles pulling down as the arm goes up.

When a weight is to be lifted to a position overhead, as in one familiar type of weight-lifting contests, the trunk is used as far as

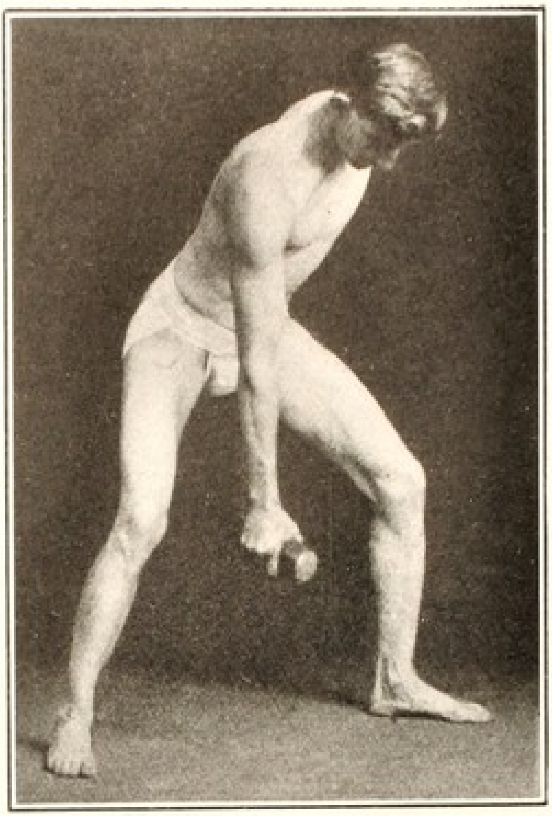

FIG. 167

FIG. 168

possible to aid the arms. Grasping the weight as it lies on the floor, it is brought to the first position (Fig. 167), by the action of the extensors of the trunk and limbs, the flexors of the hand and the trapezius also acting. To come to the next position, seen in Fig. 168, the trunk is raised with enough speed to give the weight a quick upward movement, making it easier for the biceps group to flex the elbow; then to finish the lift the trunk is quickly flexed to the left, the side pushing against the elbow and giving the weight another upward movement. This makes it possible for the triceps and the arm-raising group to bring the arm to the third position (Fig. 169).

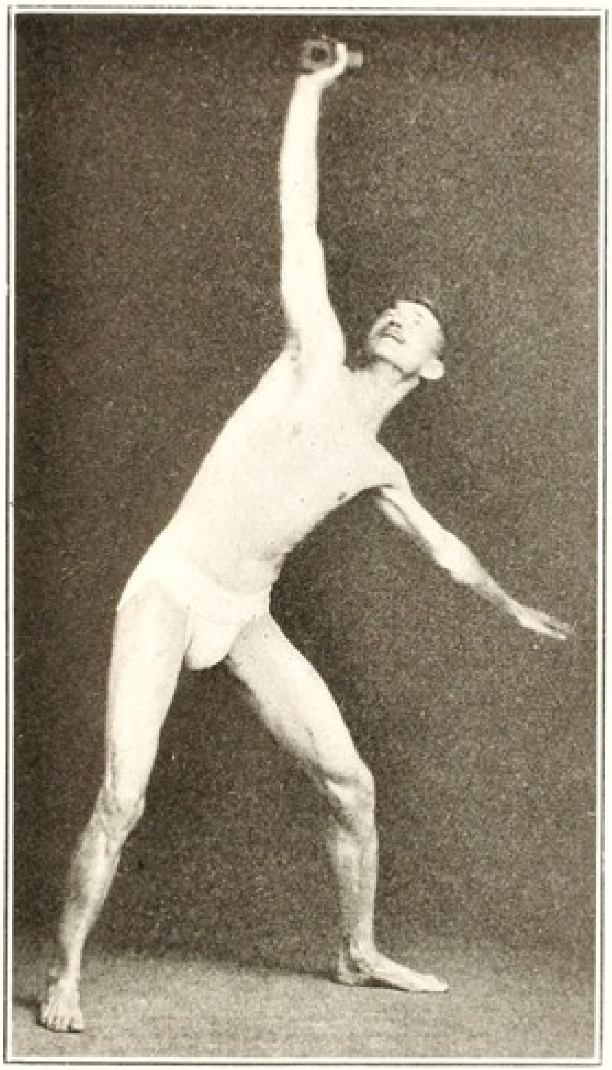

Fig. 169

Figs. 167, 168 and 169.—The three stages of lifting heavy weight in one hand.

Lifting is made easier, as we have seen, by shortening the weight arm of the lever, and more can be lifted with the elbows flexed, as in Fig. 149 than when they are fully extended, as in Figs. 165 and 166. But the extensors of the trunk and limbs are larger and stronger muscles than those of the arms and it is therefore easier to lift a weight by starting with these joints flexed and do the work by extending them instead of by moving the arms. By actual trial a person lifted 42 kilograms with arms as in Figs. 165 and 166, 68 kgs. in the position of Fig. 149, 120 kgs. in the position of Fig. 6 and 175 kgs. in the position of Fig. 95.

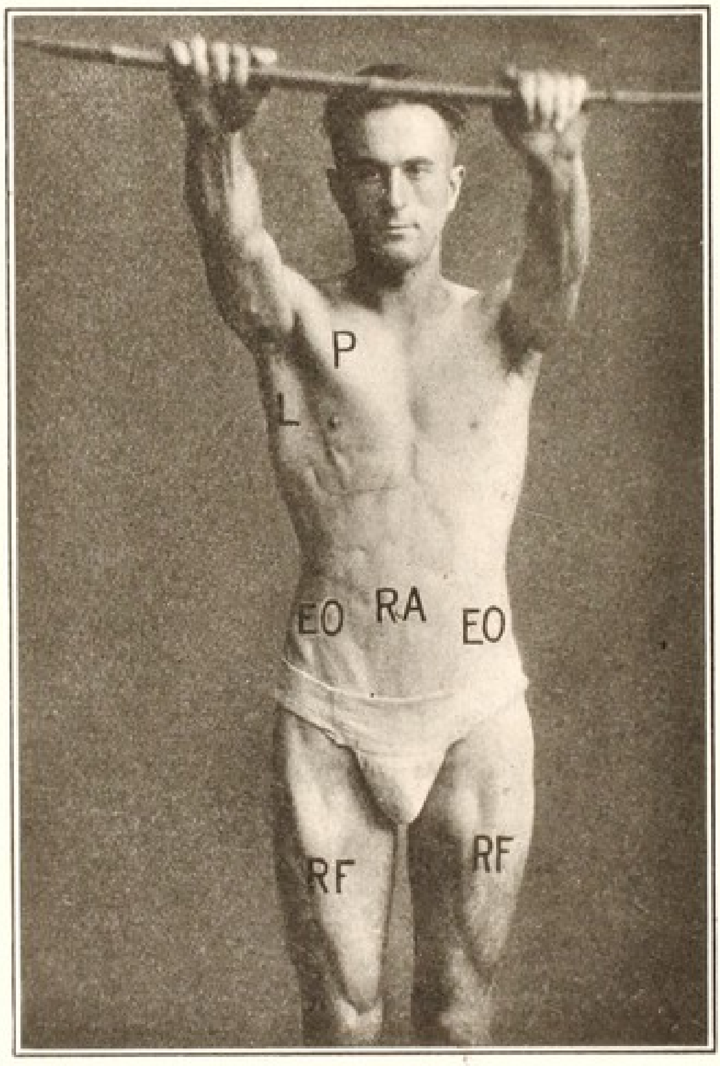

FIG. 170.—Action of trunk and limbs in arm depression: *RA*, rectus abdominis *EO*, external oblique; *RF*, rectus femoris; *P*, pectoral; *L*, latissimus.

Depressing the Arms.—Depression of the arms against resistance brings the trunk muscles into action in just as vigorous fashion as we have seen in lifting. Here the action of the arm needs to be reinforced by the contraction of the trunk muscles that are on the same side of the spinal column as the arm, the abdominal group working when the arm is forward and the muscles of the same side when it is sideward. In depressing the arms forcibly in the forward position the flexors of the hip also contract.

The action of the trunk muscles in this case can be felt in such movements as slow downward movement of the arm while the hand holds the handle of an overhead pulley or a chest pulley, but it is most noticeable in quick and forcible movements, like striking downward with a hammer or dumb-bell. The movements of the arms in climbing also show this effect on the trunk muscles. In all these movements the arms act like third-class levers, the fulcrum being at the spinal column and the trunk muscles acting on the same side of it as the resistance.

Pushing.—Pushing forward with one or both arms while the body is erect or nearly so calls the abdominal group and the flexors of the hips into action to assist the triceps, upper serratus and pectorals. The extensors of the trunk are fully relaxed in this movement, but by flexing the trunk and hips, bringing the body into a position more nearly horizontal and the arms more nearly in line with the trunk it is possible to bring the extensors of the hips and spine into action instead of the flexors. The latter position makes the movement the same as lifting overhead, with the arm-raising muscles acting and the reinforcement by the extensors of the trunk and limbs.

Throwing.—Throwing the *medicine ball* with both hands calls the muscles of the arms, trunk and limbs into strong action.

Throwing forward from between the knees brings in the elevators of the arms and extensors of spine, hips and knees. Throwing forward from over the head uses the arm depressors, flexors of trunk and hips and extensors of knees and ankles. Pushing it forward from the chest brings in the pushing muscles of the arms, flexors of spine and hips and extensors of knees and ankles. Throwing it backward over the head uses the elevators of the arms, extensors of hips and spine, with use of the abdominal muscles to recover erect position if one leans far back in the throw. A swinging throw with one arm uses the elbow flexors, pectorals and anterior deltoid, serratus, and rotators of trunk and hips to the side the ball goes. A throw backward between the knees uses arm depressors and flexors of trunk and hips.

Chest Weights.—Exercises on chest weights involve the action of the muscles of the trunk and lower limbs, which muscles will act depending chiefly on which side of the body is toward the machine. Arm movements of all kinds with the face toward the machine bring into action the extensors of the trunk and hips to resist the tendency of the arm movement to pull the body toward the machine. When the back is toward the machine it is the flexors of the trunk and hips that assist; when the side is toward the machine it is the muscles of the opposite side. In all positions the weights are pulling the body toward the machine and the muscles of the opposite side of the body are required to maintain erect position. This is characteristic of all movements of pulling in a horizontal direction or nearly so.

Standing Positions.—The fundamental standing position of gymnastics and military drill is like the ideal position previously described (Chapter XIV) except that it is more vigorous. It is considered a corrective exercise for all kinds of faulty postures and the muscles used in holding the body erect are brought into strong contraction with the object of increasing their strength and shortening them, at the same time stretching tissues that may have been shortened by faulty habits of posture and work. (Fig. 171).

The ankle-joints are slightly extended, lifting the heels or at least keeping all the body weight from resting on them, by action of the gastrocnemius, soleus, peroneus longus, and the smaller extensors of the foot. The knees are slightly overextended by contraction of the triceps of the thigh. The hip-joints are firmly extended by the hamstring group. The trunk is held vigorously erect by associated contraction of the back and abdominal muscles, the upper spine being extended more forcibly than the lower. The arms are held well back at the sides, shoulders adducted and chin not raised. The muscles of the right and left sides must be perfectly balanced to make the two halves of the body symmetrical.

Standing on one foot causes an increased tension of several trunk muscles because the balance is so unstable. In a vigorous balancing exercise the muscles on all sides of the waist are brought into strong contraction to hold the trunk firm and immovable.

When the free foot is carried well to the side not only is there strong contraction of the gluteus medius and minimus of both sides, as can easily be felt, but the trunk muscles contract to help. If the trunk is held erect, as the Swedish system requires (Fig. 97), the trunk muscles on the side of the free limb contract to hold the spine laterally flexed; if the trunk tips over in line with the free limb the same muscles act to sustain the weight of the trunk (Fig. 172).

When the free foot is raised toward the rear the hamstring group acts strongly on the side of the free foot but less strongly than normal on the supporting side, since the free limb by its weight helps to keep the supporting hip extended. In order to carry the leg far back much effort is required, which may bring into action the gluteus maximus. To carry the leg much to the rear of its fellow there must be a flexion of the supporting hip to allow the pelvis to tip forward, as the free hip cannot be but slightly overextended in normal subjects. If the trunk is at the same time held erect it must be accomplished by overextension of the lumbar spine by vigorous action of the erector spinæ, easy to observe either by feeling or sight.

When the free limb is raised forward or the knee raised forward with knee flexed, the abdominal muscles are not brought into strong action as one might expect and as many teachers suppose, because the hamstring group of the supporting limb is in strong action and this keeps the pelvis from being tilted forward by the weight of the raised limb. Indeed, if more force is needed to do this, those same hamstrings can do it by an increased contraction more easily than the abdominal muscles because they are usually so much stronger. Attention has already been called to the error so often made by teachers in giving leg-raising forward for development of the abdominal muscles. To bring these muscles into action at all in this movement the limb must be lifted vigorously with flexion of the pelvis on the trunk and slight flexion of the supporting knee. This flattens the back, stretches the hamstring muscles and tends

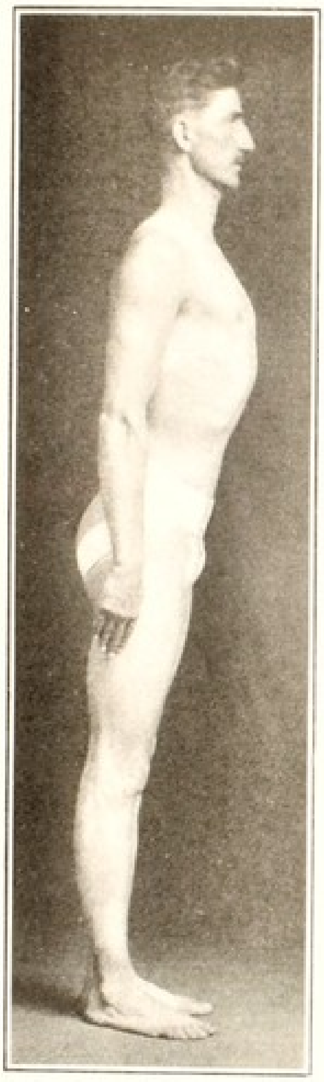

FIG. 171.—Gymnastic standing position.

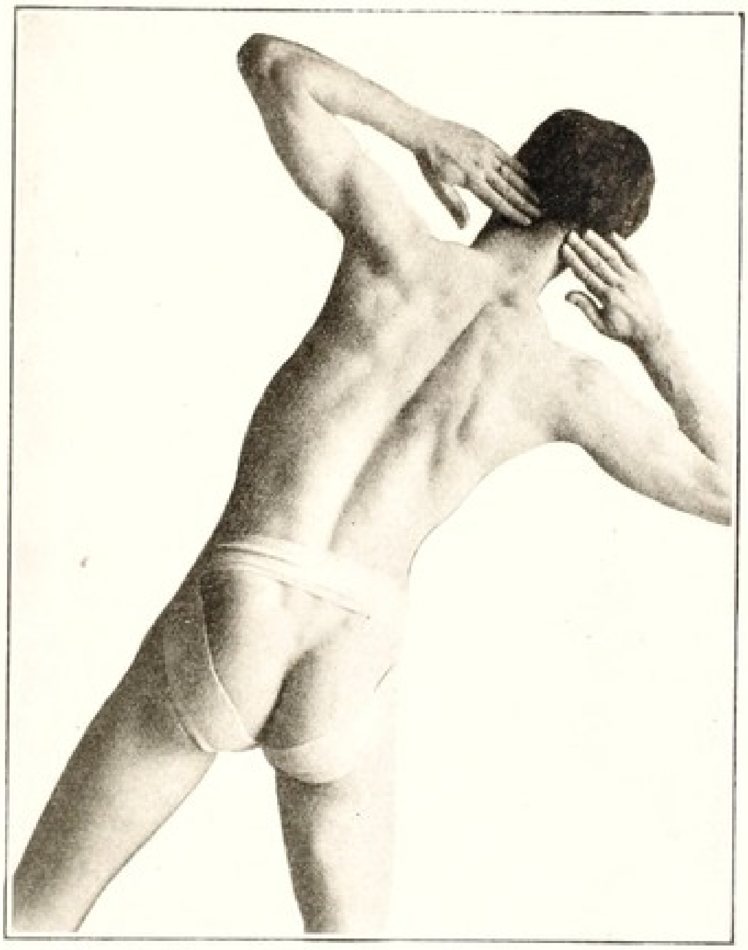

FIG. 172.—Raising one leg sideward while standing on one foot.

to put the performer in the gorilla type of posture. If the spine is held strongly extended the effort tends to inhibit the abdominal muscles, which are antagonists of the extensors of the trunk. Lifting the flexed knee high up in front is excellent work for the flexors of the hip, but it cannot be lifted high enough to bring in the abdominal group without doing more harm than good to the posture, as long as the other limb is supporting the weight. If the body is tossed in the air as in hopping or running, the lifting of the knee calls the abdominal group into action to support the front of the pelvis.

Sideward Stride.—The sideward stride position to right is taken by first contracting the left gluteus medius and minimus and the left erector spinæ and quadratus lumborum to raise the right side of the pelvis and free the right foot from supporting weight; then abduction of both hip-joints by the gluteus medius and minimus of both sides and a relaxation of the trunk muscles contracted at first to bring the trunk to erect position on the new base. The sideward stride position braces the body for lateral movements and lessens any balance problem involved; this is important in bending sideward, especially when working against resistance, as in using pulley machines with side toward machine and in wide side bendings with arms high and a weight in the hands.

In sideward bending of the trunk, which has been described and explained, the work of the muscles is made greater by raising the arms, because it raises the center of gravity and hence lengthens the weight arm of the lever and also because raising the arm puts a tension on the latissimus, which must be elongated by a side bending, the tension caused by the arm raising stretching it still farther and requiring more force to make a complete lateral flexion.

Forward Stride.—The forward stride is executed by partial flexion of hip and knee on the moving side together with strong contraction of the abductors and hamstring group of the supporting side and slight overextension of the lumbar spine by contraction of both erectors spinæ. The inclination of the rear limb tips the pelvis and necessitates hollowing the back a little unless the iliofemoral ligaments are lax. The forward stride position braces the body and eliminates balance difficulties in exercises of pushing and pulling and bending forward and backward. It is useful in teaching beginners arch flexions, neck firm and arms upward, the elimination of the balance problem aiding in the coördination to avoid overextension of the lumbar spine. It is not used in inclining trunk forward from the hips because the inclination of the forward foot increases the tension on the hamstrings and prevents tilting the trunk on the hip-joints—the sideward stride being a better starting position for forward bendings for this reason, unless the nature of the movement will allow flexion of the forward knee to slacken the hamstrings. Forward stride position favors twisting the hips toward the side of the rear foot and hinders it in the opposite direction, so that where an extensive twisting movement to the left is wanted, as in throwing and striking with the right arm, the right foot is placed forward. In twisting trunk to left as a gymnastic movement, where it is desired to eliminate twisting in the hips, the left foot is placed forward.

Raising of the arms increases the work of forward bendings of the trunk by raising the center of gravity and thus lengthening the weight arm of the lever. The tension that arm raising puts on the latissimus may or may not affect the work, depending on the form of the exercise.

In ordinary walking the trunk inclines slightly forward, the inclination increasing with the speed. This throws the weight of the trunk on the back muscles and the erector spinæ can be readily felt in contraction, the muscle on the side of the forward foot coming into action with each step. If one inclines the trunk backward, as one is inclined to do when walking in the dark, so as to feel his way and avoid stumbling, the abdominal muscles act in a similar manner.

In a moderate walk the arms seem to swing passively, no action of the pectoral or latissimus being apparent and the arm seeming to lag behind as one side and the other swings forward in alternation. In brisk walking the swing is active and the action of the muscles can be felt as it swings. The latissimus may act with the erector spinæ and swing the arm.

As shown in Fig. 99, the hips swing forward considerbaly in alternation, especially in walking with a long stride, but the shoulders of a graceful walker do not swing nearly so much, and this involves a twisting of the trunk with each stride, partly brought about by the swing of the arms and partly by the oblique muscles. The muscles on the sides of the abdomen seem to be in mild contraction in vigorous walking, but one would not expect to feel rhythmic contractions and relaxations, since the external of one side works as the hip goes forward and the internal of the same side as it swings back, making the action continuous.

In running we have a more vigorous movement, but during the time that the weight is supported by one foot (about three-fourths of the time) the action as regards the arms and trunk is the same as in walking, with a little greater intensity due to the spring from the ground and to the shock of alighting. While the body is unsupported there is ordinarily little for the flexors or extensors of the trunk to do, unless the limbs are raised forward or backward farther than in the reverse direction. In such a case work is thrown on the abdominal muscles if they are lifted high up in front and on the extensors if raised high at the rear.

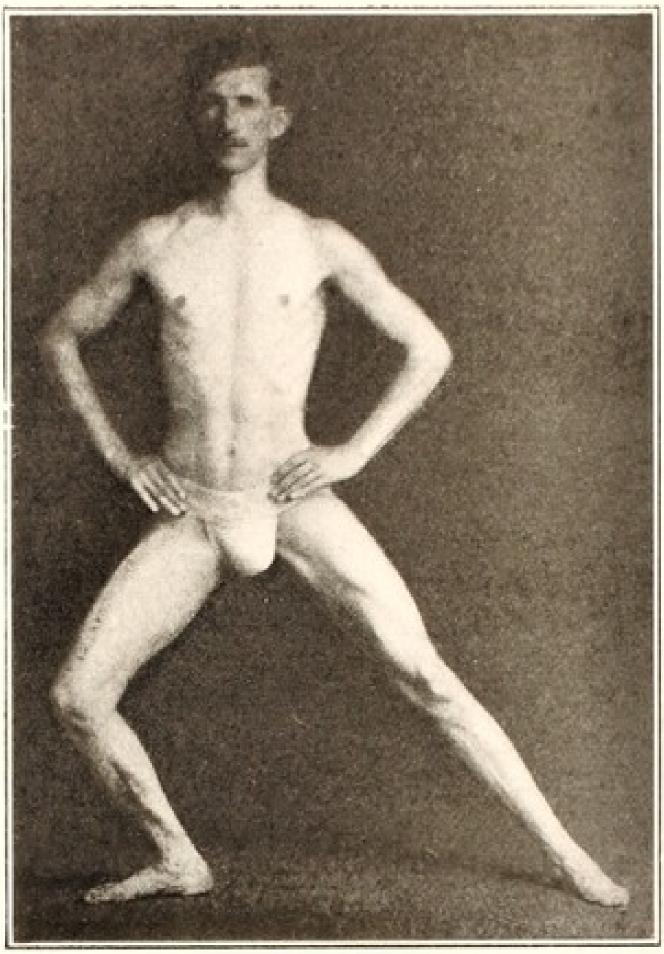

FIG 173

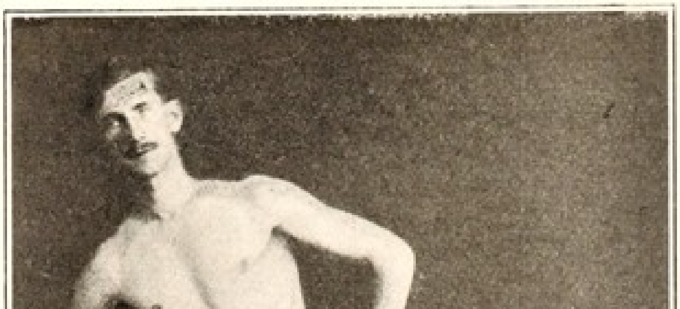

FIG. 174

FIGS. 173 and 174.—The sideward lunge and fallout.

Lunge and Fallout.—The forward lunge and fallout are gymnastic positions in which the foot is placed forward a long stride and the forward knee flexed until it is vertically above the toes. The posi-

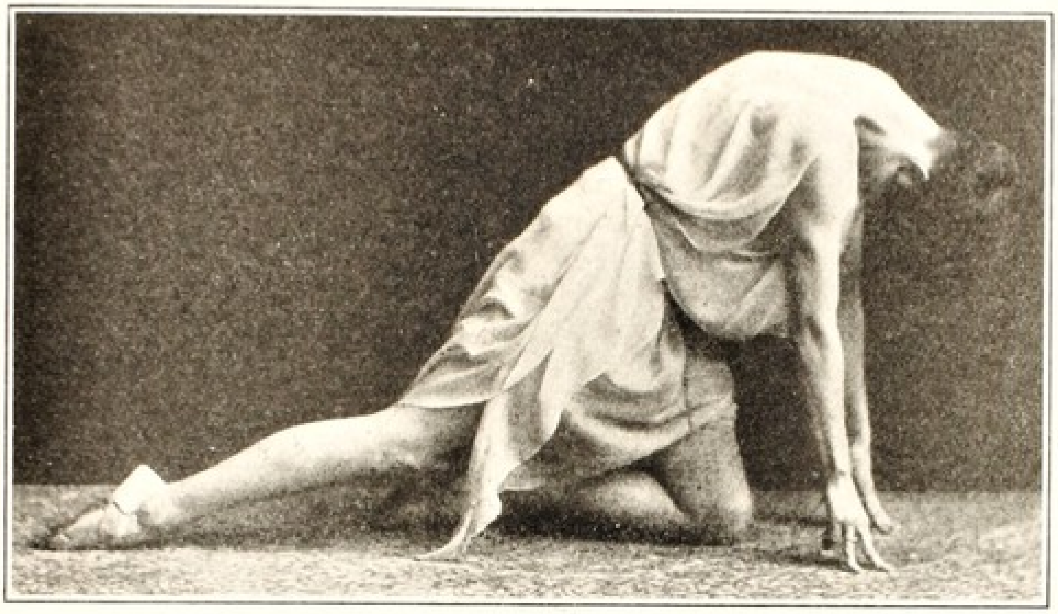

FIG. 175

FIG. 176

tion puts nearly all the body weight on the flexed limb, the extensors of the forward hip, knee and ankle being used. In the fallout the trunk is held in line with the rear limb, which calls the extensors of the spine into action to sustain its weight. The lunge differs from the fallout in holding the trunk erect, which lessens the work of the front limb and overextends the lumbar spine, since the inclined rear limb keeps the pelvis tilted forward at a large angle. This makes the fallout preferable for posture training, unless the pupils have flat backs and need special practice in hollowing the back at the waist line.

The lunge and fallout are taken sideward as well as forward. The action of leg muscles is about the same as in the forward movements. In the sideward movement the free abduction that is possible in the hip makes it possible to hold the pelvis level, eliminating the trunk bending that the forward lunge involves. In the sideward fallout the weight of the trunk is thrown on the muscles of the upper side. With elevation of arms and bending toward the flexed limb this position gives opportunity for strong work of the lateral flexors of the trunk.

Fig. 177

Figs. 175, 176 and 177.—Action in natural dancing. Stages of the progressive forward crawl. (Photographs furnished by Miss Donnabel Keys.)

The lunge and fallout can also be taken at any angle between forward and sideward. It should be observed that in these movements the face and shoulders are always turned in the direction

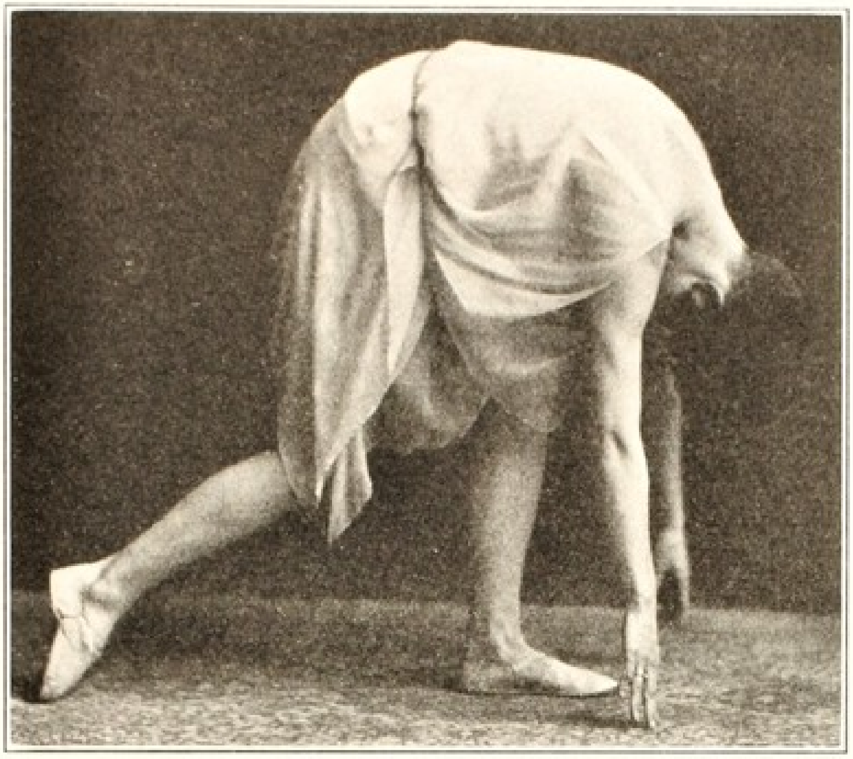

Fig. 178

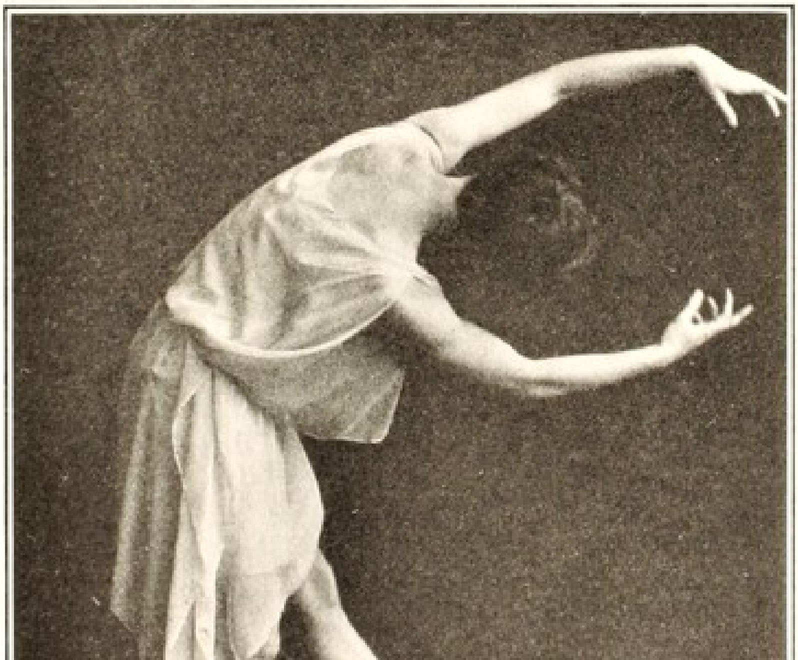

Fig. 179

they had before starting. If the body is turned in the direction the foot is placed the mechanism will always be like the forward movement. In the diagonal fallouts the weight is thrown on the muscles on the side of the trunk that is uppermost.

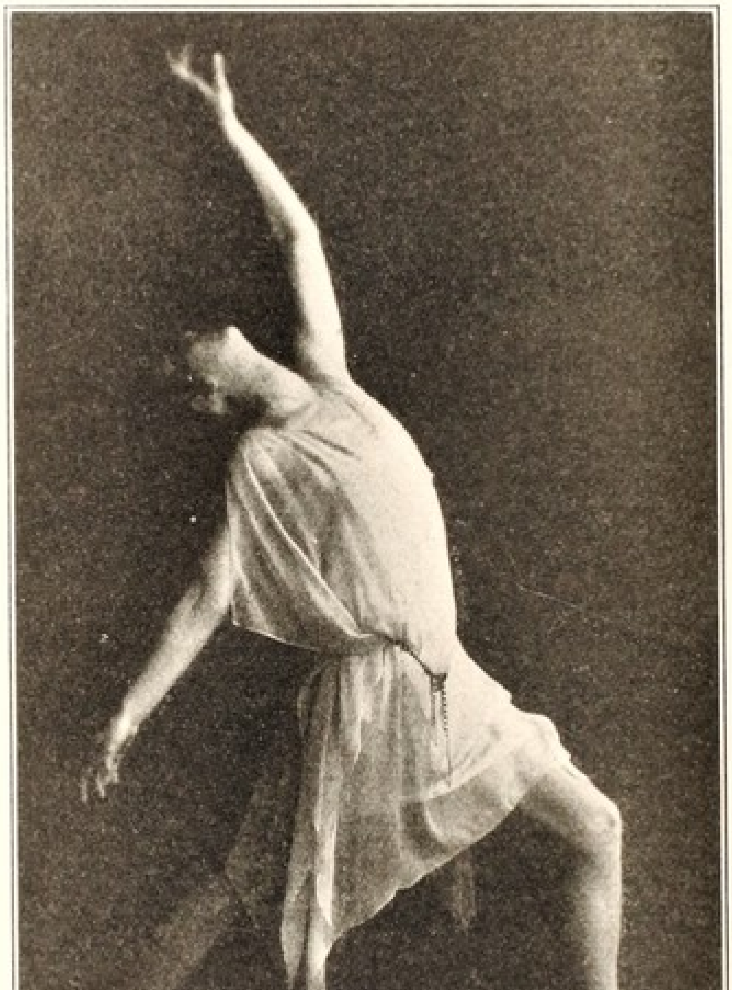

Fig. 180

Figs. 178, 179 and 180.—Action in natural dancing. Stages of unfolding, with the base wide. (Photographs furnished by Miss Donnabel Keys.)

Gymnastic Dancing.—Gymnastic dancing includes a great variety of movements on the feet and involves leaping, poising, hopping and bending. It brings into action the extensors of the ankles, knees, hips and spine strongly and the flexors of the limbs and trunk moderately, with mild action of the arm-raising muscles. The abductors of the hip-joints are strongly developed by the emphasis placed on poising and alighting on one foot.

Prone Falling.—The prone fall or leaning rest position, shown in Fig. 132, supports the body by the arms and toes in nearly horizontal position. The weight pulls down on the head, requiring action of the extensors of the upper spine to keep it in position, and tends to make the body sag in the middle, requiring strong action of the flexors of lumbar spine and hips and slight action of the extensors of the knees. The action of the arms is the same as in a typical exercise of pushing. Flexion and extension of the arms while in the position is strong work for the pushing muscles and is done most easily with the fingers pointing somewhat inward, which turns the elbows out at right angles to the trunk and enables the whole pectoralis major to work (Fig. 48). The work can be made easier when desired by allowing the knees to rest on the floor or by placing the hands on an object above the floor.

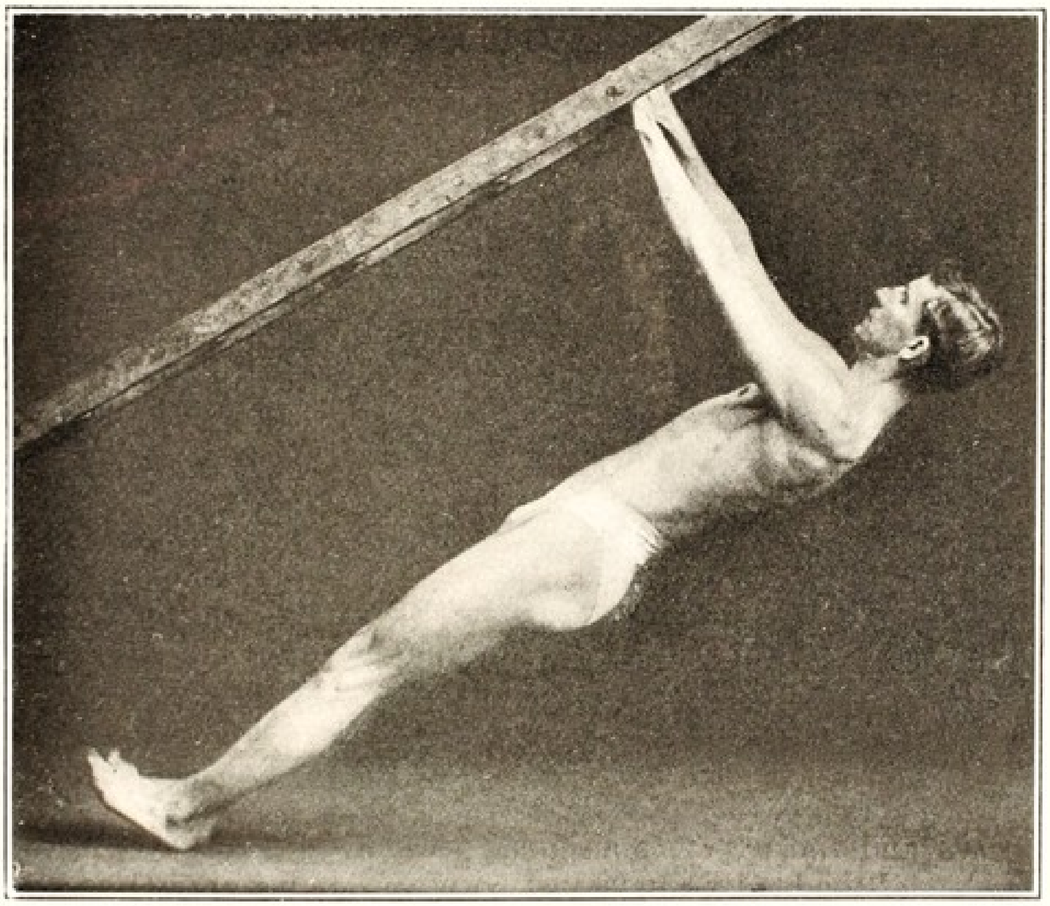

Fig. 181.—The fall hang or leaning hang position.

Fall Hanging.—The fall hanging or leaning hang position, shown in Fig. 181, requires work of exactly the opposite sets of muscles—flexors of neck, extensors of lumbar spine and hips, and pulling muscles. This, too, can be made lighter work by increasing the slant of the body.

Side Falling.—The side falling or side leaning rest position, in which the body is straight and supported by one arm, the side being toward the floor, calls into action the muscles on the lower side of the body and the upper side of the neck as in the two preceding exercises. The lateral flexors of the waist region and abductors of lower hip, which may be assisted by the adductors of the upper hip, keep the body straight. The triceps and upper serratus do most of the pushing, while several of the muscles about the shoulder work more mildly to keep the body balanced on the arm.

Side Holding.—The side holding or side leaning hang position is taken beneath a ladder or similar support and resembles Fig. 181 except that the weight is sustained by one arm, the body being turned 90 degrees, so that one side is downward; it involves the pulling muscles of the arm, muscles of upper side of neck and lower side of body, as before.

Exercises in which the weight of the body is supported by the hands, like hanging by the hands from bars or rings (Fig. 76), cross rest on the parallel bars (Fig. 77), and front rest on the horizontal bar, do not involve any work of the trunk or lower limbs if one simply supports his weight the easiest way; but it is usual in those exercises to adduct the scapulæ and to fully extend the spine, hips, knees and ankles. Most gymnasts know no reason for doing this except that it is recognized everywhere as "good form;" yet there is a good reason.

All movements of suspension and of arm depression tend to chest expansion through the upward pull on the ribs by the pectoral muscles, unless the movement involves the action of the abdominal muscles, which hold the ribs down. The vigorous extension of the upper spine tends itself to expand the chest, and the vigorous extension of the lower spine brings about an inhibition of the abdominal muscles, lowering their tone below that of the resting condition and hence interfering to the least possible extent with elevation of the ribs. Extension of the hips is helpful because any flexion of the hips will require action of the abdominal muscles to hold the pelvis up.

Strong action of the pectorals always tends to draw the shoulders forward and the upper spine along with it, and for this reason exercises of the kind we have just been considering are not considered good for anyone unless he is able to hold his shoulders back and spine extended while doing them.

ACROBATIC WORK OR TUMBLING

Elementary acrobatic work or tumbling brings in strong action of many muscles.

The **forward roll** begins by passive flexion of the lower limbs and the spine by a lengthening contraction of all the extensor muscles, and placing the hands firmly on the floor close in front of the feet. In this position a circle 2 feet in diameter will nearly coincide with the back, and the hands and feet will also be on its circumference (Fig. 182). Now a quick extension of the ankles throws the whole weight of the body on the hands and the arms support it momentarily by a forward and upward push; then the roll continues, first the back of the head touching the mat, then the neck, back (Fig. 183) and hips in turn, the momentum soon bringing the feet to the floor again (Fig. 184). As soon as the middle of the back comes to the floor the flexors of spine and limbs must come into action or the weight of the separate parts will extend them and the movement will finish with the gymnast lying at full length on his back. The body must be held in complete flexion by action of the flexor muscles until the feet come to the floor again and then the extensors must work in turn, the movement finishing in standing position. By a strong push by the arms at the right time the head can be kept from touching the mat.

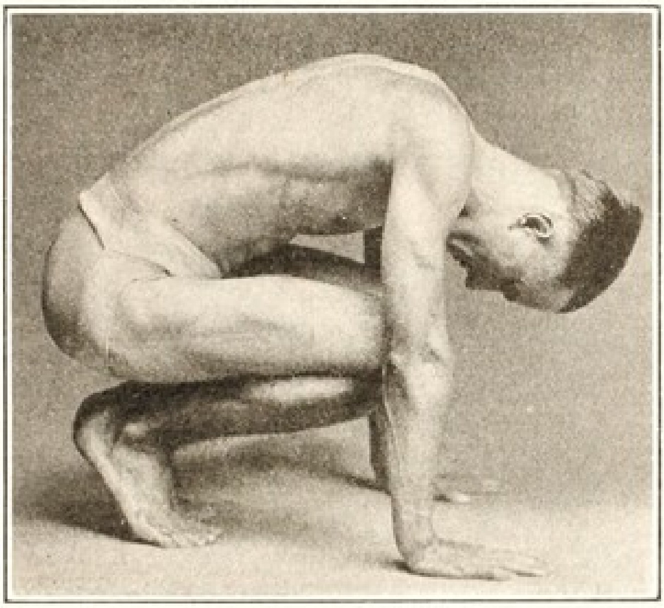

FIG. 182.—The forward roll. Starting position.

By practise of this simple movement one who is strong enough, as soon as he has learned the coördination of the push with the hands, the full flexion of the body and then its full extension, can undertake the *long* or *high dive*, in which the body is launched into the air head first by a forcible extension of the limbs, touches the mat first with the hands, and completes the movement as in the forward roll. The muscular action is the same but much more vigorous, the arms having to sustain more weight to protect the head from striking too hard and the speed of the movement making it more difficult to flex the body soon enough.

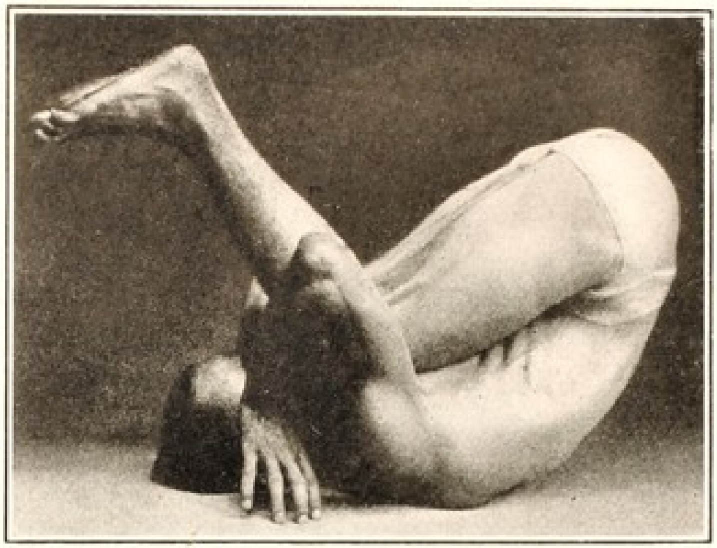

FIG. 183.—The forward roll. Midway.

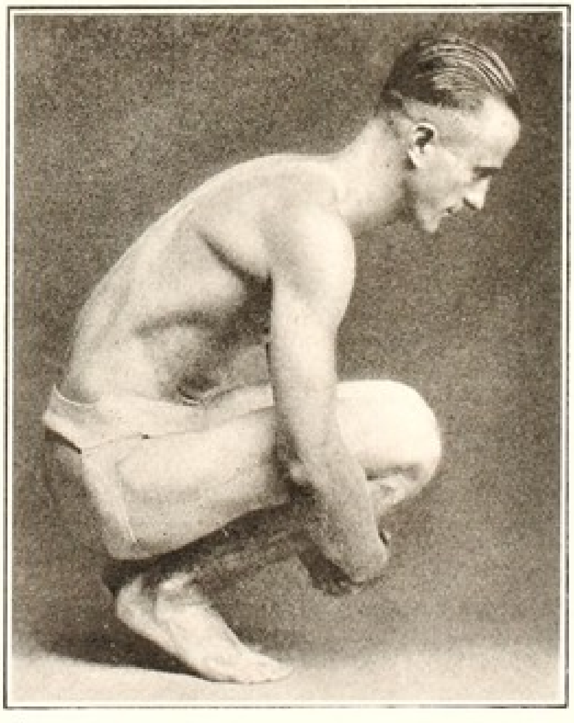

FIG. 184.—The forward roll. The finish.

The **front summersault** is a variation of the high dive. The gymnast springs high into the air and then suddenly flexes his whole body into the position it takes in the forward roll. To do this in the air and to do it quickly enough calls for a very sudden and strong action of the flexor muscles of trunk and limbs, beginning with a violent downward swing of the arms. The body turns completely over in the air and at exactly the right time the extensors act and support it in normal position on the feet.

The **backward roll** reverses the movement of the forward roll. The body is quickly flexed to the circular position described above (Fig. 184) and tipped strongly backward to give momentum, with the hands held back over the shoulders at each side of the head. The back strikes the mat first and the body rolls (Fig. 183) backward on to the shoulders, neck and head, the arms pushing backward and keeping the weight from bearing too heavily on the head. This stage calls for strong action of the flexors of the entire spine and limbs, to maintain the flexed position, and strong arm elevation with flexed elbows to support most of the weight. The arms bear practically all the weight for a moment and then as the roll continues the feet come to the mat and the body rises to erect position. It is difficult for beginners to strongly elevate the arms and strongly flex the trunk and limbs at the same time, but as soon as this coördination is mastered the backward roll is little harder than the forward roll.

The **backward summersault** is a more difficult variation of the backward roll. The gymnast springs strongly into the air, at the same time swinging his arms strongly upward and backward and overextending his spine. As soon as his feet leave the mat the limbs are strongly and quickly flexed and then the trunk is completely flexed. If the flexion of limbs and spine can be done quickly enough the body makes a complete turn in the air and the gymnast alights on his feet.

The **back handspring** is a slight variation from the summersault. The difference is that the jump is not quite so high and the arms are partly extended as the head is downward, the weight rests momentarily on the hands and the movement finishes as in the back roll.

The forward and backward rolls are taken on the parallel bars with almost the same muscular action as on the mat, and a number of pleasing variations are there possible. The backward roll is an especially strong abdominal exercise.

In **circling the horizontal bar** the gymnast first hangs by his hands, lifts his weight by flexors of elbow and arm depressors, and then by flexion of trunk and limbs and still stronger arm depression he raises his knees over the bar; by this time the trunk is curved and the center of gravity is so nearly above the shoulder-joint that further arm depression is possible, sliding the thighs over the bar to the hips; now the weight is so nearly balanced on the bar that by flexion of the wrists one can raise the trunk and lower the limbs,

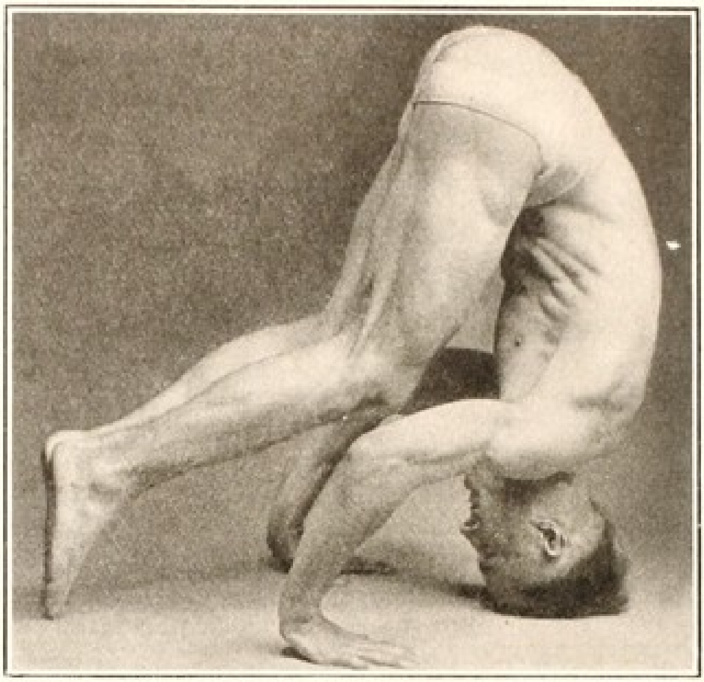

FIG. 185

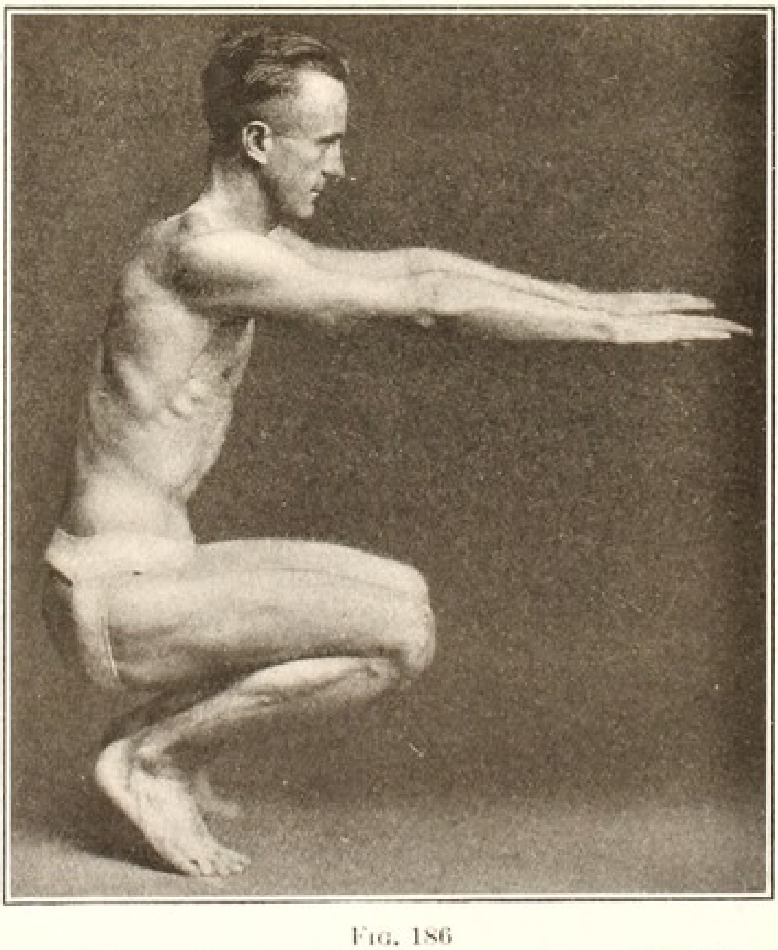

FIG. 186

FIGS. 185 and 186.—The headspring. Start and finish.

the knees having been extended to aid in the process. As soon as the center of gravity has been transferred to the side of the bar where the feet are, the spine can be extended, which brings the body to the rest position on the bar.

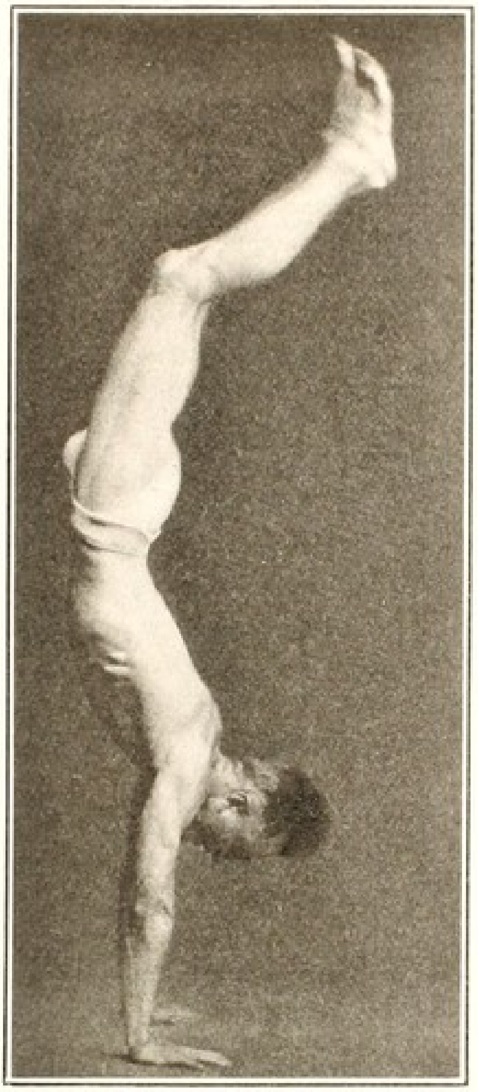

Fig. 187.—The handstand.

The **headstand** is begun like the forward roll, but when the hands have been placed upon the mat the head is extended and placed on the mat a foot or thereabouts in front of the hands. Using the head and the hands as the three legs of a stool the gymnast, by careful extension of his elbows and of his spine, lifts his limbs vertically into the air. Although much of the body weight must be borne by the arms, the latter must gradually flex more and more as the hips and spine extend so as to keep the balance. The extensors of the arms and of the spine and limbs have the work to do in this exercise, for as soon as the weight is carried far enough back to call the abdominal muscles into action the balance is lost.

The **headspring** begins like the headstand. The body weight should be balanced on the head and hands with hips fully flexed and knees nearly straight (Fig. 185). When this position is gained the elbows should be gradually extended by action of the triceps until the body begins to fall backward. A sudden and strong extension of arms, trunk and hips should now be made by use of all the extensor muscles, projecting the body into the air feet first, in a direction diagonally upward and backward. If this is followed by a quick flexion of trunk and limbs the body will turn enough to come to the mat with head up and feet on the mat, and erect position can be gained by use of the extensor muscles again (Fig. 186).

The **handspring** resembles the headspring but is taken with arms extended up at vertical position beside the head. A run is usually needed to give the required momentum for turning completely over. Ending the run by bending completely at the hips and with the hands on the floor, with a jump as in any running jump the body is fully extended with enough momentum to project it into the air and this is followed by a strong push with the hands. Until the coördination is learned it is usually necessary to flex the limbs and spine to gain a position on the feet, but with skill the finish can be made standing fully erect. The same alternate use of the flexors and extensors of the trunk and limbs is here combined with strong work of the arm-raising muscles, triceps, and extensors of the wrist.

The **handstand** is begun like the handspring except that it is taken from standing position without a run and is started slowly and carefully. With hands on the floor as far apart as the shoulders and close to the feet, the body is lifted by a spring from the feet and extension of hips and spine. To get into balance is the main difficulty here, and to do it the head should be held far back and neck and spine overextended. The work is practically the same as that done when one stands on his feet and holds a weight overhead, the difference being in the lessened action of the extensors of knees and ankles. (Fig. 187.)

The **snap-up** or spring from the shoulders starts with the back on the mat and the limbs and spine flexed as in the midposition of the backward roll (Fig. 183). When the weight reaches the point of balance on the hands and shoulders a strong extension of all the joints is made, finishing as in the headspring. When good control of the extensors of trunk and limbs has been gained this can be done with the arms folded.

SUGGESTED FORM OF CHART FOR ANALYSIS OF BODILY MOVEMENTS.

				Number of exercises.				
				1	2	3	4	5
Hand	Flexion		R	*	*			
			L	*	*			
	Extension		R					
			L					
Forearm	Pronation		R					
			L					
	Supination		R					
			L					
Elbow	Flexion		R					
			L					
	Extension		R	*				
			L	*				
Humerus	Elev. S.		R					
			L					
	Elev. F.		R					
			L					
	Depression		R					
			L					
Scapula	Abduction		R	*				
			L	*				
	Adduction		R					
			L					
	Rotation	Up	R					
			L					
		Down	R					
			L					
Trunk	Flexion			*				
	Extension							
	Lat. flex.		R					
			L		*			
	Rotation		R					
			L					
Hip	Flexion		R	*				
			L	*				
	Extension		R		*			
			L		*			
	Abduction		R					
			L					
	Adduction		R					
			L					
	Rotation	In	R					
			L					
		Out	R					
			L					
Knee	Flexion		R					
			L					
	Extension		R	*	*			
			L	*	*			
Ankle	Flexion		R					
			L					
	Extension		R		*			
			L					

Exercise No. 1, prone falling (page 225, Fig. 132).
Exercise No. 2, side fallout (page 294, Fig. 174).

QUESTIONS AND EXERCISES.

1. Demonstrate the difference between fallout, charge and lunge, and explain the difference in the action of the trunk muscles.

2. What muscles are brought into action most strongly by balancing across a horizontal bar, face upward, body and lower limbs in a straight line?

3. Point out the places in the front roll-over where the action changes, one set of muscles relaxing and another acting instead.

4. Explain how the back roll-over calls for different muscles than front roll-over.

5. In what part of the headspring is the back most used? The abdominal muscles? The arms? The legs?

6. What muscle groups help in the pull-up and not in the push-up? In the push-up and not in the pull-up? Which are used alike in both tests? See Figs. 76, 77, 132 and 163.

7. When a pupil is unable to circle the horizontal bar by grasping it with the hands and putting the feet and limbs up over it, what exercises on pulley machines will help to prepare him for it? What particular muscle groups are most apt to be at fault?

8. What muscle groups are most used in the exercises of Figs. 173 and 174? How does the mechanism differ?

9. Show a dancing position that will develop the right erector spinæ; the left external oblique; the external rotators of the hip.

10. Mention an exercise on the vaulting horse that will develop the abdominal muscles; the back muscles; the lateral trunk muscles; the arm depressors; the arm elevators; the biceps; the triceps.

CHAPTER XVI.

PLAYS, GAMES AND SPORTS.

We can class all the bodily movements found here into two main groups: locomotion and the handling of objects. The handling of objects involves pushing and pulling, catching and throwing, striking and kicking. Pushing and pulling have been explained. Catching involves action of the flexors of the fingers, hands or arms, together with other movements not definite enough to be described or explained readily. Throwing, in the general sense in which it is used here, includes all such movements as tossing, pitching quoits, bowling, throwing a ball or stone, putting the shot and throwing the hammer.

Tossing.—Tossing is done by a forward swing of the arm, which hangs down by the side, the ball or other object being released near the end of the swing. When the purpose of the play calls for a toss to a considerable distance the movement is apt to start with one foot advanced and the trunk and lower limbs somewhat flexed; as the toss is made there is quick extension of all these joints to add to the force of the toss. The arm-raising muscles and the extensors of the trunk and lower limbs do the work, the flexors of the elbow assisting in some cases.

Pitching.—Pitching quoits and bowling employ exactly this form of toss, with a quick extension of spine, hips, knees and ankles to add force to the swing of the arm. Bowling requires a little more power, and this is gained by taking two or three quick running steps just before the toss is made. Tossing differs from other forms of throwing in the absence of rotation of the body around a vertical axis; this makes it milder than the others.

Throwing.—In throwing a ball or stone, the arm movement of which has been explained in Chapter VI, the problem of the thrower is to combine accuracy of aim with the greatest possible speed. To gain the latter the arm movement is reinforced by a forward movement of the body combined with a rotation around a vertical axis.

In preparing to throw, when distance or speed is important, the foot of the throwing side is placed well back and the body tilted far back by flexion of the limb, with the opposite arm held forward in the direction of the throw. In preparing to throw with the right hand the trunk is turned far toward the right by the rotators of

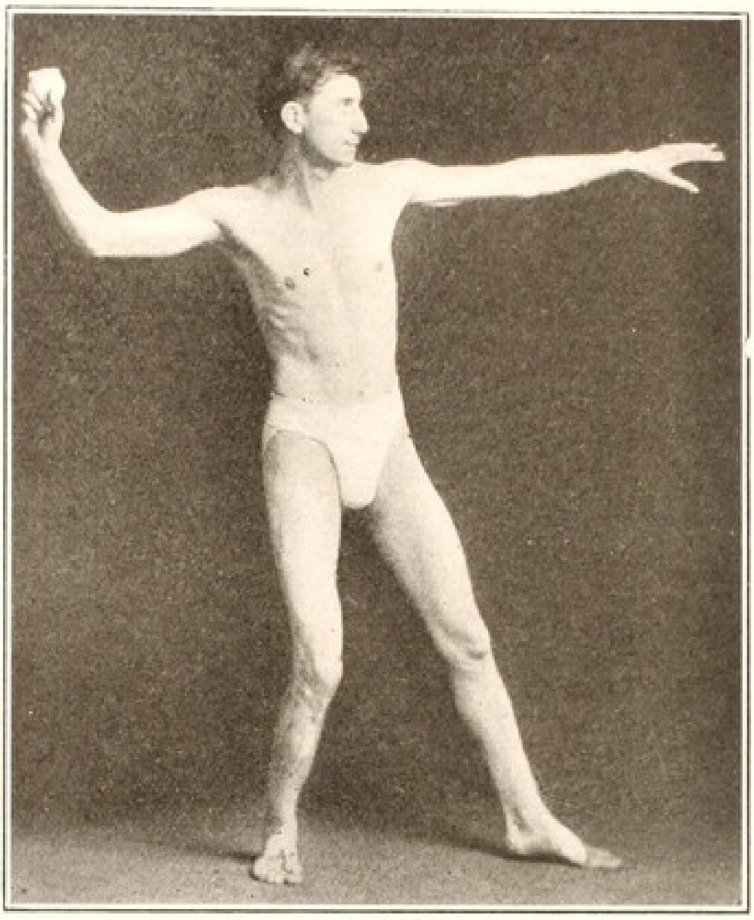

FIG. 188

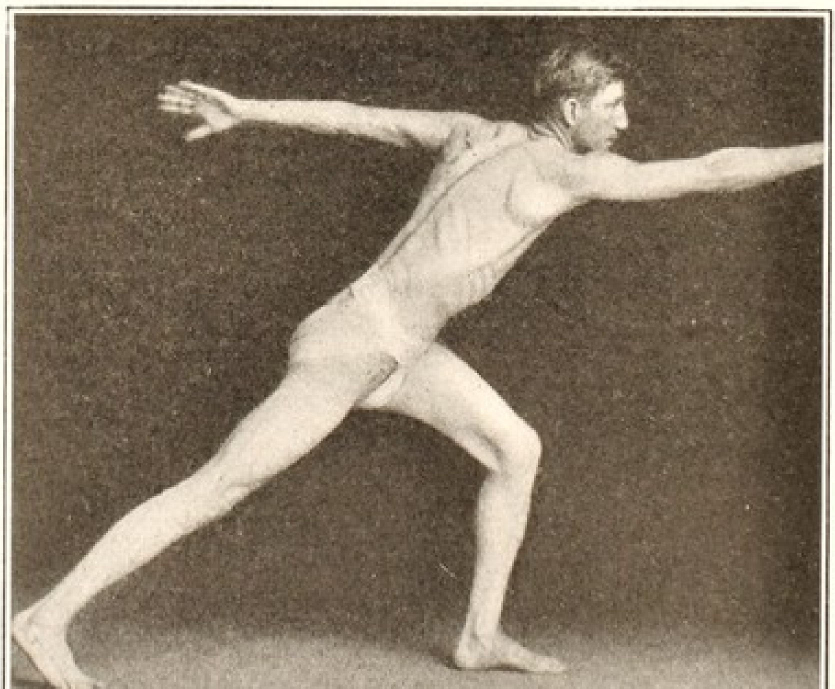

FIG. 189

FIGS. 188 and 189.—Action of the whole body in throwing the spine and by rotating the right hip inward and the left hip outward. Then, as the arm goes forward the body is inclined quickly in the same direction by a vigorous contraction of the extensors of the right hip, knee and ankle and the flexors of the spine, and at the same time it is swung quickly to left on its vertical axis by the oblique muscles of the trunk, reinforced by strong action of the outward rotators of the right hip and inward rotators of the left, and by a violent backward swing of the left arm. This action of the body almost doubles the distance the ball travels in the time it is being moved forward by the arm and consequently nearly doubles the speed with which it leaves the hand.

A ball is made to curve as it passes through the air by giving it whirling motion on an axis at right angles to its line of flight, or nearly so. The rapid rotary movement of the ball causes greater air friction on the front and one side of it than on the other side, and this friction acts to turn it slightly out of its course. One can remember which way it will go by recalling that the side of the ball that rotates toward the thrower will have least friction with the air and therefore the ball will turn that way. When the lower side of the ball spins toward the thrower it will have a "drop" curve; when the top turns toward the thrower it will have a rising curve if there is sufficient speed and spin, for of course it takes more air friction to move a ball upward than it does to turn it any other way. When the right side of the ball turns toward the thrower it gives the "inshoot" and the opposite the "out curve." The out and in curves show a combined motion sideward and downward which forms a spiral path for a short distance.

The spin that produces the curving of the ball from its path is given by the manner of releasing the ball from the hand. The drop and out curves are usually made with the ball held between the thumb on one side and the fingers on the other, releasing it so that it will roll off the thumb side of the forefinger by quickly extending the thumb and thus removing its pressure on the ball. If this is done while the fingers are in a horizontal position, thumb upward, the ball will make the drop curve; if the fingers are pointing upward, knuckles down, it will give the "out." The inshoot and rising curve are given by making the ball roll off the ends of the fingers, the direction of the curve depending, as before, on the way the hand is turned when the ball is released. A ball released in the latter way is apt to have more speed and less curve than in case of the drop and the out curve.

In the game of cricket the act of throwing the ball to the batsman is called "bowling" instead of the American term "pitching," and the bowler is not allowed to flex or extend his elbow in making the throw. This, as it is intended, limits the speed and accuracy of the throw but it does not prevent the throwing of curves. Since the ball must be released while it is moving in the arc of a circle instead of a straight line it requires a greater degree of skill to throw with the same accuracy and this puts a limit on the speed one can attain. The bowler, however, is not required to throw the ball within so narrow a limit as the pitcher.

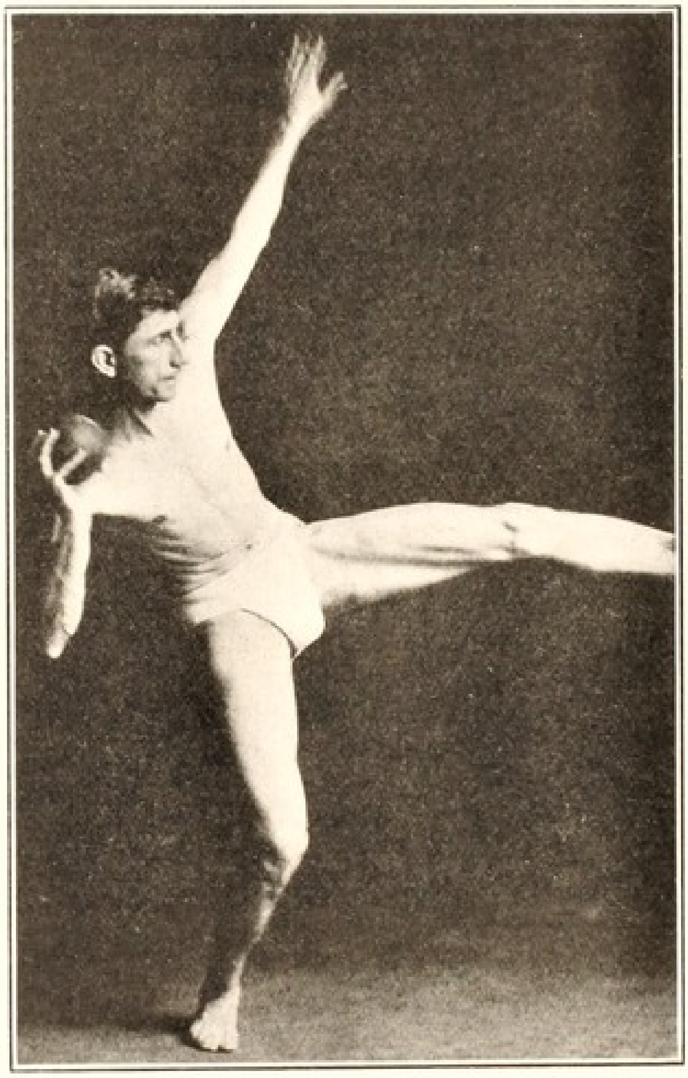

FIG. 190

Some pitchers are able to throw a very speedy and quickly curving ball by a snappy and jerky swing of the arm, without much body movement. They are often very effective for a time, but experience shows that the man who uses the more widely distributed movement survives longer.

Pitchers have during the last few years developed the custom of using a widely swinging preliminary movement of the arms, familiarly called the "wind-up." This was for a time considered as a mere mannerism of some of the men, persisted in to make themselves conspicuous, but it has become almost universal among pitchers in spite of the general ridicule allotted to it, which argues its utility. It is light work mixed in with the violent work of throwing—a practice that is good for the muscles, helping to circulate the blood through them in a manner similar to massage.

The essential difference between the throw and the **shot-put** arises because the shot is too heavy to handle in the manner of throwing, the throwing movement is forbidden by the rules, and the sole object of the sport is to secure the greatest possible distance, measured from the circle in which the thrower stands to the place where the shot strikes the ground. Such a purpose and manner of measurement calls for the precise elevation that will give the longest put with a certain force. As a consequence the shot-putter uses more extension of the arm and body and less rotary movement, although the latter is important.

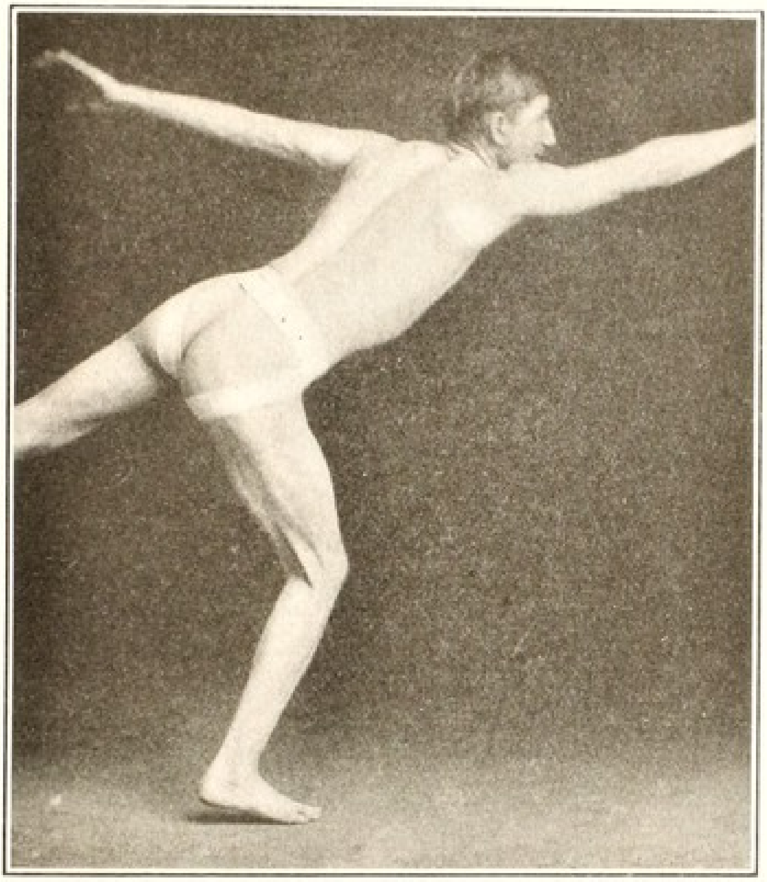

FIG. 191

FIGS. 190 and 191.—Action of the whole body in putting the shot.

In preparation for putting the shot with the right arm the athlete puts the right foot far back, like the thrower, and he flexes his right limb still more than the thrower, since he must follow the shot with his hand through as long a path as possible to give it speed. He usually perfects his balance and gets the right tension on his trunk and leg muscles by one or two hops on the right foot with trunk flexed far over sideward to right, left arm and foot extended far to left to balance the extreme lateral flexion.

As the arm is extended diagonally upward in putting the shot the abductors of the scapula pull the shoulder forward, the crosswise direction in which the movement starts being favorable to best contraction and leverage of the pectoralis major. At the same time the oblique muscles and rotators of the hip-joints turn the trunk strongly to left, aided by a violent downward and backward swing of the left arm; following this the extensors of the spine and limbs project the whole body forward and upward. The left limb swings backward to reinforce the rotation, prevent too much forward movement and give balance on alighting. At the finish the deltoid, lower serratus and left erector spinæ are doing the most work in place of the pectoral, upper serratus and right erector spinæ, which were in a position to do most at the beginning. The posture is now so far forward that the left arm and leg are needed far to the rear to prevent falling forward or stepping out of the circle, the extensors of spine and limbs continuing in action to recover erect position. As the feet strike the ground in alighting the balance is apt to be so far forward that the extensors of trunk and right limb must relax to a certain degree, using a lengthening contraction of the muscles until the center of gravity of the body is brought within the base. Notice that while the muscles used in throwing and putting the shot are almost the same the coördination is altogether different, the one putting emphasis on rotation and the other on extension; the first aiming to give a light object maximum speed, the other aiming to exert most force in the right direction against a heavy weight; the first emphasizing accuracy and the other neglecting accuracy for power and speed.

Throwing the hammer, like the use of the sling by the ancients, utilizes centrifugal force to a greater extent than other forms of throwing. The thrower stands in a seven-foot circle and begins the movement by swinging the hammer in a circular direction about his head, the circle being lower in front of him and higher behind him. This uses the pectorals, serratus and anterior deltoid of one side and the trapezius and middle and posterior deltoid of the other, reinforced by the strongest action of the rotators of the trunk and hips. The body stoops forward somewhat as the hammer swings forward, enabling the extensors of hips and spine to help as it swings backward over the shoulder. The arms, which flex in beginning the first swing or two, remain fully extended after the hammer has attained speed; the feet are separated and by alternate flexion and extension the limbs help in the circular movement of the body and arms. After attaining the most speed that can be gained in this way the athlete turns his entire body once or twice by springing from the feet and finally lets go of the hammer at the

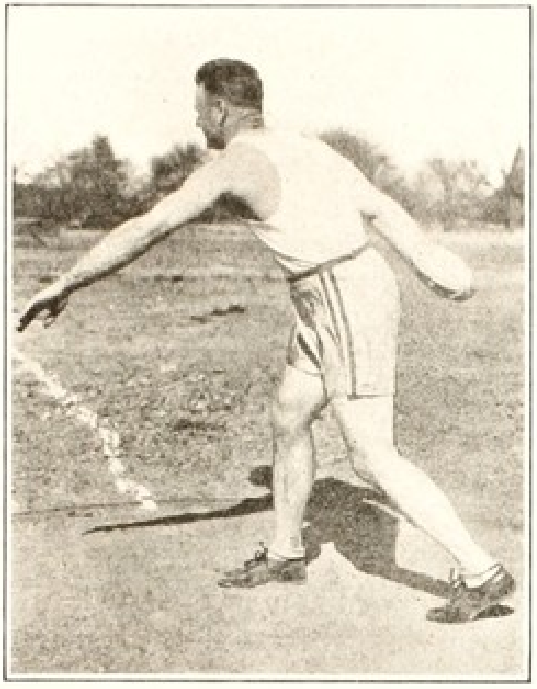

Fig. 192.—Start in throwing the discus.

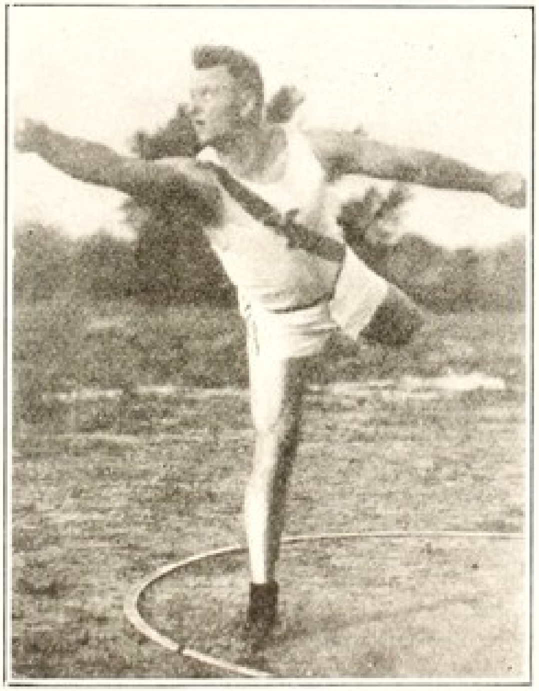

Fig. 193.—Finish in throwing the discus.

end of the backward swing by a specially vigorous extension of the trunk.

The several forms of throwing, as well as striking and many movements used in industry, illustrate the fact pointed out by Dr. Allis that the erect position enables man to use the rotary movement of the trunk about its vertical axis as one of the most effective muscular mechanisms. None excel the hammer throw in exhibiting the utmost power than can be secured by this movement, the action of the arms, trunk and lower limbs being utilized to full extent when the coördination is mastered.

Striking.—Games and sports employ several distinct forms of striking. Among them it will be interesting and useful to consider the use of the hand in volley ball, handball and boxing, the use of the racket in tennis and of the bat in baseball and cricket.

In the game of volley ball the large light ball must be struck while it is in the air and batted in an upward direction with the open palm of one or both hands. It must in most cases be batted forward and upward; sometimes directly upward and sometimes sideward and backward. When it is struck with the arms held above the level of the shoulders it will call into action the triceps and the muscles of arm elevation to bat the ball in any direction but backward, and then the flexors of the elbows may be used in place of the triceps. When the ball is sent nearly upward or in a backward direction the arm muscles will be reinforced by the extensors of the trunk and hips; in general it will employ the trunk and hip muscles of the side toward which the ball goes.

When the ball is struck below the level of the shoulders it requires action of the flexors of the elbow and the arm-raising muscles; they are assisted by the extensors of trunk and limbs in the main, as in lifting. The frequency with which the extensors of the whole body and arm elevators are used in this game makes it an especially good one for people engaged in sedentary occupations and needing moderate exercise for general development and posture.

Handball is a much more strenuous game, played by two and less often by four players, a tennis ball or other ball of about the same size being batted against a wall by the open hand. The game requires much rapid running and dodging to avoid being hit by the ball and to get into a position to play it. The ball is usually batted forward by a strong forward swing of the arm. The motion when the ball is low is much like that seen in a toss, the arm movement being reinforced by the extensors of the trunk and limbs, the trunk bent low to give the strongest blow. When the ball comes at waist level the rotation of the body is brought into action as in throwing, and when it is above shoulder level the arm depressors act with the abdominal muscles and flexors of the hips.

The form of striking used in **boxing** resembles closely in its general mechanism that seen in throwing and putting the shot. The object is in this case to strike a heavy blow with the closed fist, usually in a nearly horizontal direction. The arm and body are not carried so far back in preparation for the blow in boxing as they are in throwing and shot putting, partly because of necessity for being ready to dodge or parry a return blow. The importance of the help the arm receives from the rest of the body is emphasized by the stress laid by instructors in boxing on the "foot-work." As the arm shoots forward in the act of striking the abductors of the scapula draw the shoulder forward and the whole body turns on its vertical axis by the usual method while the extensors of the rear limb and flexors of the trunk carry the whole body forward with all the force at their command. Instead of trying to gain the utmost speed and then ceasing at the finish as when one releases a thrown ball or loses contact with the shot, the boxer makes his strongest effort of arm, trunk and leg muscles just as the fist comes

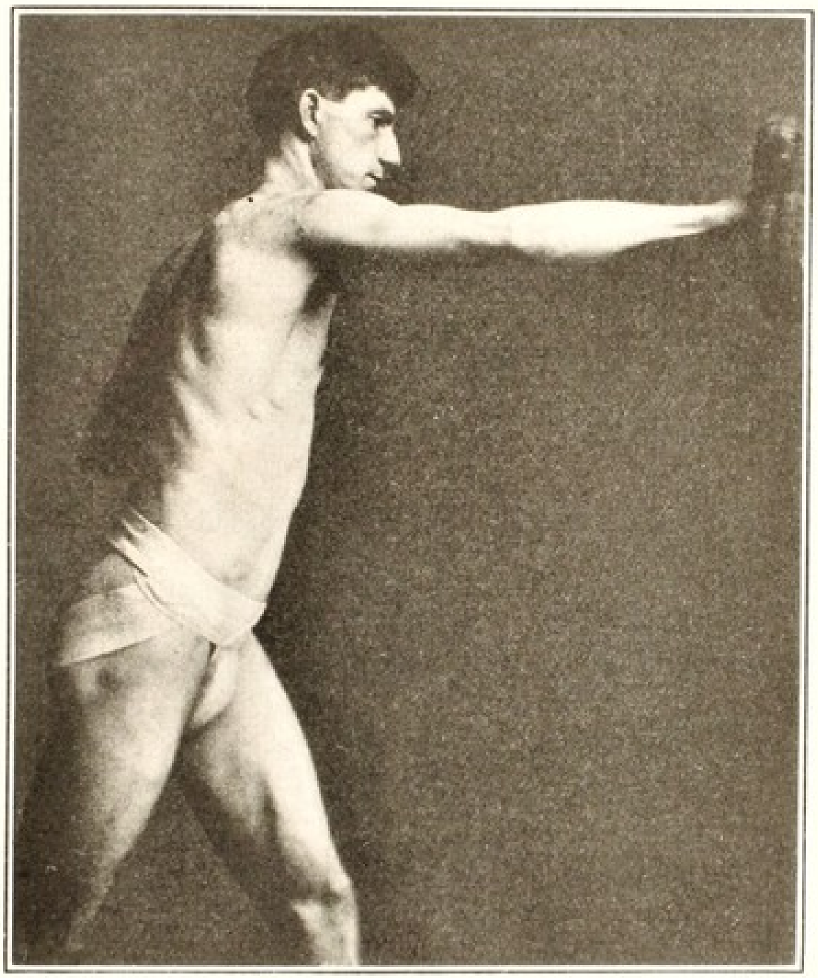

Fig. 194.—Action of the whole body in striking with the fist.

in contact with the opponent or the bag. The reaction of the blow helps in recovering, requiring no muscular action to regain balance as in throwing unless the boxer fails to strike squarely; when he "hits the air" the extensors of the forward limb and trunk must act with promptness and force to keep him from falling.

Tennis.—In serving with a tennis racket the arm movement can be effectively reinforced by both the forward inclination and the rotatory movement of the body. The best position to take in preparation for serving is with the racket arm turned away from the net nearly 90 degrees, so as to use the crosswise movement of the arm that utilizes the best action of the pectoralis major, after the manner of shot putters. This position also makes a full turn of the body possible in the movement. As the racket swings toward the ball the body rotates on its axis by action of the oblique trunk muscles and rotators of the hips, assisted by a downward swing of

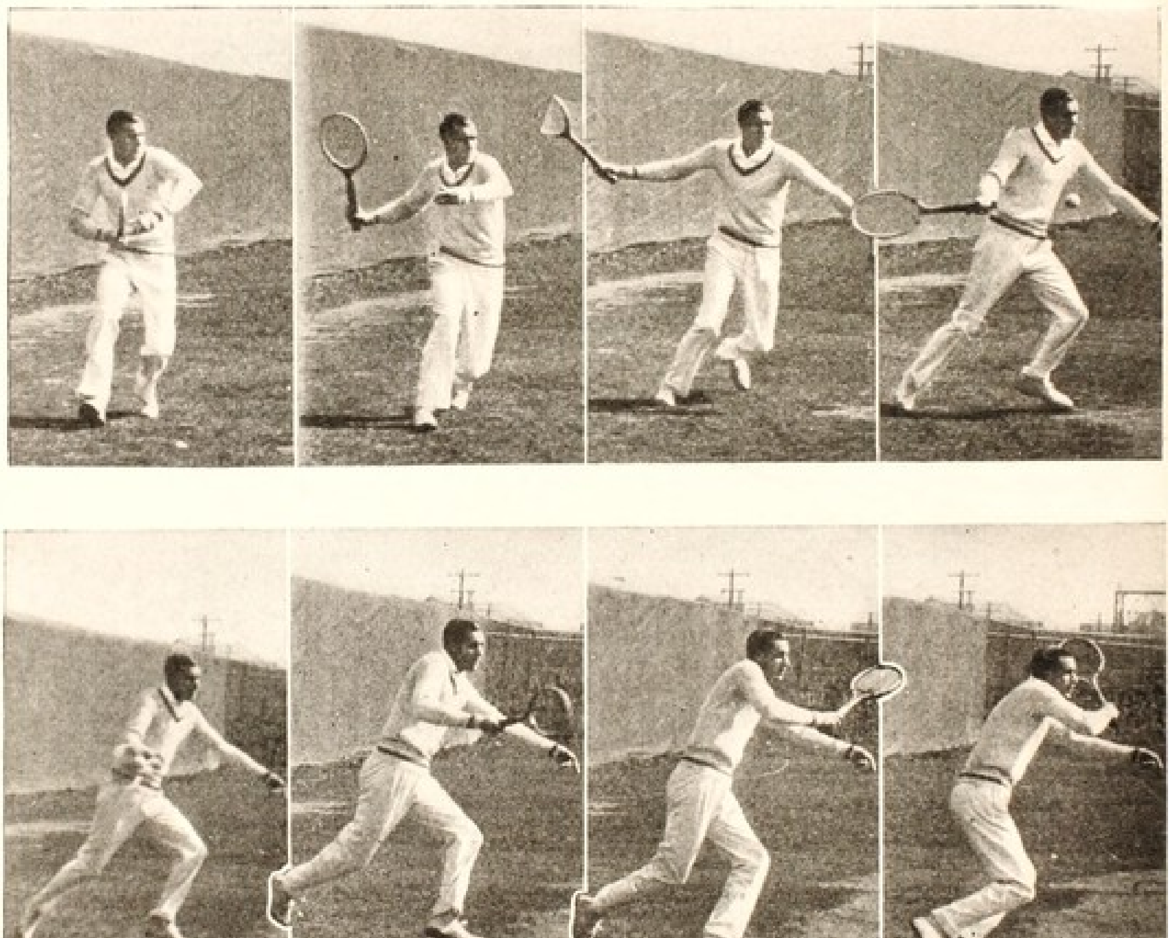

FIG. 195.—Tilden, forehand drive. (Courtesy of American Lawn Tennis, Inc. From "Mechanics of the Game." By J. Parmly Paret.)

the free arm; at the same time the body leans forward, due to contraction of the abdominal muscles and the extensors of the rear limb. When the ball is struck the blow has the momentum of the whole body behind it.

The server in tennis gets one advantage from the sharp forward inclination of the body not realized by the thrower or the boxer. His next move is to run forward into the court, and the position at the end of serving launches him well into his run, so that he does not, like the boxer, have to limit the slant and the power of the stroke for fear of falling.

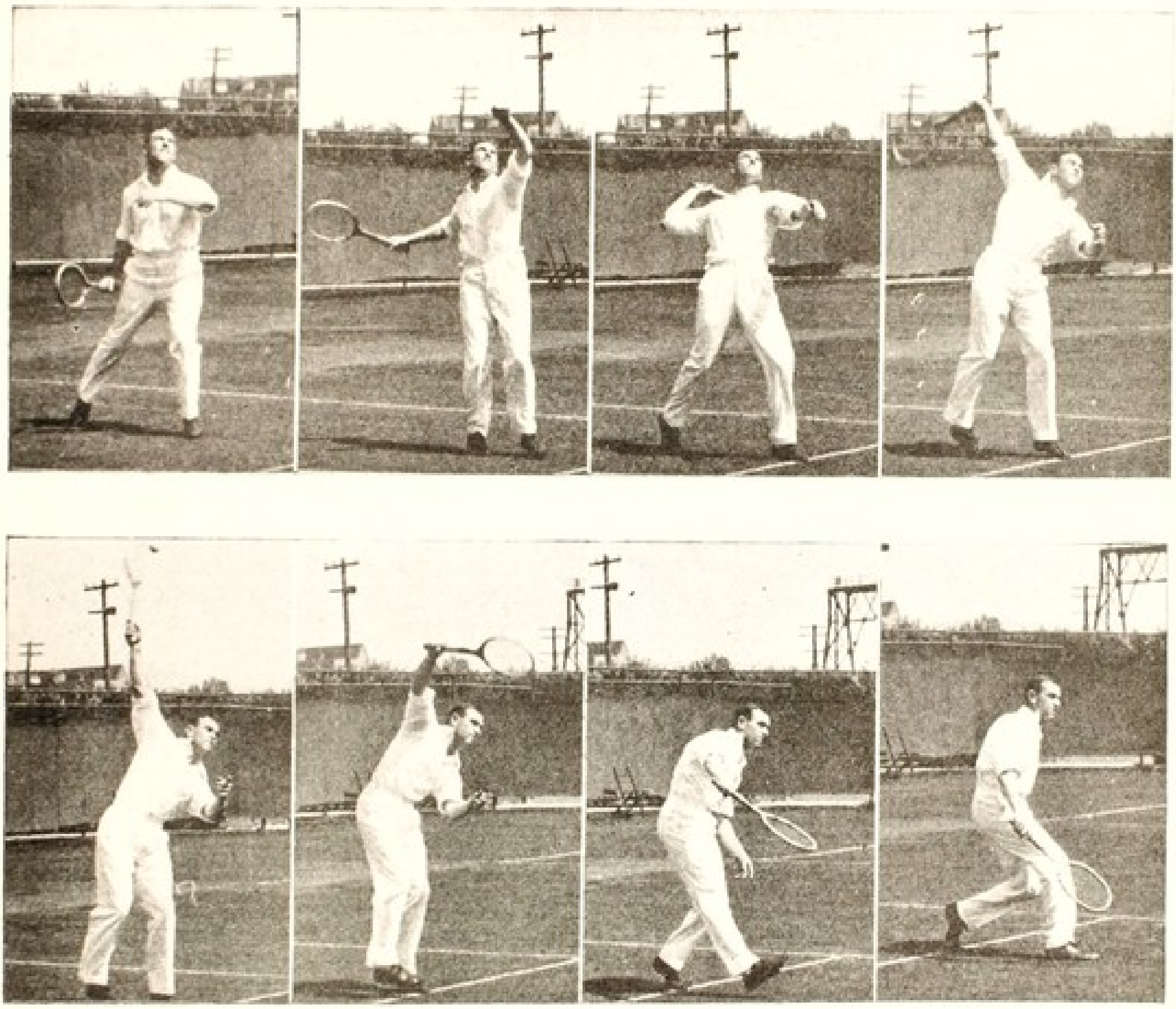

FIG. 196.—Smash by Patterson. (Courtesy of American Lawn Tennis, Inc. From "Mechanics of the Game." By J. Parmly Paret,)

The Smash.—The smash, when executed properly, is like the serve. It is seldom that one sees it done in good form, because the player is not able to place himself accurately in position for it. The ball falls from a considerable height and the wind is apt to influence its direction; besides, it is falling more rapidly than the ball tossed up for a serve and that increases the difficulty of making a perfect smash. Patterson, in the picture, is executing the smash as he would serve (Fig. 196).

Driving.—Tilden's forehand drive, shown in Fig. 195, shows perfect form. The rotation and inclination of his body, as well as the swing of his arm, are calculated to put great speed on the ball, and the lift of his racket at the end of the stroke rotates the struck ball so as to give it a sharp downward curve to bring it within the court.

Success as a tennis player depends much on agility in covering court, which means action of all the muscles of the trunk and lower limbs in great variety, and on ability to put speed on the ball, which means reinforcement of the arm by the momentum of the body in every play. In forehand drives the muscles rotating the trunk to left act while in backhand strokes it is the opposite set; work for the abdominal muscles is present in both. In quick play the free arm has so much work in maintaining balance and in helping to give the rotary movement that it is really left unused less than is generally assumed (Figs. 195 and 196).

Batting.—Batting in baseball illustrates again a reinforcement of an arm movement by forward inclination of the body on the feet and its rotation about a central axis. A right-handed batter stands with his left side toward the pitcher, body inclined and trunk and hips twisted to right, bat held well around to right. At the proper time in the pitcher's "wind-up" he steps toward the pitcher with his left foot and increases the flexion of his right knee, which makes him incline still more strongly away from the pitcher, and increases a little more the twist of trunk. As the ball approaches, he leans toward it by extending his right knee and flexing his left one, swings his bat toward the ball by extension of elbows, sideward swing of arms and twisting of trunk and hips to left. When the bat hits the ball the body should be in motion to carry the bat toward it with both its leaning and its rotating movement, thus giving it the combined momentum of bat, arms and body. Batters readily learn the arm movement and the rotation, but many of them fail after years of practice to lean toward the pitcher during the swing. This fault is increased by fear of being hit by the pitched ball.

The strokes used in hockey, lacrosse, golf, polo and other sports differ in detail from those just explained, but all of them will on careful observation be seen to consist essentially of the three parts—arm swing, forward movement of the body on the feet and its rotation on its vertical axis.

Kicking.—Kicking a football consists fundamentally of flexion of the hip and extension of the knee of the same side at once—a movement that can be made by action of the rectus femoris alone. In the mildest kick this may be all that is necessary.

To strengthen the movement we may use all the extensors of the knee and all the flexors of the hip that do not interfere with extension of the knee. This eliminates only the sartorius. The hamstring group must be relaxed, for its action would prevent both movements.

The unsupported side of the pelvis must be held up to the level of the other side, which will require the lesser glutei of the supporting side. The whole body weight must be supported by the supporting limb, requiring action of the extensors of hip, knee and ankle. The front side of the pelvis must be held up firmly to sustain the pull of the hip flexors; the hamstrings of the supporting side will do this (Fig. 197).

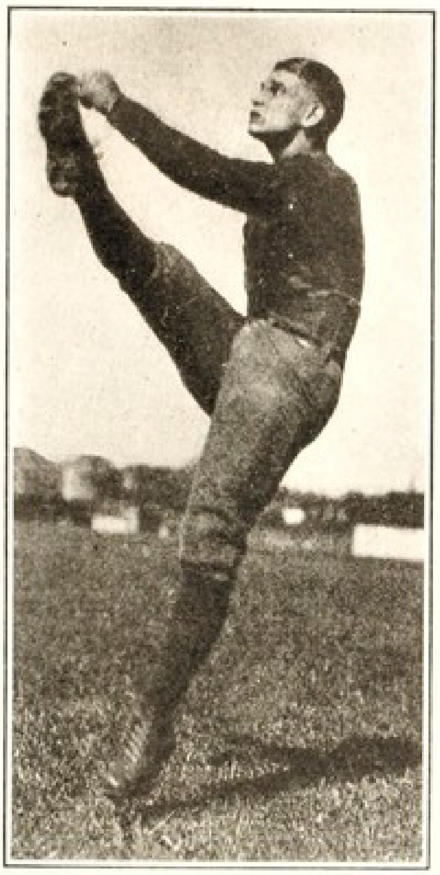

FIG. 197.—Harry Kipke, University of Michigan, punting the football.

If the kicking leg is to be raised as high and with as much force as possible, the pelvis must be flexed on the trunk. This cannot be done because of the iliofemoral ligament unless the supporting knee is flexed; when this knee is flexed a little the abdominal muscles can lift the front of the pelvis. In this case the weight is thrown so far backward that the arms must be raised up and forward to keep the balance, which brings in the arm-raising group.

The strongest kick of the ball that one can make requires then the strong action of the extensors of both knees, with the supporting knee slightly bent; strong flexion of the hip on the kicking side; strong work of the ankle extensors and hip abductors and extensors of the supporting side; moderate action of the abdominal muscles and the arm-raising group.

This is the style of kick made by goal keepers in soccer in a kick-out and by players in the Rugby type of game in the kick-off. A drop-kick requires the same form of kick without the high lift of the leg.

In punting and in advancing the ball in soccer the kick is given with the inside of the foot just in front of the instep, the whole limb being rotated outward in the hip. This position and a side sweep of the foot that is used brings in the adductors of both sides, in addition to the muscles named before. The abductors of the foot are also active.

Locomotion.—Locomotion, as seen in games and sports, includes walking, running, hurdling, jumping, vaulting, climbing, rowing, paddling and bicycling.

Walking, as used in play activities, has no special features beyond what has already been explained. **Running** in general is the same as that considered in Chapter IX except the crouching start and the swing of the arms used in sprint racing.

In the **crouching start** (Fig. 198) the trunk is horizontal, the arms helping a little in supporting the weight but mostly in keeping the poise. The hip and knee of the rear limb are flexed to a right angle and those of the other limb still more. The spine is arched.

All this puts considerable tension on the extensor muscles of the trunk and lower limbs and also puts the gluteus maximus in a position to help. No other position yet discovered enables the runner to start so quickly.

In **sprinting** the rotation of hips and shoulders is eliminated as far as possible in the belief that they interfere with the runner's speed. The arms are held straight down at the sides and care is taken to swing them directly forward and backward, so that they will not produce any rotary movement of the shoulders. The trunk muscles are all kept in static contraction to give strongest support for the vigorous action of the muscles moving the limbs. This stops the breathing, most sprinters running the 100 yards with but two or three breaths and some with but one.

Skating differs from running in several particulars. The body is supported on the skates practically all of the time, progress being made by a sliding motion instead of a flight through the air.

Because of the nature of the skate and its contact with the ice or floor the advancing movement is diagonally forward and sideward, so that the limbs are rotated outward, largely eliminating the extensors of the ankle from the work. The trunk is held nearly horizontal to avoid wind pressure, and this puts the pelvis in good position for all the extensors of the hip to act, including the gluteus maximus. The main work is done by the extensors of the hip and knee, supported by the erector spinæ. The extensors of the ankle finish the stroke and the flexors of the lower limb bring the limb forward.

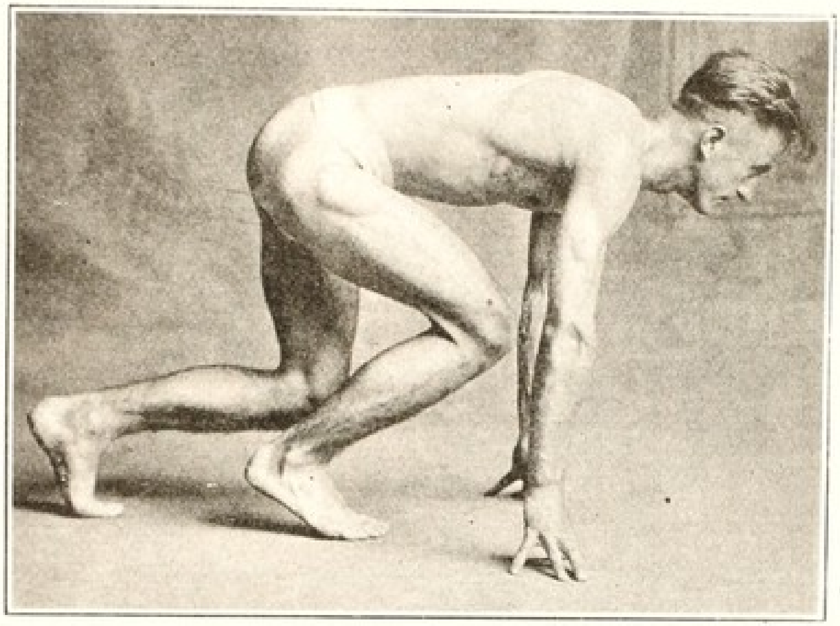

FIG. 198.—The crouching start.

In **hurdling** the runner has to spring up into the air to pass an obstacle at regular distances. He avoids the hurdle by his upward spring and by the position of the limbs as he passes it. One of his problems is to so combine these two movements as to save the most force.

The spring employs the same muscles that are being used in the run, giving a stronger contraction in this particular step. In going over a hurdle the front limb is held well forward by the flexors of the hip and the knee is flexed about to a right angle by relaxation of the extensors, the pull of the hamstrings as the hip is flexed giving the slight force that is needed. In this position of flexed hip and knee an outward rotation of the hip, produced by the six outward rotators, lifts the foot easily and to a sufficient height. The sartorious is peculiarly adapted to help in this combination of flexion and outward rotation of hip and flexion of knee.

The rear limb is made to avoid the hurdle by holding it far to the rear and flexing the knee as it passes over the obstacle. This is accomplished by inclining the body sharply forward to permit the backward slant of the thigh and by continuing the action of the hamstring group after the spring is completed, these muscles extending the hip and flexing the knee at the same time. Notice the position of the arms as they are held up by the arm-raising

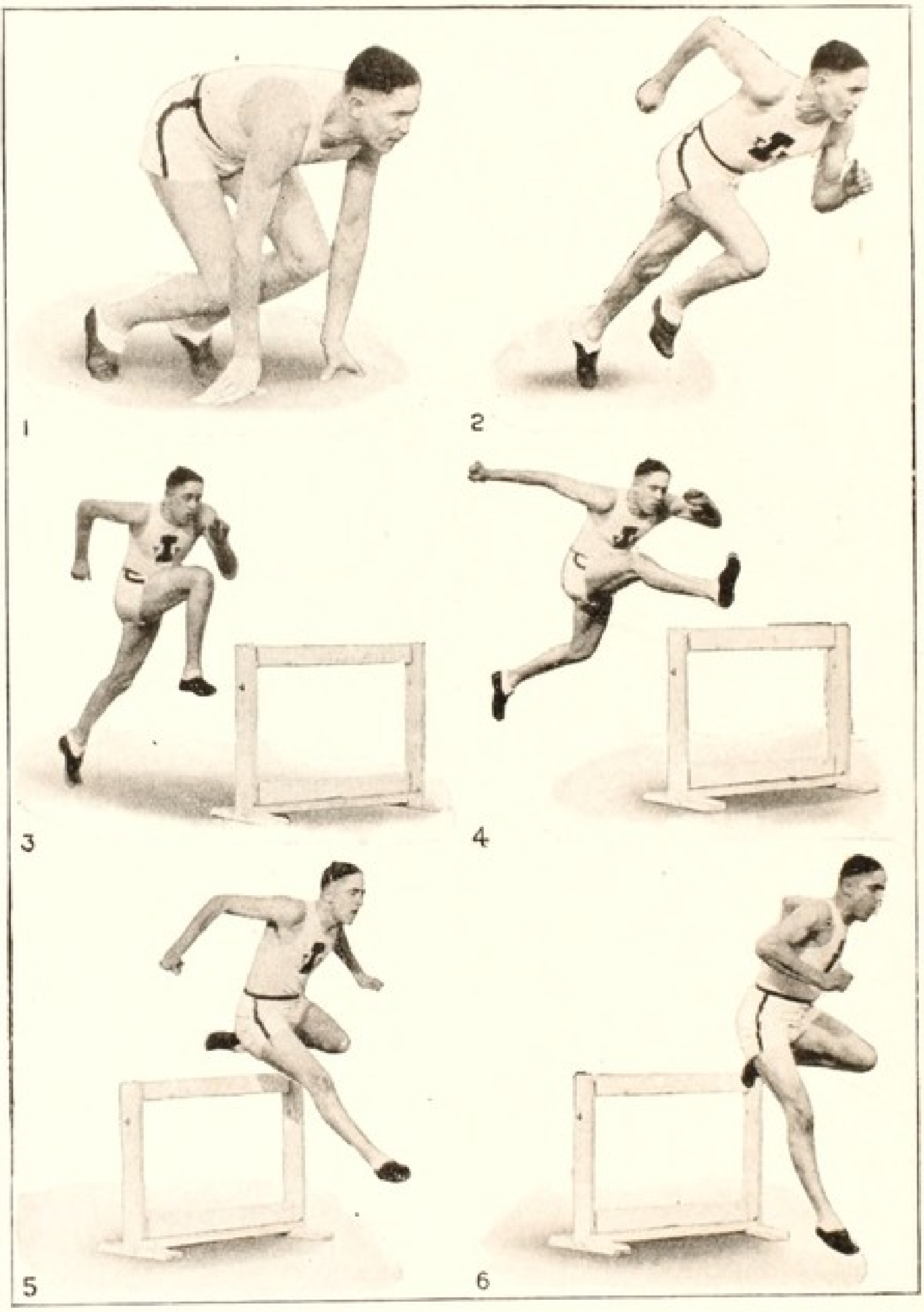

Fig. 199.—Taking the low hurdle. (From Jones, Track and Field, courtesy of Charles Scribner's Sons.)

muscles and moved forward or backward to assist in balancing by the action of different parts of the deltoid and by the pectoral or infraspinatus.

Of the various forms of **jump** in games and sports the standing broad is the easiest to analyze because both sides of the body work in unison. The movement begins by a passive flexion of trunk and lower limbs and a backward swing of the arms; then the whole body leans forward and just as it begins to fall forward the extensor muscles of the trunk and limbs contract suddenly, projecting the body into the air in a forward direction.

As the extension begins the arms are quickly swung forward by the arm-raising group, including the pectorals, and just after the feet leave the ground the arms swing quickly down again by action of the arm depressors, especially the latissimus. The upward momentum of the arms, gained while the feet are still on the ground, is used to help in lifting the whole body. The effect is more marked when weights are held in the hands and still more so when the hands rest on a fixed support, as in vaulting. The distance gained by the movement of the arms is not great but a fraction of an inch may win a contest and is always worth gaining.

After the violent extension by which the spring is made and while the body is in the air there is a general flexion of trunk and limbs, not made with any purpose or even consciously. It is probably caused by a recoil from the strong extension, the flexor muscles being put on a stretch as the spring is made and shortening like an elastic cord when the extensors relax.

Before the feet strike the ground the joints are nearly straightened again by a mild contraction of the extensors, and when they reach the ground there is another passive flexion, the extensor muscles undergoing a lengthening contraction to ease the jar; after reaching partial flexion the body straightens to erect position by continued action of the same muscles.

The **running broad jump** differs but slightly in mechanism from the standing broad. The momentum of the run carries the body farther even if the height is no greater. The running jump is usually said to be taken from one foot, but this is scarcely true, for while the feet are not together at the time of the spring and they do not leave the ground at exactly the same time, they both take part in the spring and apparently they work all the more effectively by extension of the limbs in quick succession rather than in unison.

In the standing high jump the jumper stands with his side toward the bar and begins by a slight passive flexion as in the other jumps; the limb nearest the bar is then thrown strongly upward by the flexors of the hip and the abdominal muscles, the other limb still being flexed somewhat; this is quickly followed by a spring from the other foot, using the extensors of the trunk and limb. The arms aid in the movement by swinging in practically the same manner as in the standing broad. A slight inclination toward the bar, made without any considerable effort as the first limb is raised, gives the jump its sideward trend. The pelvis is flexed on the trunk by a forcible contraction of the abdominal muscles as the flexors of each limb act to lift the limb over the bar.

Fig. 200.—De Hart Hubbard doing a winning broad jump at Detroit, 1923.

The **running high jump** is made in several ways but in two main styles: the scissors form, which closely imitates the standing high, and the straight jump, in which the jumper runs in a direction at right angles to the bar.

The scissors jump, taken with a run lengthwise of the bar, is too much like the standing jump to need a separate analysis.

When one who jumps from the left foot makes the straight form of jump he runs squarely at the bar and extends the limbs in rapid succession, the right one first. As the left limb is being extended the right is being lifted by the flexors of the hip and the whole body is thus turned to the left on the left toe as a pivot. The turn thus begun continues while the body is in the air and the jumper passes the bar with his left side or face toward it, according to the force of the turn, and alights facing the starting-point.

In all forms of **vaulting** the main work of lifting the body is done by the extensors of the trunk and limbs, as in the jumps. The arms aid more or less by supporting a part of the weight so that the jump does not have to lift the whole of it.

In the **vault with the pole** there is a considerable gain in the height over that of the jump, partly because the arms help to lift the body and partly because the momentum of the run and the jump is applied to a lever that shifts the direction of the force and turns a horizontal motion into a circular one.

The jump is practically the same as that used in high jumping. The body is at first suspended by the arms in nearly a passive manner, the hand flexors being the only muscles in strong action. As the body nears the bar the trunk and limbs are lifted by contraction of the flexors of all the joints and the arm depressors and then extended to the position shown in Fig. 201 by the extensors. The hands hold to the pole long enough for the body to clear the bar and for the feet to begin the downward movement due to gravity, then drop it with a push that will vary in force with the exact position of the body and the pole. On alighting the extensor muscles of trunk and limbs come into action to lessen the jar by a lengthening contraction, followed by a shortening contraction to bring the body to erect posture unless the balance is lost.

FIG. 201.—Myers of Chicago A. A. practising the pole vault.

Mountain climbing is essentially like walking up stairs, using the flexors of the limbs to lift the feet and the extensors of trunk and limbs to lift the body, the complete flexion giving the gluteus maximus a chance to help. In going down the mountain the weight is lowered at each step by a lengthening contraction of the extensor muscles. There is much turning and bending that varies the work of the trunk muscles and brings all of them into action a part of the time.

Climbing the rope or pole, using both hands and feet, starts by grasping it with the hands, using the flexor group. Then the feet are lifted by action of the flexors of the trunk and limbs and the whole body may be lifted at the same time with arm depressors and flexors of the elbow. The rope is now grasped by the feet, using the adductors of both thighs and the flexors of one limb acting against the extensors of the other; then the hands are moved up the rope by use of the arm-raising muscles and the extensors of the trunk and hips, after which the movement is repeated.

In practically all forms of **swimming** the body is propelled along or through the water by the use of the arm depressors and the extensors of the lower limbs. There are a few exceptions—the flexors of one hip being used in the scissors kick and the adductors of the thighs in the breast stroke. When the arm depressors are not used on opposite sides of the body at once, as in the side strokes and the crawl, they are reinforced by the trunk muscles of the same side.

The arms are returned to position for the stroke by the arm-raising muscles and the limbs by the flexors except in the scissors kick, where the hip extensors of one side are used. This work is of course milder than that of the propelling muscles.

Rowing is a typical pull of the arms alternated with a combination of push and arm depression. The pull is aided by extension of the trunk and lower limbs and the push by flexion of the same joints. The push may also be accompanied by flexion of the wrists to feather the oar.

Paddling is a complex one-sided movement. In paddling on the right side the arms are moved downward to the right, using the latissimus and teres major of the right arm and the pectoral of the left, reinforced by the rhomboid of the right and the serratus of the left side and the right internal and the left external oblique muscles.

Bicycling employs the extensors of the lower limbs in alternation, the action being supported by the extensors of the trunk. The extension of the trunk is reinforced in turn by a pull of the arms on the handle bars. The flexion of the limbs may be brought about by allowing them to rest on the pedals, but that will waste force.

In order to secure the greatest speed in bicycling the rider leans far forward and lowers his arms, since this puts a tension on the trunk muscles, giving them more power, and also puts the gluteus maximus in position to work powerfully through more of the circle. Instead of simply pushing down on the pedals he follows each pedal and pushes it with his foot as much of the way around as possible. With toe clips to attach the foot to the pedal the work can continue practically all the way around the circle, the extensors acting to push part of the way and the flexors acting to pull it around during the balance of the revolution. This uses the flexors as well as the extensors in the work and there is another advantage—the force used is not limited by the weight of the body as it is in the simple downward push. One limb flexing and the other extending reinforce each other, requiring less action of the trunk and arms for this purpose. There is probably no bodily mechanism capable of exerting so much force per minute as this way of driving the bicycle.

The position just described uses the extensors of the spine in such an elongated position that it is bad for posture when taken too often or for too long a time. Since boys are apt to be more interested in speed than in posture it is important to teach them how to follow the pedal with the foot and to have their bicycles equipped with toe clips, so that they can get the racer's speed without his characteristic hump.

CHAPTER XVII.

INDUSTRIAL OCCUPATIONS.

The bodily movements involved in industrial occupations, like those of play and sport, include both the handling of objects and locomotion. In sport locomotion is perhaps the more prominent of the two, but in industry the reverse is true. This has come about because in the displacement of muscle by machinery it is the field of locomotion that has been invaded most. While boats, steam trains, trolley cars, automobiles and elevators now do most of the transportation of people and freight—once done by muscular power—many of the primitive ways of handling objects are still in use and the use of machinery is leading to the invention of new forms of movement.

Beginning with movements in which lifting and arm raising are prominent features, **handling brick** will serve as an example of the simplest type.

Handling brick is seen most often in the loading and unloading of wagons and cars. It is done by picking them up in the hands, two bricks at a time, and tossing the two to another workman who catches them and places them in a pile. The work involves the flexors of the hands and fingers, the arm-raising muscles and the extensors of the trunk and limbs. The knees are flexed by some workmen while others bend forward from the hips. Flexion of the elbows by the biceps group is usually present. Each of the two men has about the same amount of work and uses the same muscles in nearly the same way.

Gathering beets, turnips, cabbages, and other vegetables and pulling weeds are tasks of the farmer and gardner using practically the same bodily mechanism as handling brick. The stooping position of the body and the lifting bring in the extensors of trunk and limbs, while pulling the plants from the soil requires vigorous action of the hand flexors. Handling baskets and bags of grain is very similar, with a one-sided action when the object is shouldered. Picking strawberries and weeding onions and other small plants, because of the stooping posture, give much work for the extensors of trunk and limbs.

Baggage men, expressmen, and men who haul lumber, stone and freight of all kinds have to grasp, lift, and in general use the bodily mechanisms just mentioned. Many other special examples will occur to the reader.

Lifting and reaching upward is seen in hanging clothes on a line. Women with weak arms are especially likely to hollow the back and protrude the abdomen in this work, for reasons given elsewhere.

Carrying hod is work for the extensors of the trunk and lower limbs and for the middle parts of the trapezius and levator of the side holding the hod. The workman is apt to flex his trunk laterally to avoid putting the weight on the muscles of one side of the trunk, and this is apt to induce lateral curvature unless the hod is carried on alternate sides.

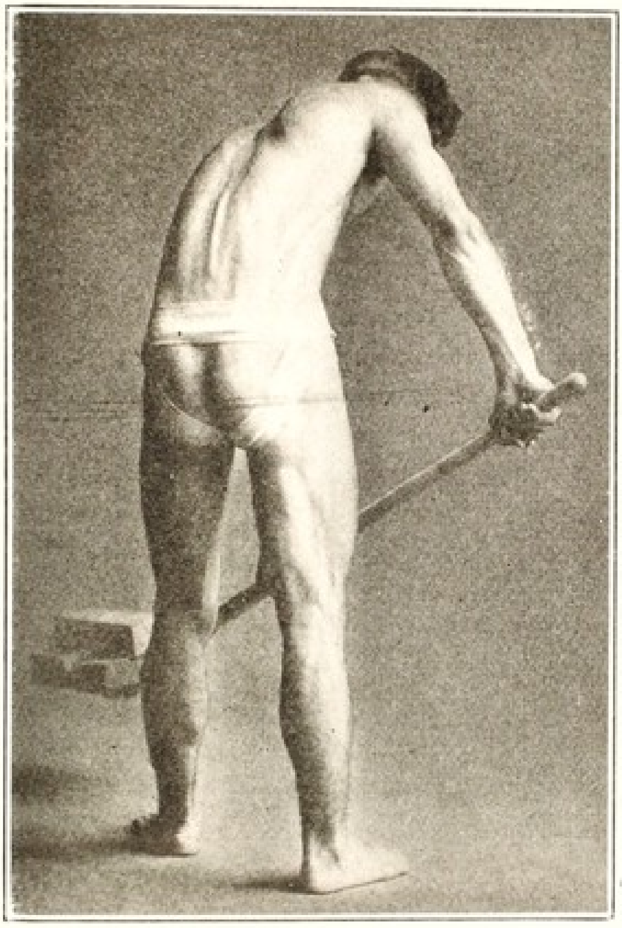

Fig. 202.—The action of the body in shoveling.

Shoveling is a more complex movement. When the material moved is loose like sand or coal the shovel is loaded by pushing it into the pile, using the triceps to extend the elbow and the arm-raising group to support it. When the work calls for more force these two groups increase their action and the abdominal muscles, particularly on the side toward the shovel, act to aid them. The entire weight of the body is brought to bear on the work by leaning forward and the rear limb helps by a push with its extensor muscles.

The shovel and its load is lifted by the extensors of the spine and hips, the arms remaining extended. The hand and arm nearer the shovel bear the whole load, the other arm pushing down on the upper end of the handle, using triceps and arm depressors. The lifting arm is strongly supported by the trapezius and after it has been raised 45 degrees, by the lower serratus.

The easiest way to move the loaded shovel horizontally is by a rotation of the body on its vertical axis, the lifting muscles just mentioned remaining in action during the swing. This brings in the rotators inward of one hip and outward of the other, with the rotators of the spine and a swing of the arms made by the pectoral of one side and the latissimus of the other.

If the loaded shovel must be moved upward there must be increased action of the lifting muscles, including those of the arms, trunk and limbs. Usually the flexors of the elbows will be used at the end of the movement; the pronators of one forearm and the supinators of the other will empty the shovel.

Pitching hay or grain is a similar movement. It takes less force to insert the fork and it can be tilted to vertical position of the handle with the load still in place. If the load is to be moved horizontally the action is the same as with the shovel. When it is to be moved high overhead the fork is either lifted by raising the arms or, if it is too heavy for that, tilted to upright position and then lifted upward by an extension of the trunk and limbs. With the fork handle upright it can be held close to the body, enabling the arms to lift it more easily.

The study of work in which pushing is prominent may be begun by using a **lawn mower**. The pushing mechanism of the arms, already explained, is in vigorous use here but is for most of the time in static contraction, the use of the limbs in walking giving the motion and the extensor muscles of the limbs being the moving muscles. The arms are supported by the abdominal muscles when the trunk is erect or nearly so, but if the trunk is inclined forward far enough this work is transferred to the extensors of the trunk.

The use of the **wheelbarrow** involves lifting combined with pushing. To begin work the workman flexes trunk and lower limbs and grasps the handles, then lifts it to erect posture; to walk forward while lifting the weight the extensors of the limbs must each in turn bear the added weight of the barrow. If there is resistance to the forward motion the pectorals, anterior deltoid and upper serratus must act; work is thrown on the abdominal muscles and the extensors of the trunk a little relieved by the backward traction on the shoulders. To balance the weight as nearly as possible on the spinal column and thus relieve both the flexor and extensor muscles of the trunk the workman leans forward in going forward or up hill and backward in going backward or down hill.

The combination of arm depression with pushing is found in **washing**, using the old-fashioned washboard. The clothes are rubbed up and down against the board by alternate flexion and extension of the elbows, assisted by the arm elevators and depressors and reinforced by flexion and extension of the trunk.

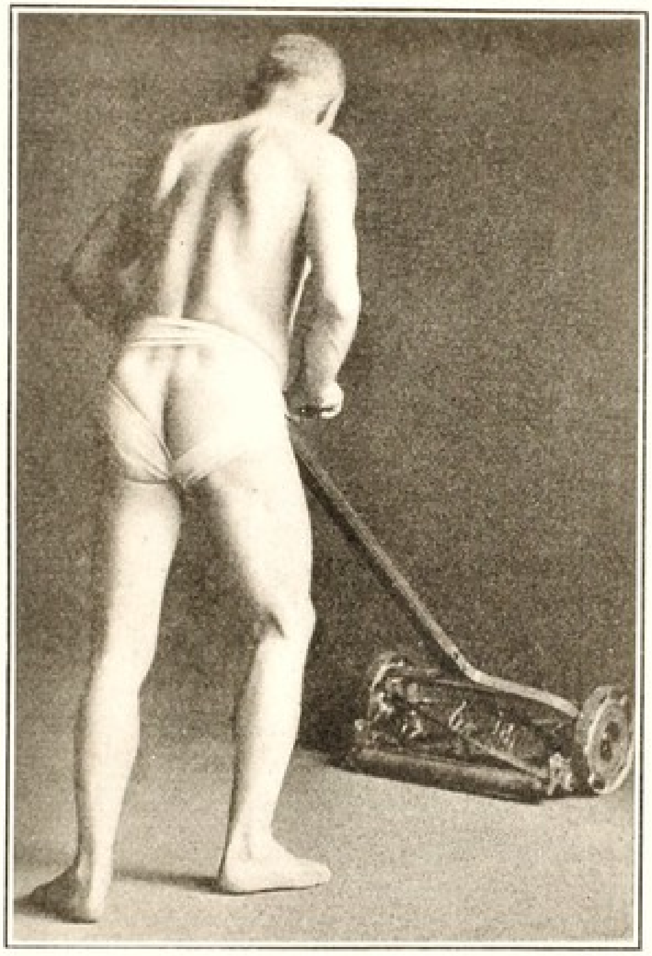

FIG. 203.—Action of the whole body in using the lawn mower.

Vigorous depression of the arms calls for contraction of the abdominal muscles to reinforce the movement. The abdominal muscles being relatively weaker in women than in men, women are more apt to flex and extend the trunk in work of this kind by alternate contraction and relaxation of the extensors of the hips and spine, the body weight acting in place of the flexor group. The muscles for arm depression act all of the time to press the clothing against the board.

Ironing is another occupation that has depression of the arm as a leading feature. The heavy iron gives much of the needed pressure by its weight, so that one arm can do the work. The usual aid is given the arm muscles by action of the trunk muscles on the side toward the iron.

Alternate flexion and extension of elbow aided by the usual pushing and pulling muscles move the iron over the goods. The combined forward and backward motion with twisting of the whole body that we have noticed in so many cases is useful here. Lifting is also involved.

Sawing is a good example of pushing with one arm. The work of the arm is reinforced by the rotators of the trunk and hips. When the saw is pushed forward horizontally the abdominal muscles are required, and if it is pushed vertically upward it is the trunk extensors. Workmen prefer to have the piece that is to be sawed placed horizontally and then it is easily held by placing one knee upon it and the saw is pushed diagonally forward and downward. This makes it possible to use the weight of the body to reinforce the arm muscles and the extensors of the spine and hips can be used to raise the trunk again each time.

Plastering is another kind of work that calls for lifting and pushing. The soft plaster is rubbed onto the wall with a flat trowel and leveled and smoothed by rubbing the trowel against the surface with considerable force. When the wall to which the plaster is applied is overhead the triceps and arm-raising group, supported by the extensors of the trunk and limbs, do the work. Sometimes the workman leans backward, relieving the extensors of the trunk and bringing the strain on the abdominal muscles. When it is a side wall there is less elevation of the arms and more lateral pressure, involving the abdominal group, particularly of the side toward the wall.

The use of the carpenter's **plane** is much like ironing, but the movement of the tool is more extended and more in a straight line. Both arms can be used, bringing into action the extensors of elbows, pectorals of right and latissimus of left, each with their regular associates. The force and extent of movement is increased by rotation of trunk and hips to left and forward inclination of the body through the action of the flexors of the trunk and hips and extensors of right knee.

A similar case is the use of the **screw-driver**. Here the work of the arms, also explained in a former chapter, is supported by the same muscles as in sawing as far as the pushing movement is concerned, while the twisting movement brings into action various muscles of the trunk and limbs, depending on the height and direction of the tool. Another is boring with **bit and brace**. Here all the force at command is often needed to push endwise of the bit, the limbs being braced and the trunk leaned far forward against the tool while the right arm makes the circular motion by successive action of pectoral, deltoid, shoulder extensors and depressors of the arm. Still another interesting example is boring with an auger, in which a push of arms and body is combined with the twisting of the tool by the arms. This twist is made by the biceps group and pectorals supported by the upper serratus and the flexors of the right side of the trunk.

Driving a fast horse will illustrate pulling movements. When it is not necessary to pull very hard the arms do the work, supported by the rhomboid and by the extensors of the trunk and hips. If the pull must be stronger the arms remain straight and the pull is made by the trunk and hip muscles, the extensors of the knees possibly acting also.

The **cross-cut saw** is a long saw pulled by two workmen, one at each end. This is a pull by one arm usually; both arms may be used but even if they are the pull is one-sided. The rotators of the trunk and hips are employed here as well as the extensors of the trunk and limbs. The foot of the same side as the arm used is placed to the rear; this favors twisting of the hips to that side and the extensors of the forward limb work in the pull.

The use of the **pickaxe** or mattock is a good example of striking movements, using both arms at once and nearly in the same way. The tool is swung high overhead by the arm-raising group and the extensors of trunk and hips; then the arm-depressing muscles add their force to the weight of the tool and the abdominal muscles act to add to this the weight of the trunk. One foot is usually advanced to make it easier to keep the balance. Driving post with a sledge and chopping a log that lies flat are similar.

Chopping down a tree requires a diagonal stroke, down and sideward. The axe is raised over one shoulder and swings down and across the body, combining the rotary action of the body with the movement of flexion seen in the last examples.

Sharpening a stake with an axe held in one hand while the other holds the stake gives the one-sided type of striking movement. The striking muscles of the arm are here reinforced by the side musces of the trunk of the same side and by lifting the limb of that side, so as to put most of the body weight into the blow.

Beating rugs with a carpet beater, driving nails with a hammer, pumping water, and chopping with a hatchet are familiar uses of the arm depressors and triceps of one side assisted by the flexors of the trunk, especially of the same side, or by the weight of the trunk brought in to reinforce the blow by sudden relaxation of the extensor muscles. Both the weight of the trunk and the action of the abdominal muscles are apt to be used.

Hoeing is especially interesting because it illustrates how the muscular action and the posture of the body vary with the vigor of the work. The tool being light and being used in rather loose soil or in mixing mortar it is not lifted high like the pick but is moved up and down much more rapidly.

To make the hoe cut into the soil a blow is struck with varying force according to the condition of the soil. In some cases the weight of the hoe may be sufficient; then it is only necessary to use the arm-raising muscles and extensors of the trunk and let the tool fall; when a little more force is required the arm-depressing muscles act; with a slightly increased hardness of soil the arm depressors are reinforced by the abdominal muscles.

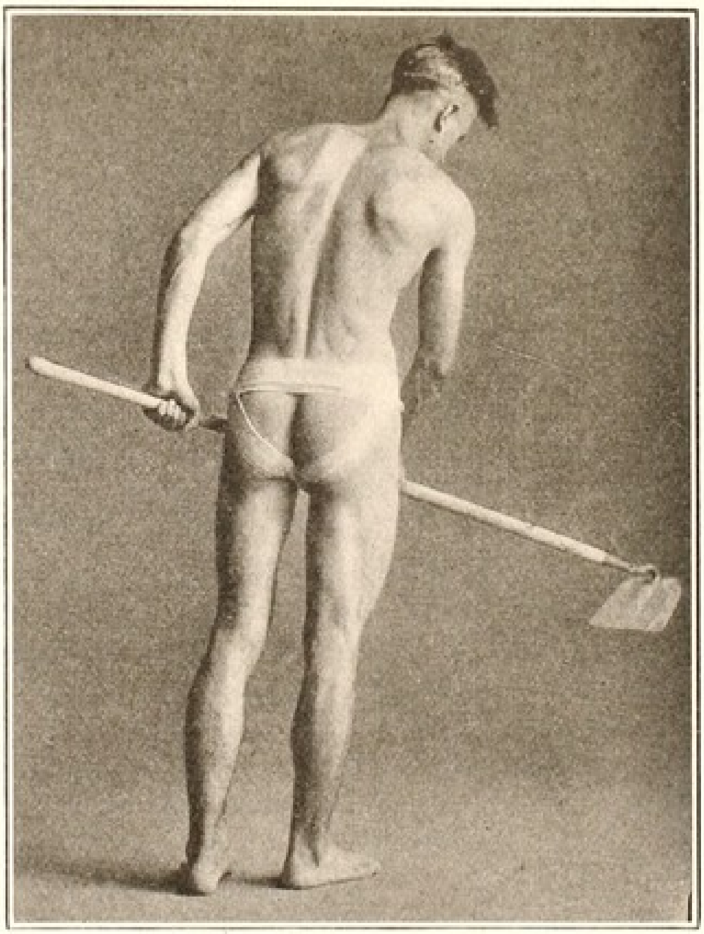

Fig. 204.—The action of the body in hoeing. The extensors in action as the hoe is lifted.

The gradual beginning of the action of the abdominal muscles in cases of this kind can be easily noticed by placing one hand on the table as the reader is seated and placing the other hand on the abdominal muscles. Begin with a slight downward push against the table and gradually increase it while feeling the condition of tension of the abdominal group. They are lax at first and only after a certain amount of arm depression is given do they begin to contract, but with any more of the downward movement they contract with each push of the arm.

The strong and rapid contraction of the abdominal muscles in hoeing soon begins to tire them and then the workman bends the trunk forward. The weight of the head and shoulders can reinforce the arm depression if there is a sudden relaxation of the extensors with each stroke. This makes it unnecessary to use the abdominal group but it soon becomes tiresome for the extensors, as they have to hold the weight of the trunk in a stooped position for most of the time and relax exactly with the stroke of the hoe. The result is that the workman unconsciously assumes a more and more stooped posture until he becomes aware of it and that it is tiring his back muscles; then he stands more erect until he forgets again.

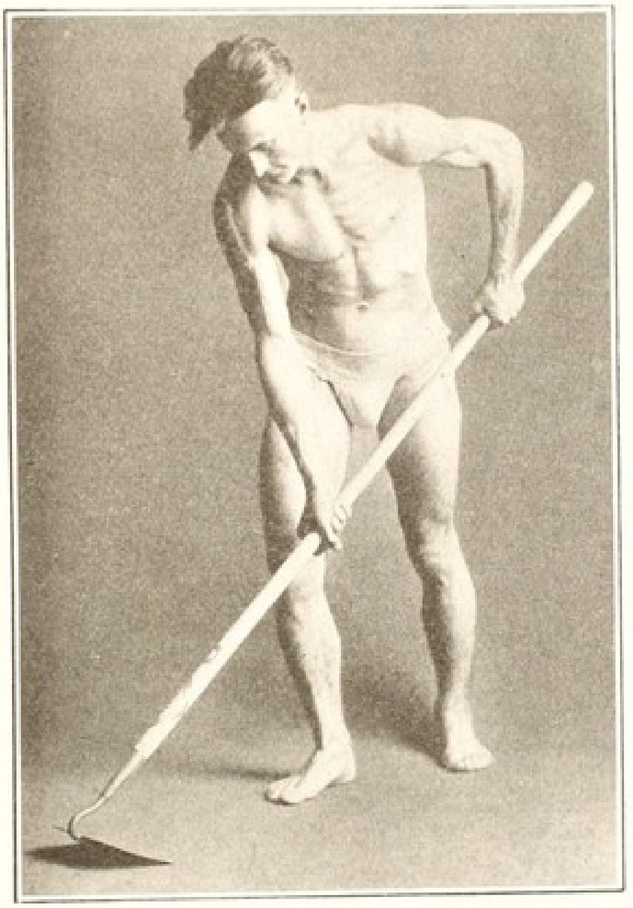

Fig. 205.—The action of the body in hoeing. The flexors of the trunk acting as the hoe strikes.

Mowing grass with a scythe is a horizontal stroke with the arms that must be supported by action of the rotators of the trunk and hips. The tool is made to cut as it swings from right to left. The arms are swung to left, shoulders twisted to left, right hip rotated outward and left hip rotated inward; then the tool is lifted by the arms and trunk and swung in the reverse direction above the level of the cut grass.

Sweeping with a broom is quite similar to mowing so far as the work of the body is concerned, while the vertical position of the broom handle makes the arm movement different. In sweeping toward the left with the left hand uppermost both arms act crosswise of the body, as in turning an auger; pectorals, anterior deltoid, upper serratus and flexors of elbows are in action. The arm movement is aided by trunk and hips turning to left as in mowing. The work of the body can be varied by sweeping the other way, but the arm work is nearly the same.

Turning a crank that is hung upon a horizontal axis, as in various farm, shop and household machinery, includes arm extension, depression, flexion and elevation in turn, supported by the flexors of the trunk in the first two movements and by the extensors in the other two. The trunk work is more prominent on the side of the active arm and the push and pull at the top and bottom of the turn bring trunk twisting into it. The support needed by the arm can often be supplied in part at least by use of the other arm, when a solid object is near that can be grasped by the free hand. The work of this arm is the reverse of that done in turning the crank.

When the crank is mounted on a vertical axis, as in some machines, the elevation and depression of the arm is eliminated and a movement sidewise and crosswise must be used. This is not so easily done by the arm, partly because of the location of the arm muscles but chiefly because the body weight cannot be used to reinforce the arm movement. The horizontal push must be reinforced by the abdominal muscles, the pull by the extensor group, and the lateral movement by the rotators of the trunk, using both sets in the two phases of the turn.

Walking is by far the most important type of locomotion in industrial lines.

The farmer has much walking to do over soft and uneven ground, the driving of team or stock occupying his attention meanwhile. As a consequence he is apt to develop the habit of a long and laborious stride that is not well suited to the smooth streets and walks of the town, giving him a reputation among townsfolk for awkwardness of gait.

The walking done by the man who drives the delivery wagon, involving jumping on and off the wagon and running along smooth walks and up the steps of dwellings gives him an elastic and graceful step.

Much of the walking seen in industry is combined with lifting and carrying, adding the action of arm muscles and increasing the work of the walking mechanism by the added weight.

Climbing in industrial occupations is most often the climbing of stairs and ladders.

Climbing stairs is one of the most violent of exercises, as to the total amount of work done, for it requires a lift of the whole body weight through many feet in a short time. It has been found that going up stairs involves as much work as walking thirteen times as far on a level place. Persons with well-developed extensors of hip, knee and ankle usually go up stairs in an erect position, while the old and weak incline the trunk forward, enabling the gluteus maximus to help. This of course adds much to the work of the erector spinæ and makes stair climbing a generally tiresome exercise, but it is necessary with those who lack the strength of limb.

Fig. 206.—Action of the whole body in climbing the ladder.

Climbing the ladder, common in the building trades and in spraying trees and gathering fruit from them, involves more balancing than climbing stairs, but when the hands are free they can be used to help in lifting the body. Grasping, flexion of elbows, and arm depression are the motions involved.

QUESTIONS AND EXERCISES.

1. Explain the peculiarity of walk developed by practice on rough ground. Are additional muscles brought in when the surface is rough or is it only a change in the way of using the same muscles?

2. What muscles are rested by changing hands in pitching grain?

3. A boy picking strawberries and another picking cherries change work. What muscle groups are rested in each boy.

4. One shoveler throws the clay from a trench six feet deep while another throws the same soil ten feet horizontally away from the trench. Is the difference mainly in quantity of work or in location of work in certain muscle groups? What would either gain by exchanging?

5. One workman dumps his wheelbarrow load sidewise while another dumps his load directly forward over the wheel. Explain the difference in the muscle groups employed.

6. What advantage is it to the washer-woman to have the tub and board placed below the level of her hips? Above it? What determines the best height for it in any case?

7. Make a list of occupations that tend to develop uneven shoulders; incomplete flexion of elbows; lateral obliquity of the pelvis; lack of the normal lumbar hollow in the back.

8. Make a list of occupations that tend to develop especially erect posture and carriage; strong feet and a springy gait; a strong back; strong abdominal muscles; a full chest.

9. Which is the best exercise for developing muscles unused by a dentist: golf, bowling, rowing, boxing or pulley weight exercises? For a postman? For a stenographer?

10. Why is one apt to hollow the back excessively in hanging up clothes? Explain the mechanism of the movement and the advantage of leaning backward at the waist.

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APPENDIX.

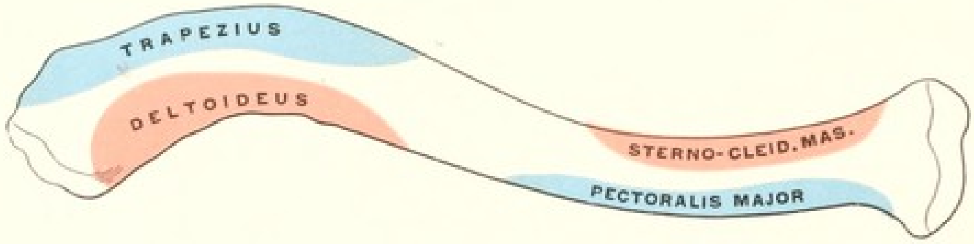

FIG. 207.—Areas of muscular attachment, upper surface of right clavicle. (Gerrish.)

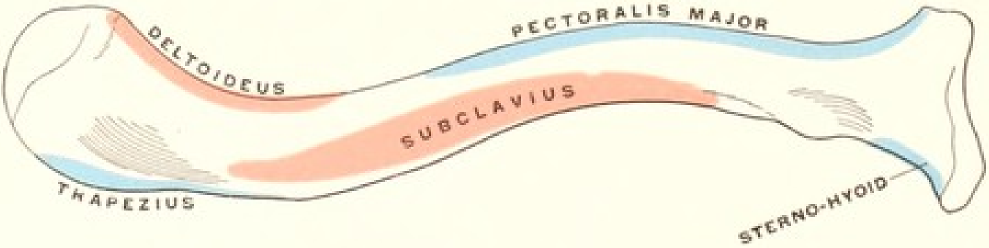

FIG. 208.—Areas of muscular attachment, lower surface of right clavicle. (Gerrish.)

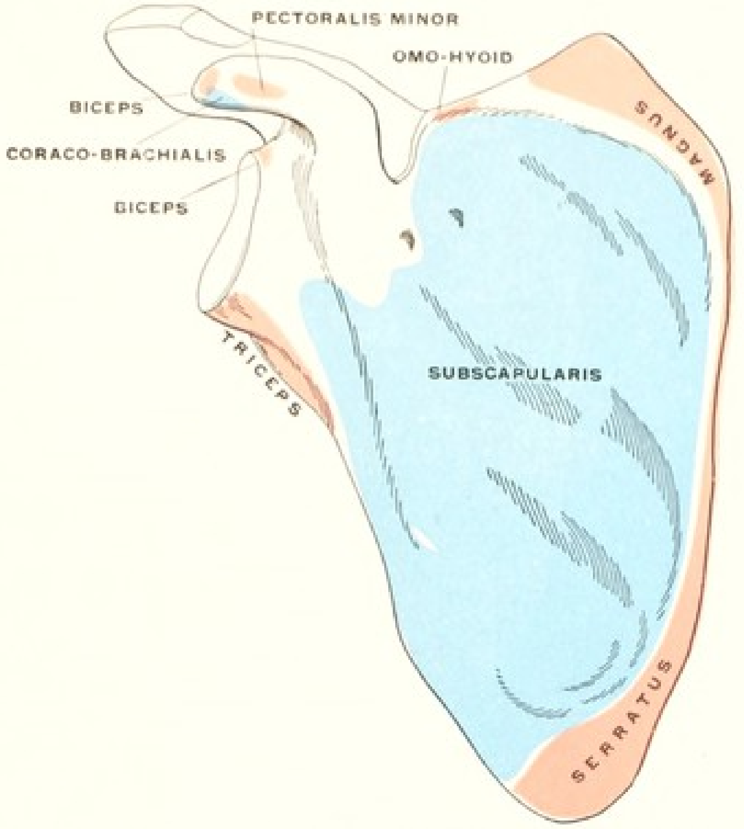

FIG. 209.—Areas of muscular attachment, ventral surface of right scapula. (Gerrish.)

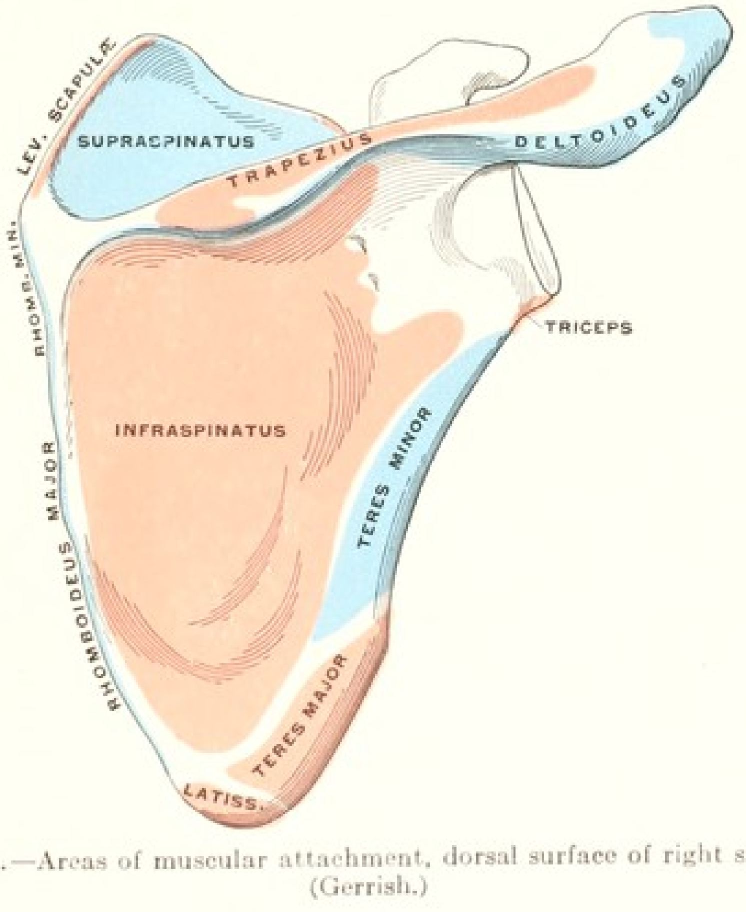

FIG. 210.—Areas of muscular attachment, dorsal surface of right scapula. (Gerrish.)

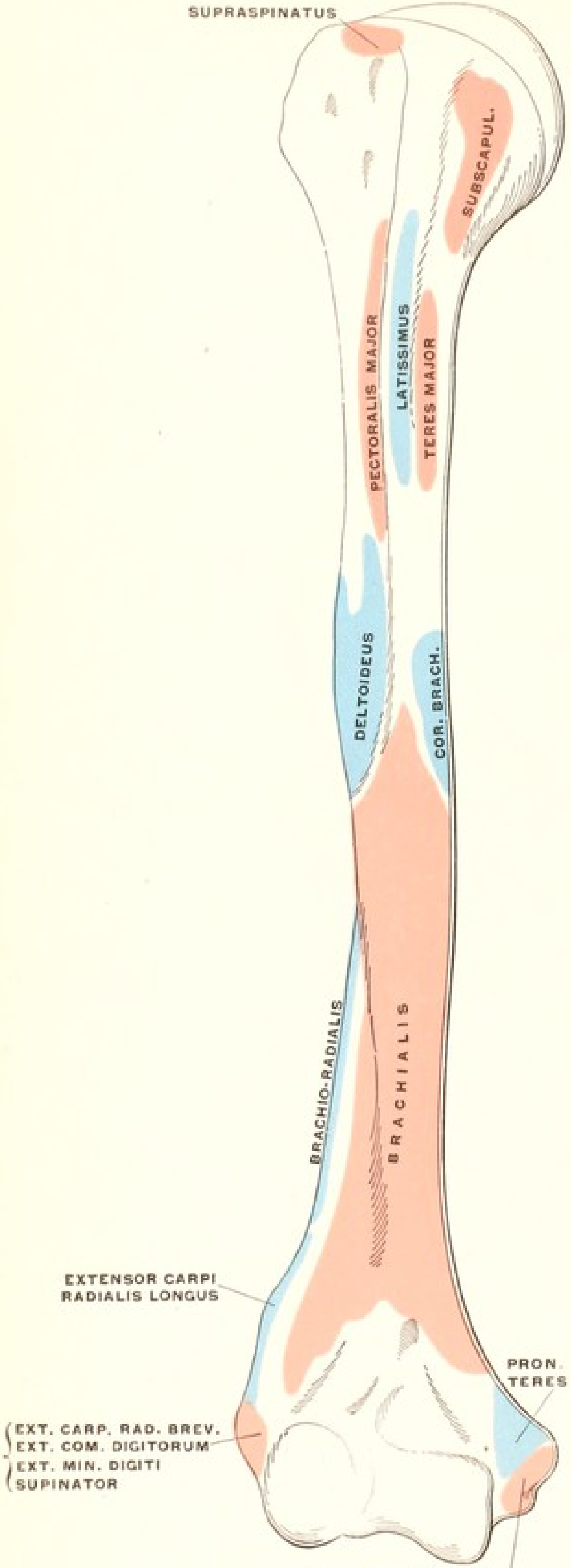

Fig. 211.—Areas of muscular attachment, ventral aspect of right humerus. (Gerrish.)

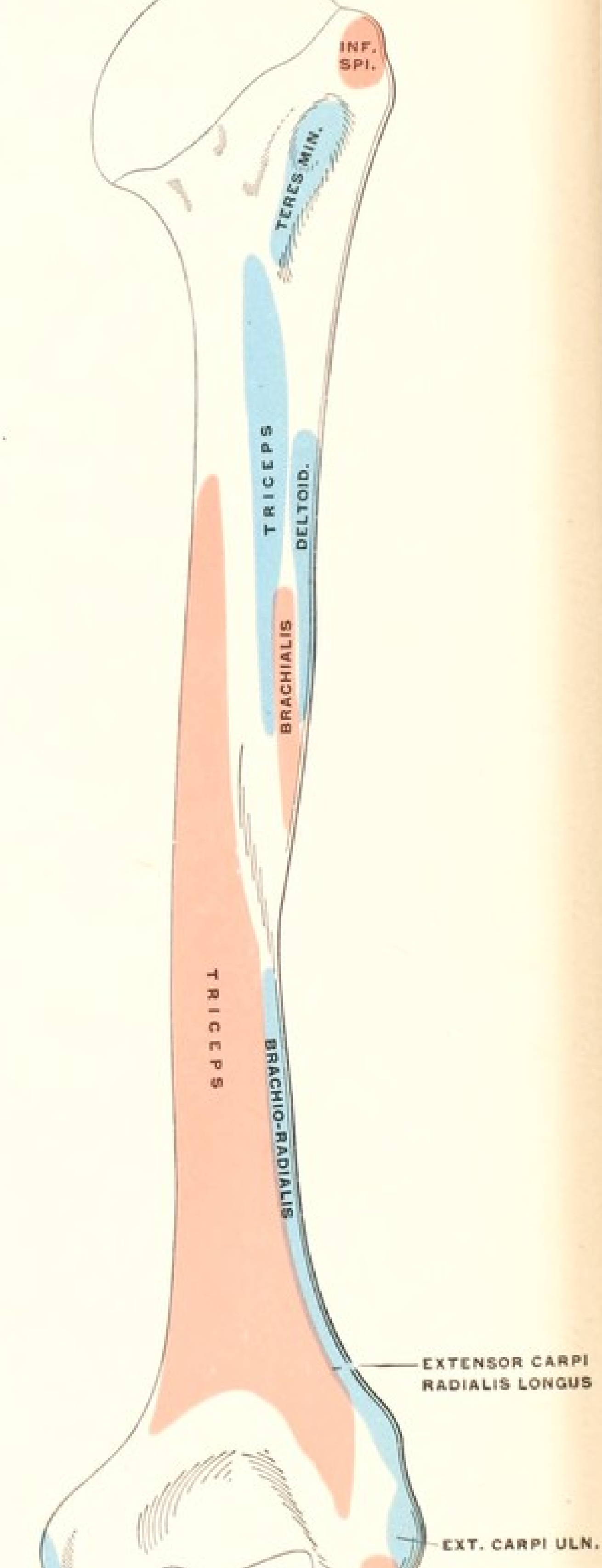

Fig. 212.—Areas of muscular attachment, dorsal surface of right humerus. (Gerrish.)

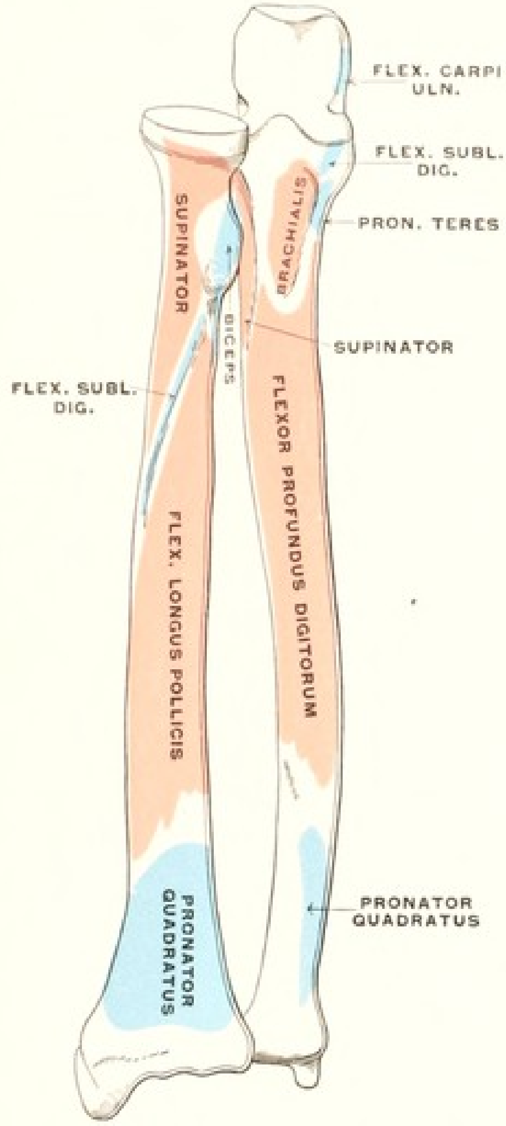

Fig. 213.—Areas of muscular attachment, ventral aspect of the radius and ulna. (Gerrish.)

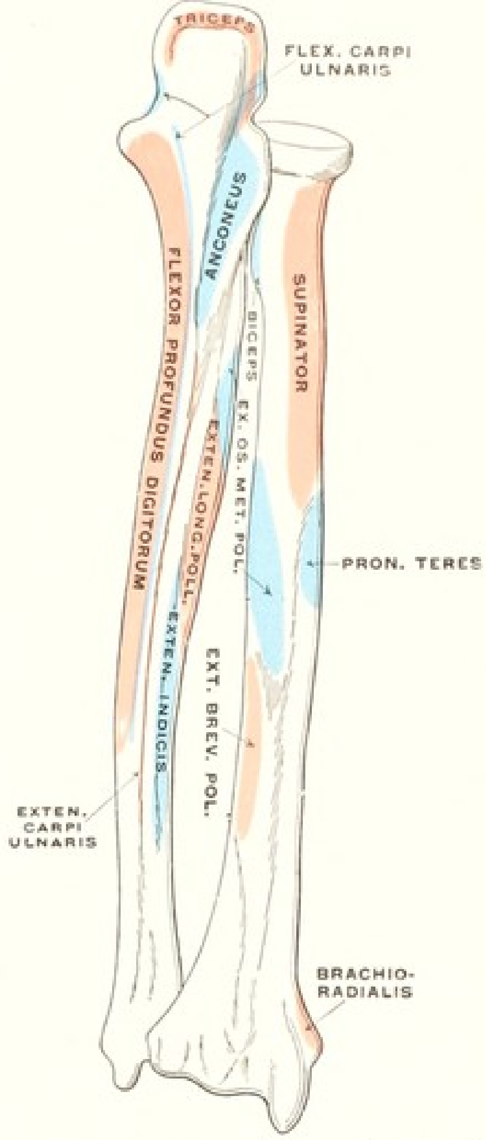

Fig. 214.—Areas of muscular attachment, dorsal aspect of radius and ulna. (Gerrish.)

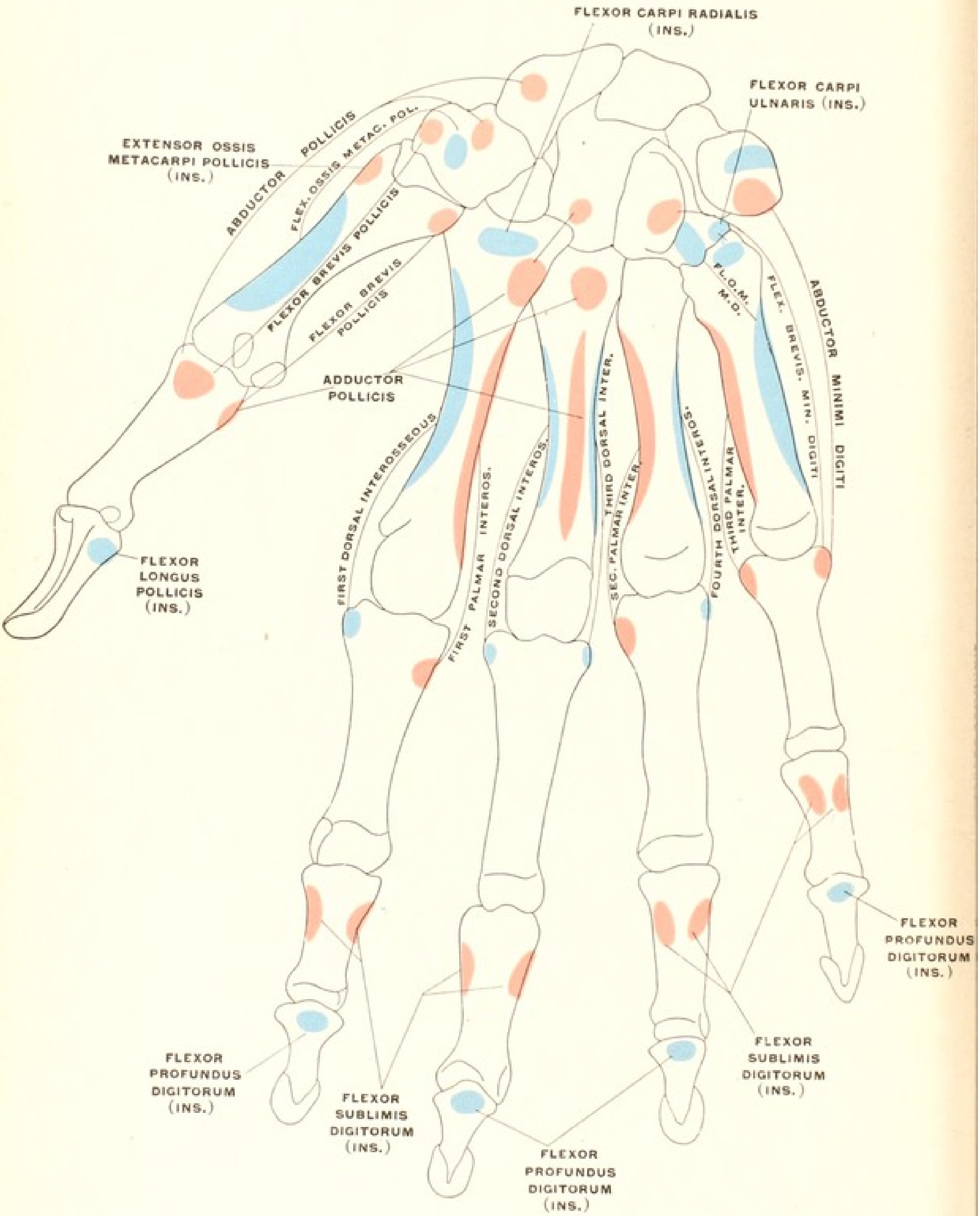

FIG. 215.—Areas of muscular attachment on the palmar surface of the bones of the hand. Where th areas of origin and insertion are both presented, they are in the same color. INS. = insertion; FL.O.M.M.D = flexor ossis metacarpi minimi digiti. (Gerrish.)

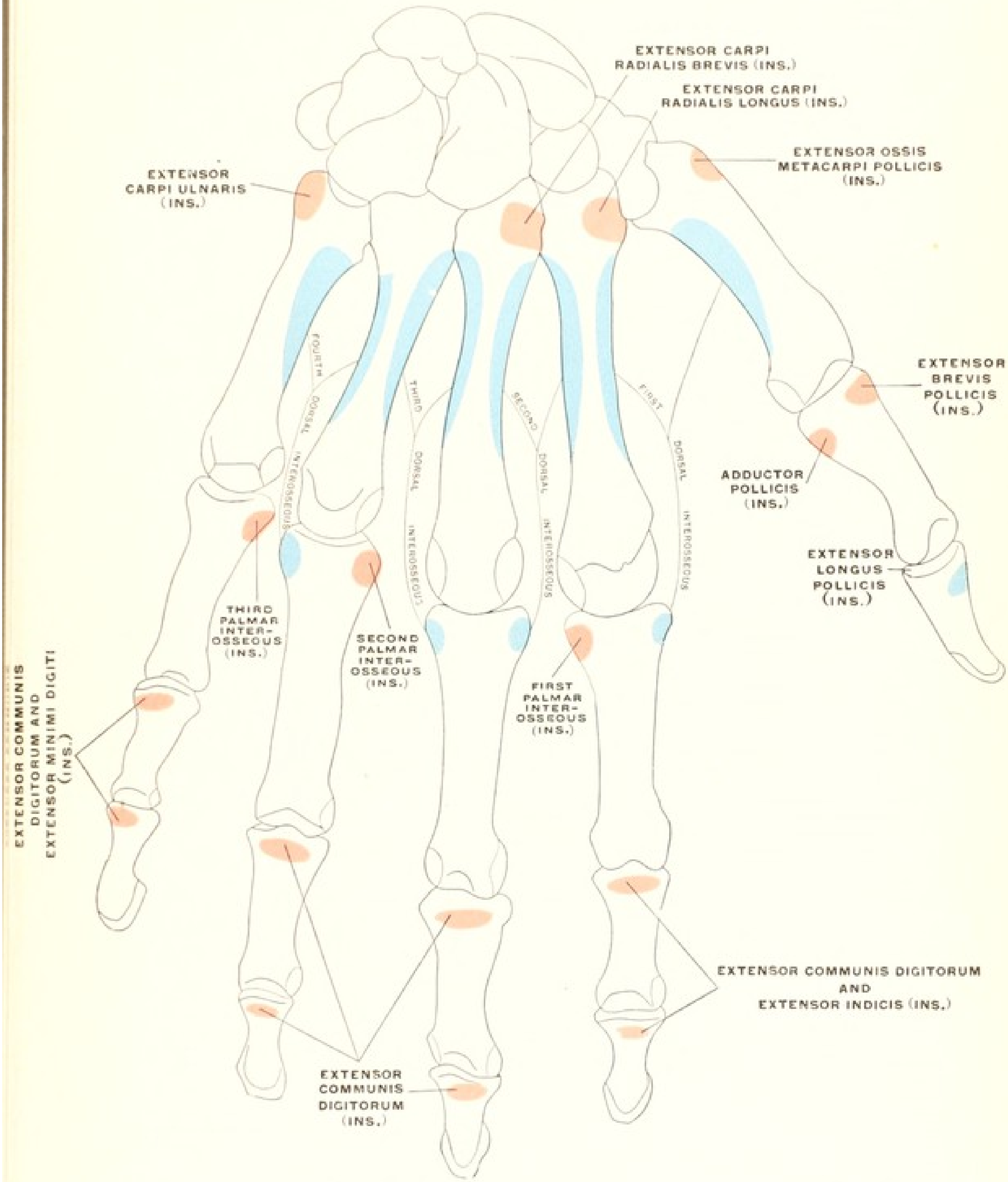

FIG. 216.—Areas of muscular attachment on the dorsal surface of the bones of the hand. Where the areas of origin and insertion are both presented, they are in the same color. INS. = insertion. (Gerrish.)

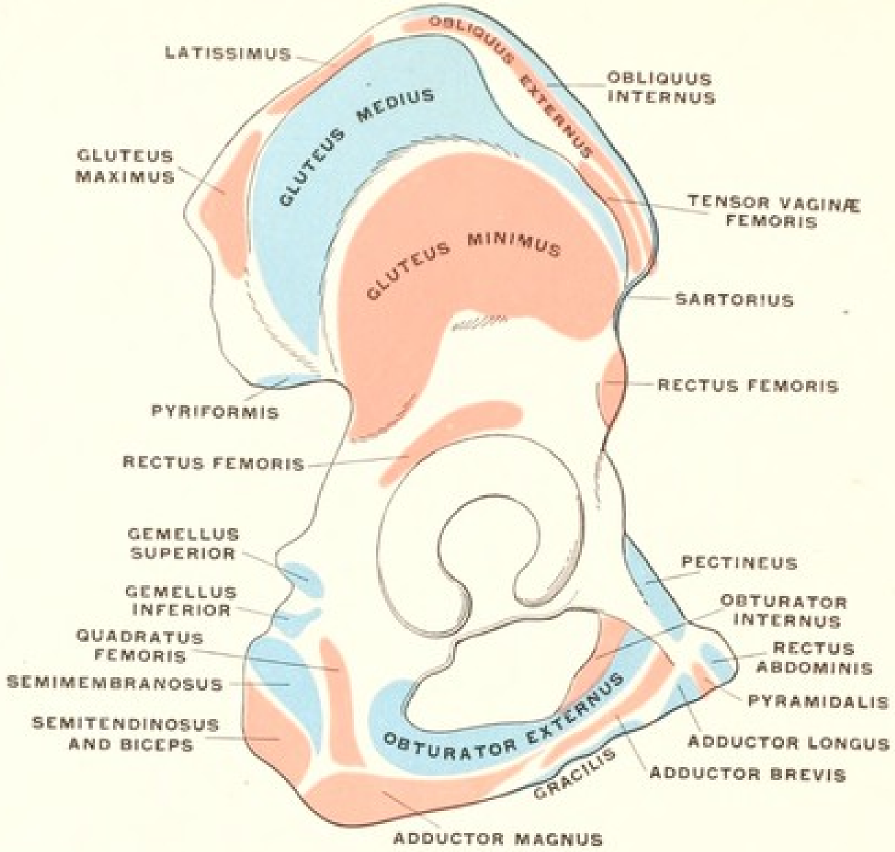

Fig. 217.—Areas of muscular attachment, outer surface of right hip-bone. (Gerrish.)

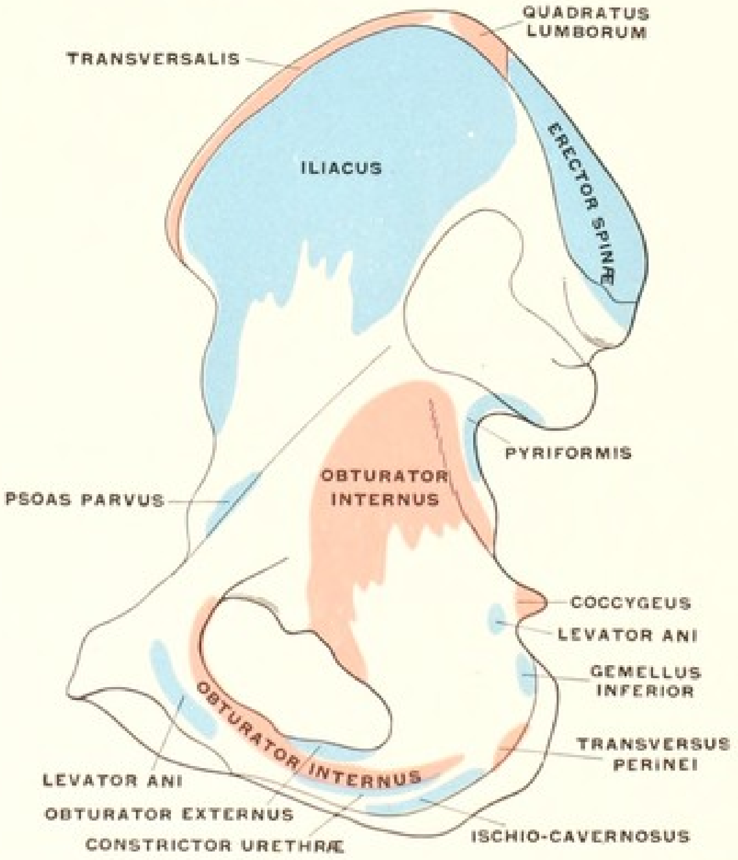

Fig. 218.—Areas of muscular attachment, inner surface of right hip-bone. (Gerrish.)

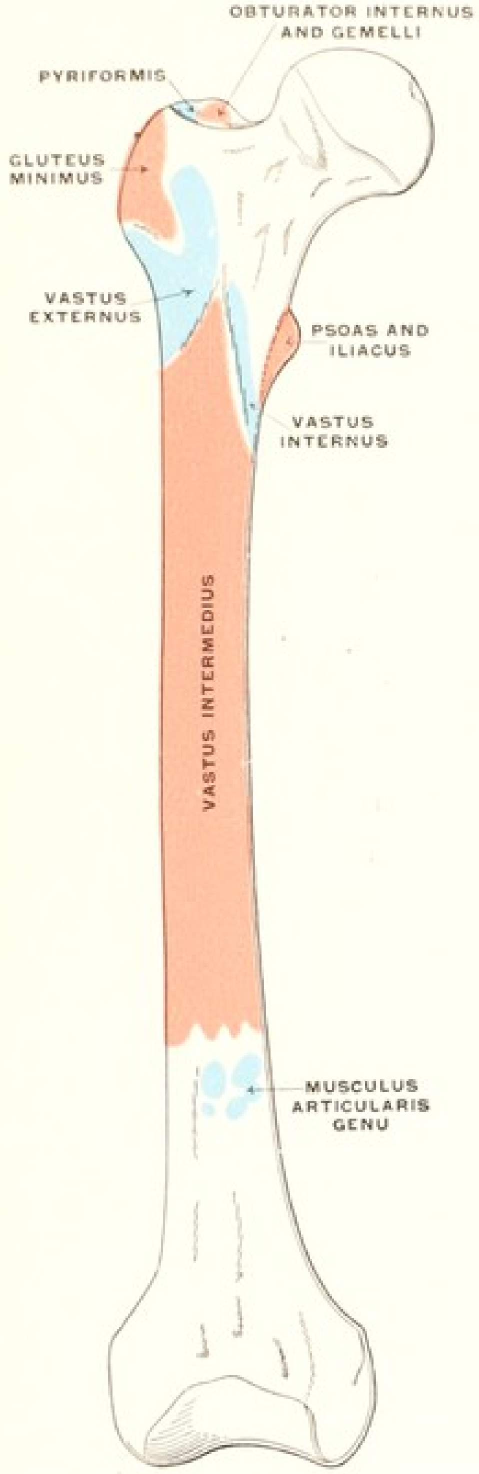

FIG. 219.—Areas of muscular attachment, ventral surface of right femur. (Gerrish.)

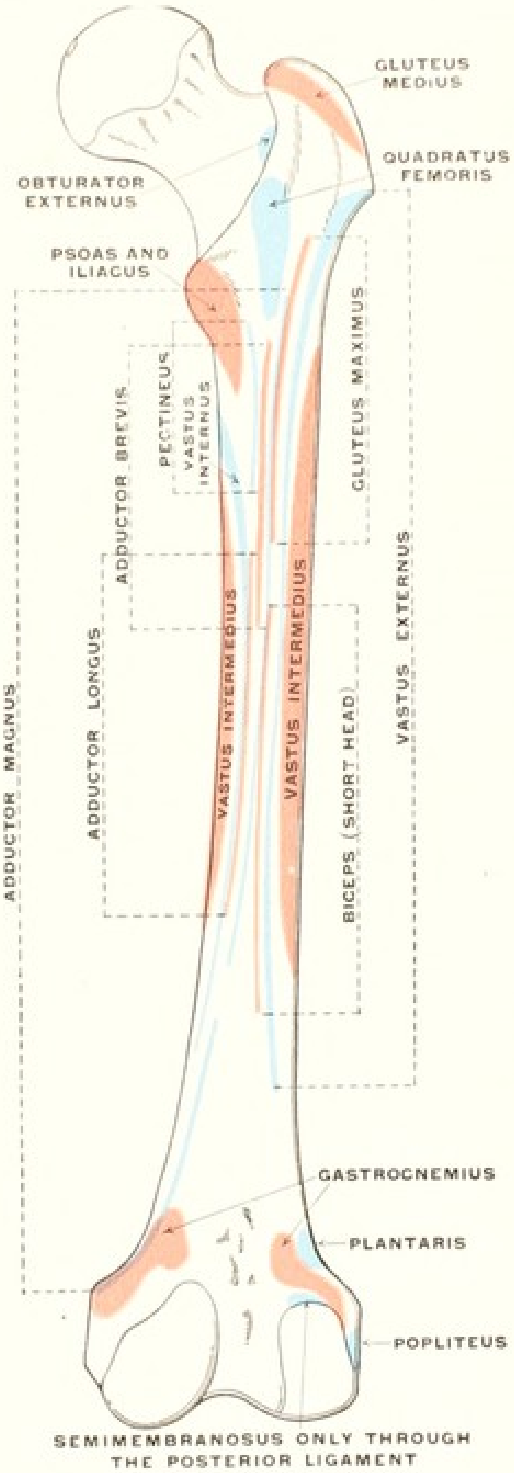

FIG. 220.—Areas of muscular attachment, dorsal aspect of right femur. (Gerrish.)

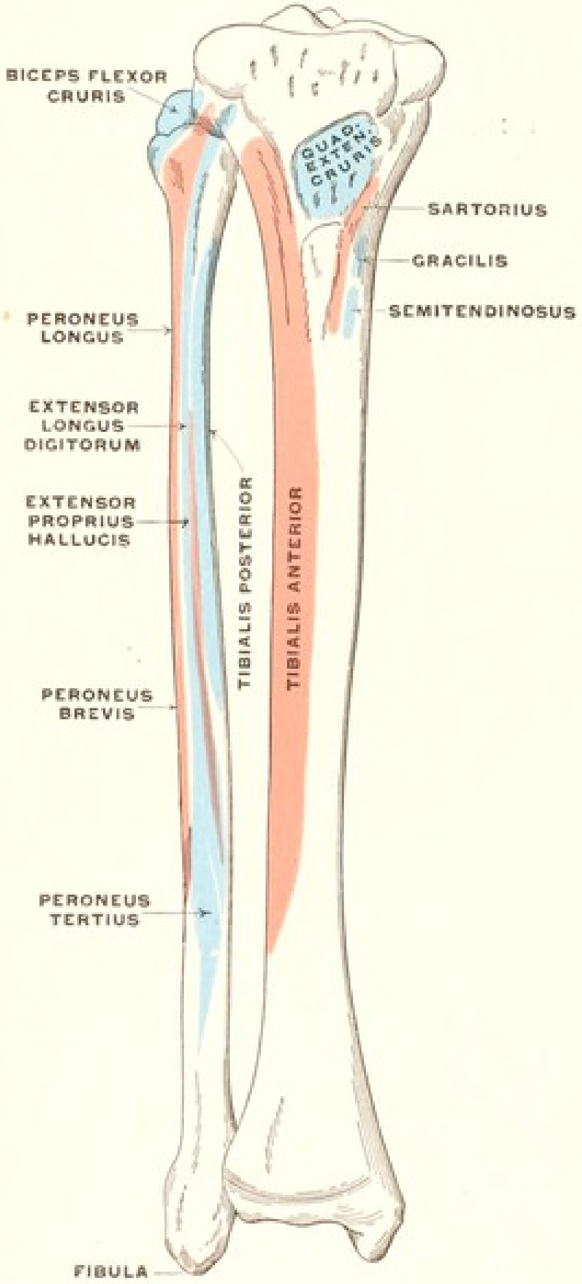

Fig. 221.—Areas of muscular attachment, anterior aspect of the tibia and fibula. (Gerrish.)

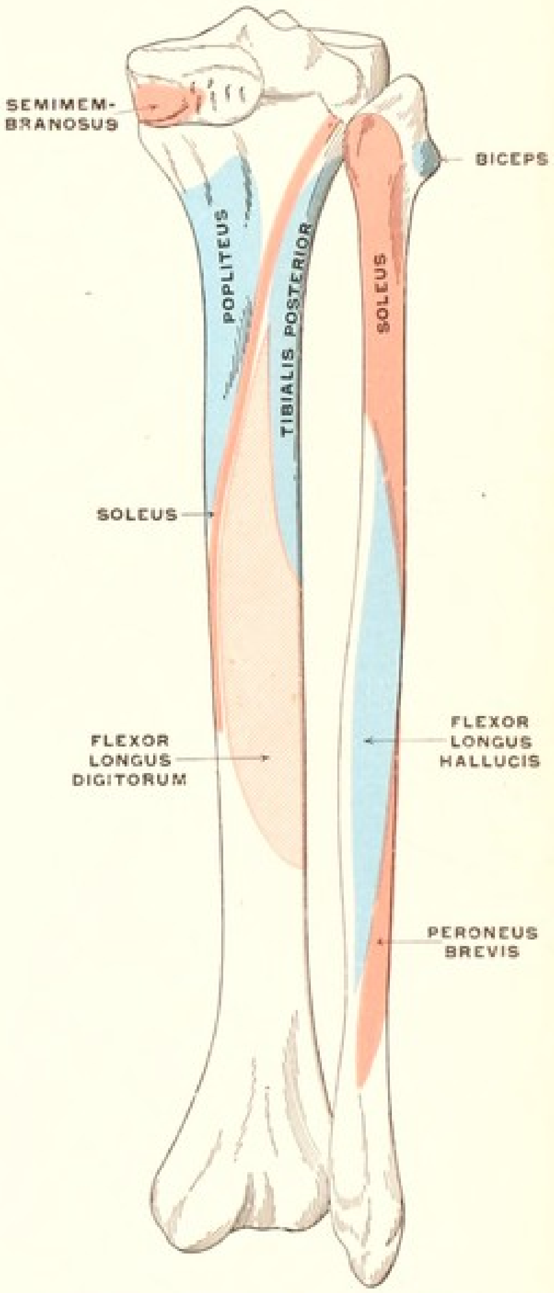

Fig. 222.—Areas of muscular attachment, posterior aspect of the tibia and fibula. (Gerrish.)

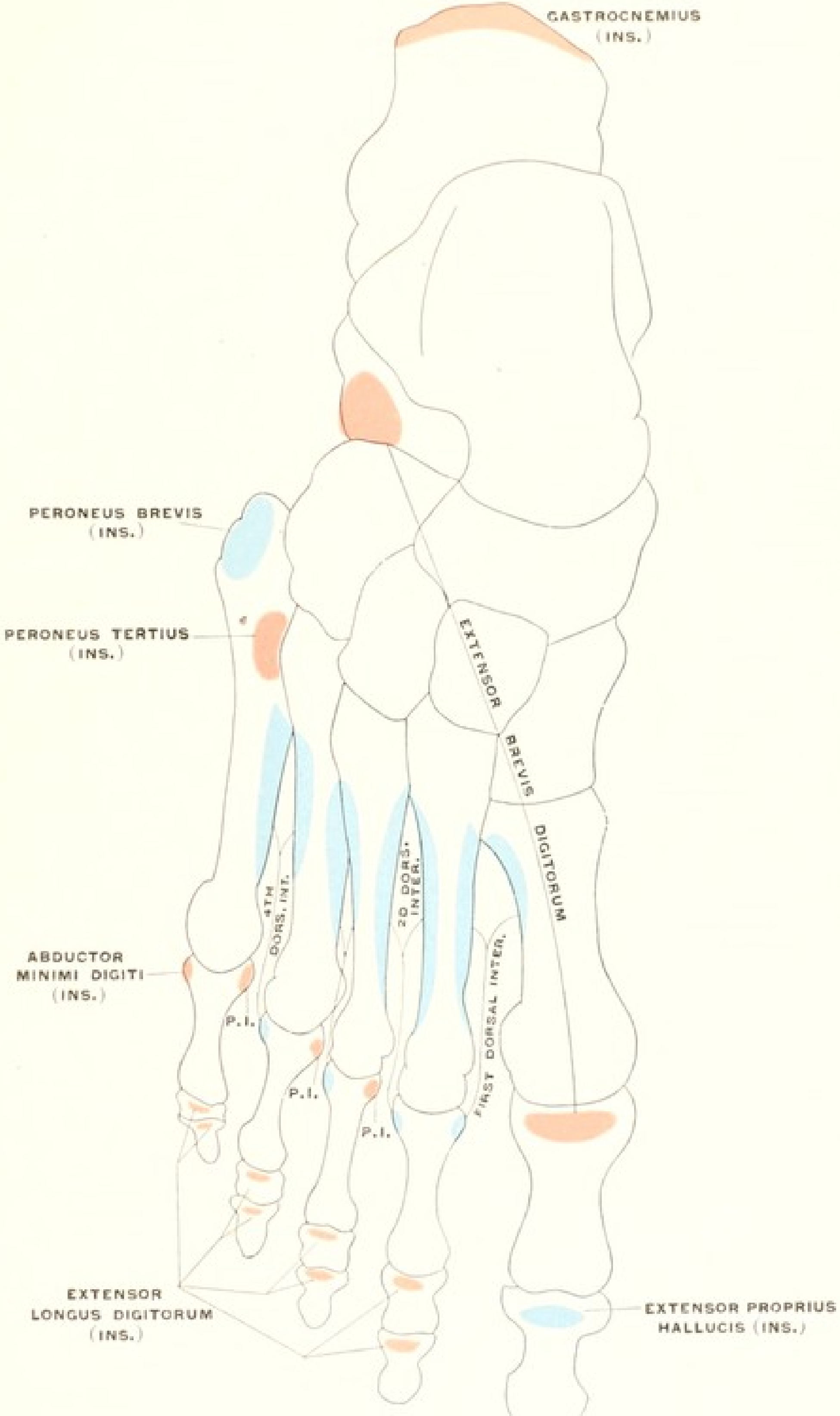

FIG. 223.—Areas of muscular attachment on the dorsal surface of the bones of the foot. Where the areas of origin and insertion are both presented, they are in the same color. The third dorsal interosseous is not labelled. P.I. = plantar interosseous insertion; INS. = insertion. (Gerrish.)

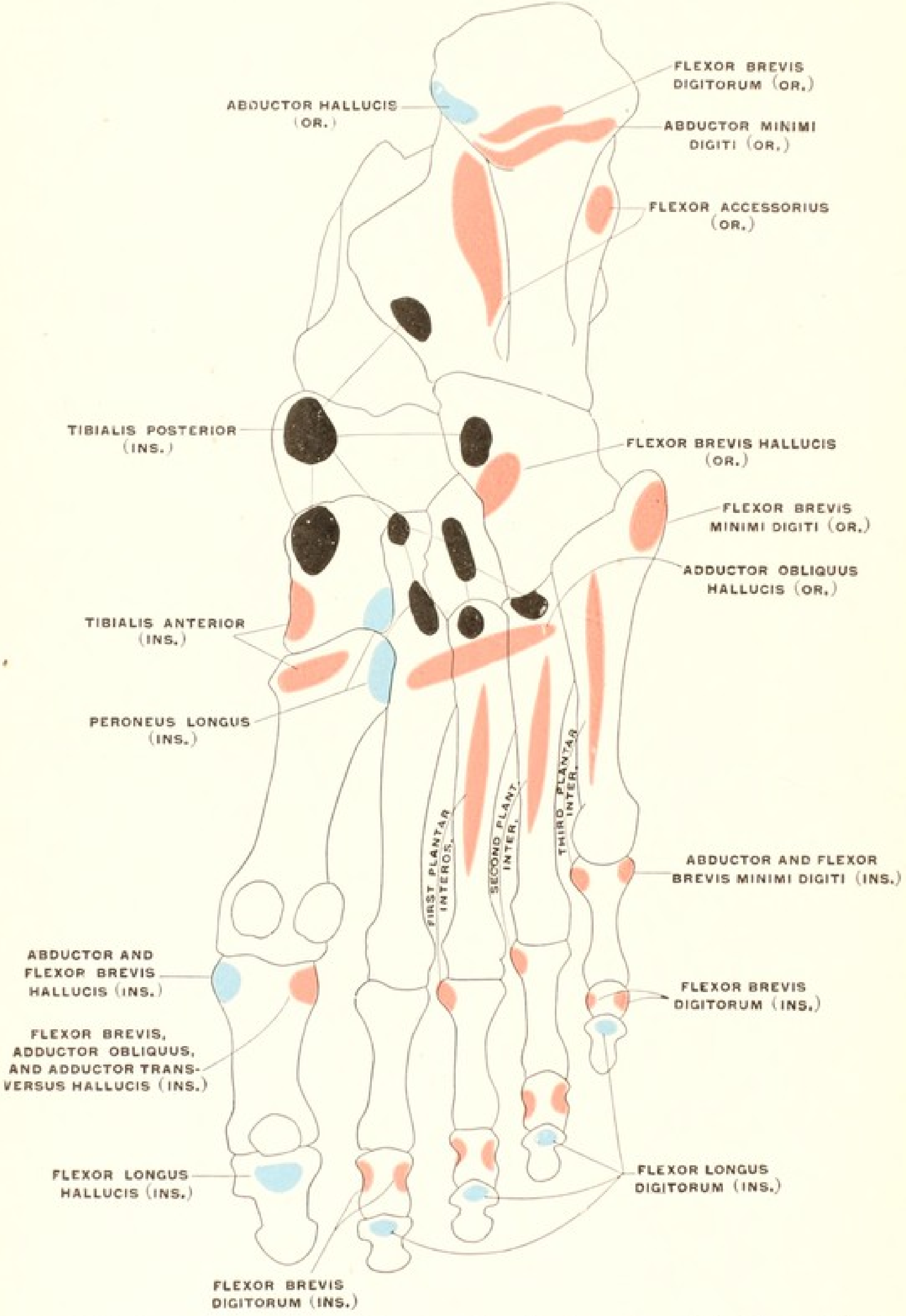

Fig. 224.—Areas of muscular attachment on the plantar surface of the bones of the foot. Where the areas of origin and insertion are both presented, they are in the same color. OR. = origin; INS. = insertion. The insertion of the second and third tendons of the flexor brevis digitorum are not labelled (Gerrish.)

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