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PHYSIOLOGICAL REMARKS

ON CERTAIN

MUSCLES

OF

THE UPPER EXTREMITY,

ESPECIALLY ON THE

PECTORALIS MAJOR.

By F. O. WARD, Esq.,

KING'S COLLEGE, LONDON.

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1836.

PHYSIOLOGICAL REMARKS

ON

THE MOTION OF THE ARM.

Read before the Royal Society June 16th, 1836.

THERE is a remarkable fold in the tendon of the pectoralis major, which, though described by all anatomists, has never yet, I believe, been explained. The muscle consists of two portions, one smaller and upper, arising from the clavicle, and passing downward and outward; the other larger and lower, arising from the sternum and ribs, and having a general direction upward and outward. The fibres of the muscle thus converging towards each other, terminate in a flat tendon several inches wide, which is attached to the upper part of the humerus.

Instead, however, of having the usual simple insertion represented in Plate IV. fig. 1, the lower part of this tendon is folded up, behind the upper portion, so that the margin B appears above the margin A, as represented in fig. 2.

As it is an axiom in physiology that every arrangement is to be accounted for, this peculiar twist has given rise to several speculations. Some suppose it designed merely to diminish the extent of the insertion. Others believe it to have the effect of equalizing the length of the muscular fibres. But independently of the consideration that the insertion would have been quite as compact if the tendon had been thick and single, instead of thin and double; and that the fibres are *not* by any means equal in length, according to the second hypothesis;—both explanations are defective, in as much as they show no reason for the muscular fibres crossing each other, so that the upper are attached *below*, and the lower *above*, the medium point of the whole insertion.

I think that the arrangement becomes perfectly intelligible when the separate actions of the upper and lower portions of the muscle are considered with reference to the species of motion those actions require.

The separate action of the lower fibres is to depress the arm when raised; that of the upper fibres, to raise the arm when depressed. Of this any person may convince himself by laying the hand on the muscle; first, while imitating the action of hammering; and then, while raising or supporting a weight: in the former case he will perceive a momentary convulsive contraction of the lower fibres; and, in the latter, a steady, continued tension of the upper.

In the third and fourth sketches which exhibit these positions, the several directions of the humerus, and of the upper and lower portions of the muscle, are represented by lines, the arrow-head denoting in each figure which set is exerted, and in what direction it acts.

Now since the humerus is a lever having the fulcrum at one end and the resistance at the other, the velocity it acquires must be directly, and the force inversely, proportionate to the proximity of the moving power to the fulcrum.

The most common, and therefore most important purpose, to which the depressing fibres are applied, is that of bringing down the arm in using the hammer, pickaxe, &c., as the carpenter, blacksmith, goldbeater, and a hundred other artizans testify. In these motions velocity alone is required from the muscle, the gravity of the tool giving force to the blow; and to produce this velocity the lower division is attached near to the fulcrum. Again, the commonest employment of the upper fibres consists in such actions as lifting, drawing, and the like, in which force, not velocity, is the desideratum; and, in order to obtain force at the expense of velocity, the insertion of these fibres is brought down as far as possible towards the resistance.

It is remarkable that, in each instance, that very fasciculus of the muscle, which possesses most of the action peculiar to its division, possesses likewise that very point of the insertion which affords it most of the leverage it requires. Thus it is not the uppermost portion, *a*, of the elevating division, (see the Italic letters in figs. 2 and 4,) which is attached to the lowest point, D, of the insertion, because there are succeeding fibres (as *b*, figs. 2 and 4,) which form a less acute angle with the humerus while *depressed*: whereas it *is* the lowermost fasciculus (C, fig. 2,) of the lower division, that seeks the highest point, B, of the insertion, because this portion forms the least acute angle with the humerus when *elevated* (see fig. 3). This trait adds another to the innumerable proofs of the *minute* accuracy of the animal organization.

Any action which requires from either portion, a species of motion contrary to that which it is adapted to produce,—as raising the body by the hands, which requires force from the fibres of velocity,—soon fatigues the muscle. Turning a winch, which is another instance of the same kind, is notoriously a very disadvantageous application of human strength; and any employment in which steady and forcible pushing has to be performed by the arms raised above the head, is extremely fatiguing. In throwing a heavy quoit, which requires both accuracy and force, the arm is swung by the side; but in throwing a light ball, for which velocity is requisite, the arm is always swung above the head. Cricketers are practically such good physiologists in this respect, that they have enacted a law which compels the bowler to swing his arm by his side in throwing the ball,—because, if the ball were flung "over-handed" at the wicket, from so near a point as the bowler's station, its velocity would be unmanageable; whereas the "long-throw" who has to send up the ball from a distance, always swings his arm above his head.

The muscles associated with each division of the pectoralis major bear out the proposed explanation by the analogy of their insertions. Thus the coraco-brachialis, and the anterior fibres of the deltoid, which cooperate with the upper division of the pectoralis major, are attached to the front of the humerus, half-way down; evidently for the purpose of gaining force, which they do want, at the sacrifice of velocity, which they do not.

On the contrary, the teres major and latissimus dorsi, which assist the lower division of the pectoralis major in depressing the humerus, act, like that muscle, near the fulcrum of the lever; being attached to the inner margin of the bicipital groove, just opposite to the pectoralis tendon. These two muscles, indeed, are in several respects analogous to the two divisions of the pectoralis major. The teres major, which is superior and smaller, and arises from the scapula, may be compared to that portion of the pectoral which is superior and smaller, and arises from the clavicle; and the latissimus dorsi which is inferior and larger and arises from the vertebræ and ribs, resembles that portion of the pectoralis major which is inferior and larger, and arises from the sternum and ribs. The tendons of the two dorsal, like those of the two pectoral muscles, are continuous at their lower margins, and, as if to render the analogy complete, (though, in fact, to render the leverage suitable,) the lowest fibres of the latissimus dorsi are folded around the teres major, and inserted above it into the humerus; because they are most nearly at right angles with the bone when lifted to strike, and therefore most effective in drawing it down. Fig. 5 is a front view of the insertion of these two muscles, B representing the teres major, C the latissimus dorsi folding round it to gain a higher point of attachment, A the tendon of the pectoralis major raised out of its natural position, and D the bicipital groove to the borders of which these muscles are attached. The proposed explanation is further borne out by the comparative anatomy of the pectoral muscle in birds, in which it is developed to a very large size on account of being the principal motor of the wing. In these animals there is no crossing of the fibres of the pectoralis; they all assist in performing one action, and are consequently inserted in regular order, those which are superior at their origin having also a superior insertion, and *vice versâ*, as may be seen in fig. 6, which is a sketch of the pectoral muscle of a pigeon. The turning under of the fibres represented at *a* seems at first sight to indicate a decussation of the upper and lower portions of this muscle, similar to that which occurs in the corresponding organ of man. But the resemblance disappears when the muscle is divided along the dotted line *b c*, and the humeral portion reflected as in fig. 7. It then becomes evident that the lower fasciculi though forming a little bundle partly distinguishable from the rest of the muscle, and inserted by a separate slip of tendon, nevertheless join the bone *below* the upper fasciculi, and *below* the central point of the whole insertion. Professor Rymer Jones, who very kindly examined with me the muscles of the breast in the pigeon, confirms the accuracy of this observation.

There is, however, an action, which, as it furnishes man with his most obvious means of self-protection, must have been carefully provided for by Nature, and which seems to throw doubt on the correctness of the foregoing explanation. I mean the action of throwing the extremity forward, as in boxing. In this action, which requires great velocity, although *all* the fibres of the pectoralis major are in some measure brought into play, the *upper* set, that namely of least velocity, are, it must be admitted, the principal agents, so far as this muscle is concerned: in other words, Nature, according to my explanation, causes a muscle to work at disadvantage, in an action of essential importance.

This, I think, is only an apparent difficulty, for in this motion as correct a balancing of leverage is displayed, as can anywhere be found throughout the body.

The fist is thrown forward by a double motion. The humerus, represented by A B, fig. 8, revolves round the point A till it takes the position A C, while the forearm, represented by B D, revolves round the point B till it takes the position B E, so that the resulting position of the whole extremity is A C F. The upper division of the pectoralis major, the anterior fibres of the deltoid, and the coraco-brachialis, are the main causes of the first motion; the triceps, anconæus, and supinator muscles, of the second.

The distance which the forearm passes through, represented by the curve 2, exceeds considerably the space traversed by the upper arm, represented by the curve 1; but as the motion of the forearm round the point B is from above downwards, its extensors have no weight to raise; on the contrary, are assisted by gravity. Whereas the humerus, though it moves through a shorter distance, moves upward, and carries with it the forearm, so that its elevators have to raise a considerable weight. In order that these two motions may be completed in the same time, the former requires the greater velocity, the latter the greater force. Accordingly the triceps and its associate extensors, act on the ulna by a lever between one and two inches long, while the three elevators of the humerus act by levers whose respective lengths are about four, five, and six inches. See figs. 8 and 9, in which P represents the tendon of the pectoralis major, D that of the deltoid, C that of the coraco-brachialis, and T that of the triceps.

I may just add, (for it is interesting to observe the unconscious acquaintance which every man has gradually acquired with the precise capabilities and most effective application of every fibre in that complicated machine, his own frame,) that in preparing to strike a blow the elbow never hangs close to the side, as in fig. 11, but is always thrown out, as in fig. 12; in order that the elevator muscles, all of which draw more or less inward, as well as upward and forward, may act during the strong effort at their full advantage.

Thus, then, not only is the leverage of the upper and lower portions of the pectoralis major accurately adapted to the actions of lifting and hammering which they respectively perform, but it is so proportioned to the leverage of the triceps, that the two muscles cooperate harmoniously in the action of striking a blow forward; unequal spaces being traversed and unequal resistances overcome, in the same period of time, so that the resulting position of the limb is precisely the one required: while the strength of the one set of muscles bears such proportion to that of the set with which it acts in concert, that both remain unfatigued for the same number of actions.

It is this DIVERSIFIED adaptation of parts, which forms the chief characteristic of the mechanism of Nature. Working with unlimited means, she yet works with scrupulous œconomy; in her structures no power is redundant, nor a single advantage lost; so that, however completely an arrangement may subserve one primary purpose, we find, upon renewed examination, an equally accurate adjustment to several secondary ends.

When the means of estimating with precision the contractile force of the muscular fibre, are obtained, I have no doubt that these compound relations of power, lever, and motion produced, will form an interesting study*.

Magendie † observes, that the intensity of muscular contraction depends partly upon certain peculiarities in the organization of the fibres, such as size, firmness, colour, &c., and partly upon the energy of the cerebral influence, or the "puissance de volonté," by which they are excited to action. Muscles acquire far more than their ordinary power, during those affections of the mind which stimulate the brain to strong action, such as rage, madness, &c., and also during certain convulsive

* Borelli in his posthumous work *De Motu Animalium*, published in 1680, has entered into an elaborate analysis of the mechanical relations of the body, with a view to determining the absolute force of the muscles. But unfortunately his experimental data (see, for instance, *Pars prima*, cap. 8,) are as loose and unsatisfactory as the subsequent calculations are minutely accurate; and his reasonings are interwoven with a purely speculative hypothesis of the nature of muscular fibre, which he supposes to consist of minute rhomboidal vesicles, contractile by inflation. By these means he brings out very startling results. Thus to the flexor longus pollicis manus alone, he attributes a tractile force of 3720 pounds; to the deltoid of 61,609 pounds; to the intercostals of 32,040 pounds; to the glutæi of 375,420 pounds, &c. (see cap. 17, prop. cxxiv. *et seq*) Dr. Bostock considers his estimate of the force of the muscles of the thumb to be a hundred times too great. He has not noticed the twisted tendon of the pectoral in man, nor calculated its force and leverage. The only remarks upon its strength I can discover, are in cap. 22, prop. cciv., where, from its small relative size, he proves it to be impossible "ut homines propriis viribus artificiosè volare possint."

† *Physiologie*, vol. i. p. 275.

diseases which have similar cerebral effects. From these and some other facts adduced, he infers that cerebral influence on the one hand, and certain qualities of the muscular tissue itself on the other, are the two elements of muscular contractility.

Mayo has indicated a method of determining the maximum strength of individual muscles, by ascertaining the weight that is required to rupture their tendons. This mode is founded upon the argument that the tension which the tendon can sustain, probably exceeds but little that which the fibres can exert; a supposition which is analogically probable, and in some measure supported by facts, since in præternatural contraction sometimes the tendon, sometimes the trunk, of a muscle gives way*; proving that there is no *great* difference between the active and passive strength of these organs.

The constant and equable stream of galvanism, afforded by Daniell's new battery, will furnish, I think, a good means of comparing the strength of muscles, of regular shape and equal size, by ascertaining the contractile force it induces in its passage through each.

In order to subject any muscle to this experiment, it should be separated from its fellows, and, at the distal end, from its insertion. By the tendon, thus detached, it should be connected with a spring moving an index; and the bone, into which its opposite extremity is inserted, should be firmly fixed at a known distance from the spring. The trunk of the muscle should then be made part of the circuit; and the distance to which it moved the index during the transmission of the current for a given period (say one minute) might be taken to express the force of the muscle as compared with others submitted to the same treatment†.

The comparative dimensions and weight of such muscles as resemble each other in colour, firmness, and texture, would also probably bear some proportion to their comparative force.

Although neither of these methods of estimating muscular contractility could be depended on alone, yet by a judicious application of each in turn, to corroborate or correct the results furnished by the others, a close approximation might at last be obtained. And since we have proof that there is an accurate balancing of muscular force in the fact that muscles, or sets of muscles, working together, are fatigued equally and simultaneously, we may fairly expect that whatever the ab-

* See *Tetanus*, Cooper's *First Lines of Surgery*.

† The contraction of the muscle only occurs at the instants of completing and interrupting the circuit. Contact must therefore be broken and renewed at regular intervals during the experiment; which is readily effected by means of a pendulum connected with the wire. See Becquerel's *Traité de l'Electricité*, vol. iv. p. 306.

solute strength of muscles in different individuals may be, their relative strength will be found nearly alike in all, exception being of course made for the influence of habitual employments upon particular muscles. If, for example, in one arm the power of the biceps were one, and that of the triceps two, in another arm the power of whose biceps was two, that of the triceps would be four, or thereabouts; or if not so, the difference would be compensated by a counter-variation in the leverage.

It is also probable that in the same individual, under various conditions of lassitude or excitement, whether produced by bodily or by mental affections, each muscle retains its normal relation in point of strength to the others, whatever may be its actual gain or loss of contractility. So that if this ratio were once established by the mean results of cautious experiments, it would be possible, from the absolute strength of one muscle, or set of muscles, to deduce by calculation the absolute strength of each of the remaining muscles in the same individual. We should of course meet with irregularities; some caused by disproportionate growth, and bearing an ascertainable relation to its degree; and others depending on circumstances beyond the range either of observation, or of calculation; but if a standard proportion does really exist, the deviations from it are certainly in opposite directions, and the true ratio will be discovered by taking the average of an extensive series of measurements and estimates. And when we reflect that within the last few years constant numerical proportions have been developed by Wenzel, Berzelius, Dalton, and others, in the chemical affinities of ponderable matter, and by Faraday in the action of the imponderable forces; and—still more to the purpose—that mathematical laws so fixed and definite as to serve for the distinction of species, have been discovered by Schimper and Braun* to regulate vegetable growth; it seems not unreasonable to surmise, that numerical proportions, as certain and invariable, may govern the secret workings of animal life, and be hereafter revealed by the discovery of accurate, though involved, mathematical relations, between the several organs of the animal machine†.

A rigorous analysis of the mechanical relations of the mus-

* *Archives de Botanique*, vol. i.; Martin's Abstract of Braun's Paper; Henslow's Introduction to Botany, p. 124; Lindley's Introduction to Botany, second edition, p. 91. Lindley thus states the result of the inquiry: "The whole of the appendages of the axis of plants,—leaves, calyx, corolla, stamens, and carpels,—form an uninterrupted spire governed by laws which are nearly constant." For the causes of the occasional deviations from these primary laws, see Henslow's Introduction, § 121.

† I trust that an hypothesis thus indicated by the analogy of several ascertained laws, capable of inductive examination, and whether erroneous

cular and osseous systems in various animals, would form a good foundation from whence, in future, to push forward such inquiries; and, besides this remote and dubious utility, contingent on the soundness of the foregoing speculation, such researches would be of considerable immediate advantage to science. They would give the geologist a new point of view in which to examine fossil bones, and might enable him to deduce, from the relative size, shape, and situation of the marks indicating muscular insertion, new particulars concerning the strength and speed of extinct creatures; they would probably point out to the comparative anatomist analogies and differences in the structure of animals, where none have hitherto been suspected; and above all, they would tend to introduce into physiology an exactness and certainty which the science has not yet attained. As a first step to such an analysis, I intend shortly to attempt a set of experiments on the contractility of the muscular fibre, by the several methods that have just been described. Those who undertake such researches should bear in mind that the friction of the tendons is an important element of the calculation. Muscles which are extended in a straight line between their attachments, and undergo no friction but that of the investing cellular tissue (as the gastrocnemius), have greatly the advantage of those whose tendons play over trochlear surfaces (as the obturator

or not, likely to suggest to its investigators *some* useful experiments, will not be classed with the extravagant iatro-mathematical speculations which retarded the progress of physiology in the seventeenth and beginning of the eighteenth century. " Prudens quæstio dimidium scientiæ," says Lord Bacon, a sentiment admirably elucidated by Herschel in the Preliminary Discourse. " A well-imagined hypothesis," he says, " if it have been suggested by a fair inductive consideration of general laws, can hardly fail at least of enabling us to generalize a step further, and group together several such laws under a more universal expression,......and we may thus be led to the trial of many curious experiments, and to the imagining of many useful and important contrivances which we should never otherwise have thought of." To which may be added the following judicious remarks of Mr. R. Young: " As in practice nothing is perfect, and few things wholly without merit, so, in theories, perhaps, none are without error, nor any devoid of truth. The difference between opinions seems to lie chiefly in the different proportions of truth and error which they contain. If this be true, every advance in principles is only substituting a less imperfect theory for one more so, and the last ever leaves something for futurity to correct."—(Essay on the Powers and Mechanism of Nature, p. ix.)

[We may refer the reader, on the subject of numerical proportions in animal organization, to our abstract of Dr. W. Adam's paper, " *On the Osteological Symmetry of the Camel*," in Phil. Mag. and Annals, vol. ix. p. 364: the paper itself will be found in the Transactions of the Linnæan Society, vol. xvi. p. 525 *et seq.* See also Lond. and Edinb. Phil. Mag., vol. iii. p. 457, vol. vi. p. 57, for notices of papers by Dr. Adam on the osteological symmetry of the human skeleton.—Edit.]

internus), or run in grooves (as the long head of the biceps), or perforate other tendons (as the deep flexor of the fingers), or turn through fibrous pulleys (as the digastric, the extensor of the toes, &c.). By comparing the effect of a known force acting on particular tendons, at first in their natural situations, and afterward detached and free, the influence of friction in each case would be readily determined. This source of error seems to have been very generally overlooked by writers on animal mechanics.

I conclude, for the present, with suggesting that to distinguish the pectoralis major into "portio elevans" or "attollens," and "portio deprimens," might serve to impress the rationale of its peculiar insertion and twofold action, upon the memory of the student.

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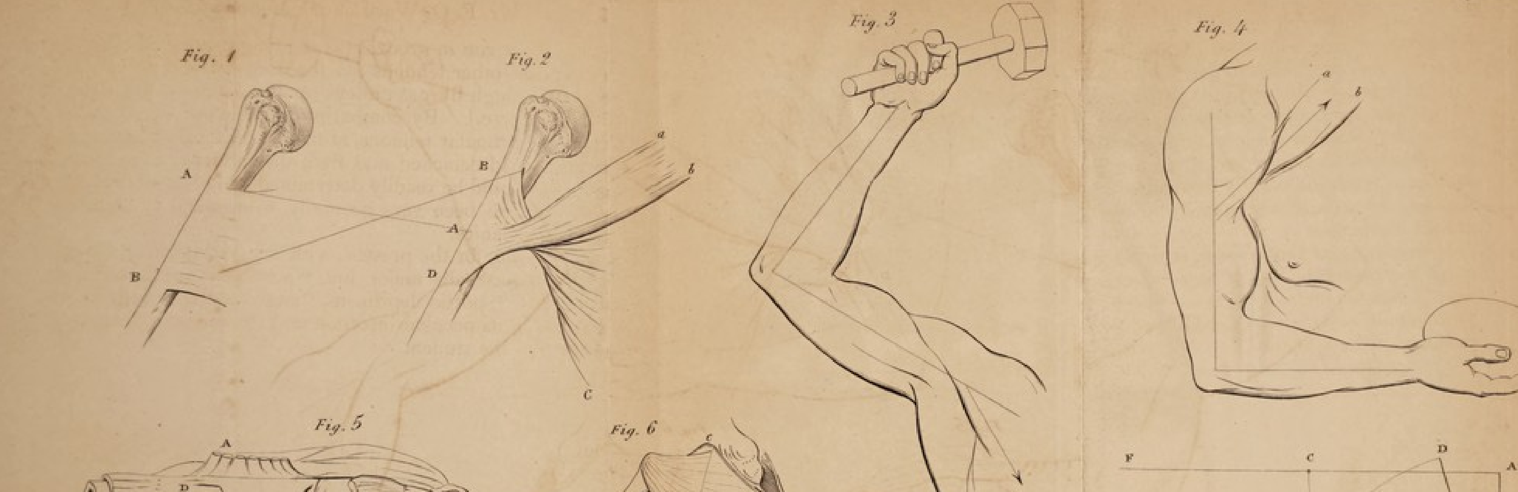

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WARD on the MUSCLES of the UPPER EXTREMITY.

E. Jones Sc.