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THE PRINCIPLES OF MYODYNAMICS.

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THE PRINCIPLES

OF MYODYNAMICS.

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By J. S. WIGHT, M. D.,

Professor of Surgery, and Lecturer on Physical Science at the Long Island College Hospital.

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1881.

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TO

THE ALUMNI

OF THE

LONG ISLAND COLLEGE HOSPITAL

THIS WORK IS INSCRIBED BY

THE AUTHOR.

PREFACE.

In the following pages I have made an attempt to analyze the Principles of Myodynamics,—and hope those who have not studied the subject may take the same interest in it that those young men have who have attended my lectures.

And I may be permitted to say that the better the surgeon understands the principles of myodynamics, the better he can treat Fractures, Dislocations and Deformities.

115 Pacific Street, Brooklyn.

THE PRINCIPLES OF MYODYNAMICS.

---

1. *Myodynamics treats of the forces of muscles and their effects.*

There are two kinds of *Myodynamics.*

I. *Myostatics*, which treats of muscular forces, when they are in equilibrium with some other force, or forces,—acting on a bony lever.

II. *Myokinetics*, which treats of muscular forces, when they are moving some other force, or forces,—acting on a bony lever.

Examples:—(1.) When the hand simply *holds* a weight,—it is a case of myo-statics: (2.) When the hand *moves* a weight,—it is a case of myo-kinetics.

2. In myo-dynamics the principles of the Lever, the Parallelogram of Forces, the inclined

Plane, and the Wheel and Axle, are used. And these principles must be well understood.

3. There are two principles involved in the Lever :—

A. (I.) In myostatics — THE SUM OF THE FORCES ACTING AT THE ENDS OF THE LEVER EQUALS THE FORCE ACTING IN THE CONTINUITY OF THE LEVER. That is :—

I. Order : $P+W=F$: . . (1.)

II. Order : $P+F=W$: . . (2.)

III. Order : $F+W=P$: . . (3.)

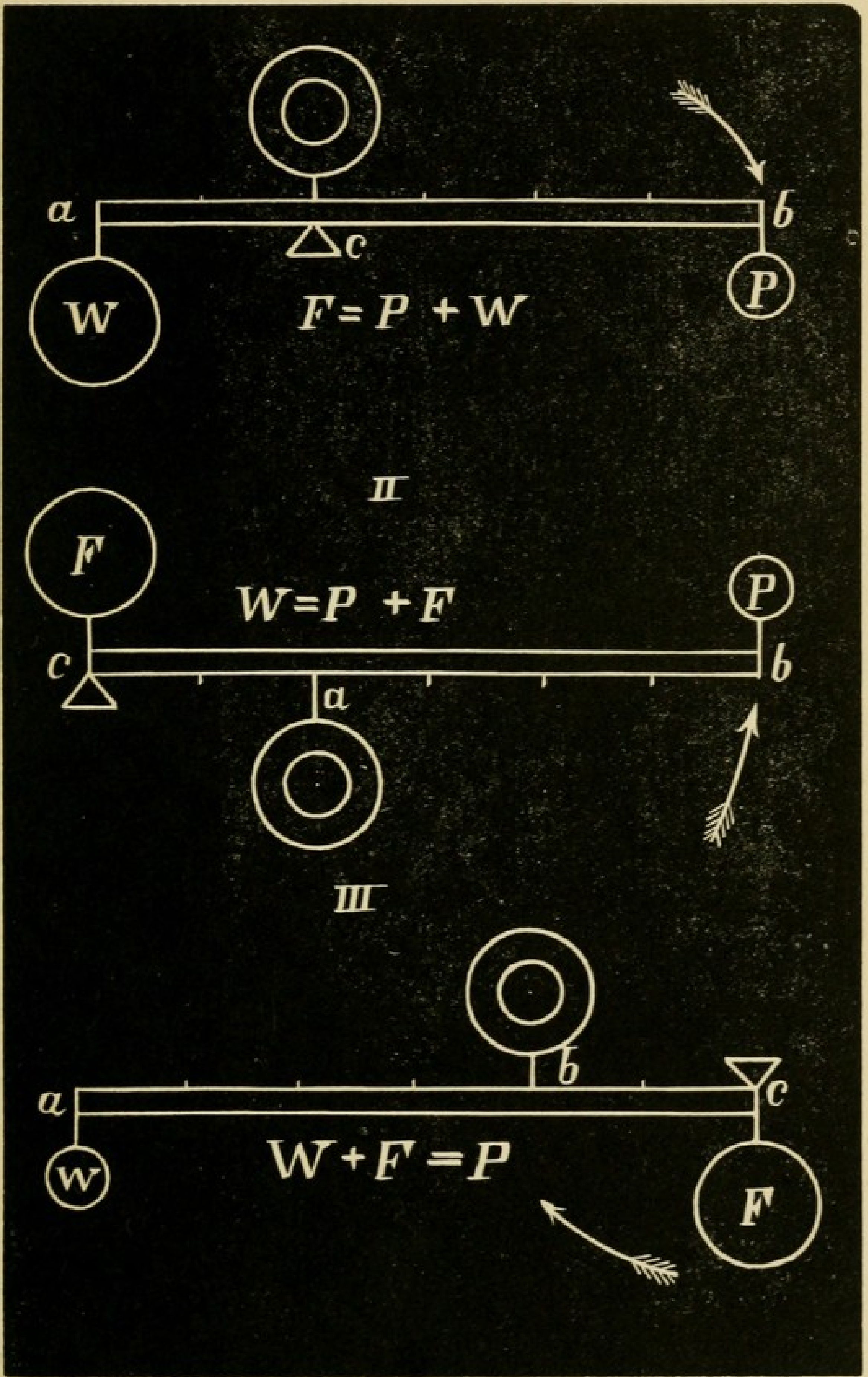
(II.) In myostatics — THE UNITS OF POWER MULTIPLIED BY THE UNITS OF DISTANCE IN THE POWER-ARM OF THE LEVER EQUAL THE UNITS OF WEIGHT MULTIPLIED BY THE UNITS OF DISTANCE IN THE WEIGHT-ARM OF THE LEVER. That is:—

$P \times (P-A) = W \times (W-A)$.

In this formula $P-A=$ the power-arm, and $W-A=$ the weight-arm of the lever.

Hence, $P=W \times \frac{(W-A)}{(P-A)}$: . . . (1.)

And $W=P \times \frac{(P-A)}{(W-A)}$: . . . (2.)


a
b
c
W
P
F=P + W
II
F
W=P + F
P
c
b
a
III
b
c
a
W+F=P
w
F

B. If the power exactly equals the weight, it can not move the weight; but if the power is greater than the weight, the weight moves, because it can not entirely resist the power: Hence, in myokinetics the force of the muscles is greater than in myostatics.

4. For the sake of convenience we have three ORDERS of the LEVER:

(1.) In the *first order* the *fulcrum* is in the *continuity* of the lever.

(2.) In the *second order* the *weight* is in the *continuity* of the lever.

(3.) In the *third order* the *power* is in the *continuity* of the lever.

5. The principles of the lever are illustrated in Fig. 1.

(1.) The circles representing the forces at the ends of the lever are seen together in the continuity of the lever.

(2.) The three orders of the lever may be remembered by the relations of the letters F. W. P. as they are located in the continuity of the lever: *F. in I; W. in II; P. in III order.*

(3.) The equilibrium of the forces at the ends of the lever is represented by the lever's horizontal position.

6. There are two principles in the parallelogram of forces :—

I. In myostatics two adjacent sides of a parallelogram may represent two components, and the inclosed diagonal of the parallelogram may represent the resultant of these two components. A force may be resolved into two components —as m into a and b : See Fig. 2.

II. In *myokinetics*.—The forces are proportional to the squares of the respective velocities with which they move, because—

$$\text{Kinetic energy} = \frac{F}{2\,g} \times V^2 \quad . \quad . \quad (1.)$$

$$\text{Kinetic energy} = \frac{W}{2\,g} \times V^2 \quad . \quad . \quad (2.)$$

$$\text{Kinetic energy} = \frac{P}{2\,g} \times V^2 \quad . \quad . \quad (3.)$$

Now g represents the increment of velocity of a falling body due to gravity, and is 32. 16 ft, or 9. 8 m.

And since the expression 2 g is a constant, it may be rejected in comparing the energy of the moving forces:

The energy of F: :$F x V^2$ . . (4.)

The energy of W: :$W x V^2$ . . (5.)

The energy of P: :$P x V^2$ . . (6.)

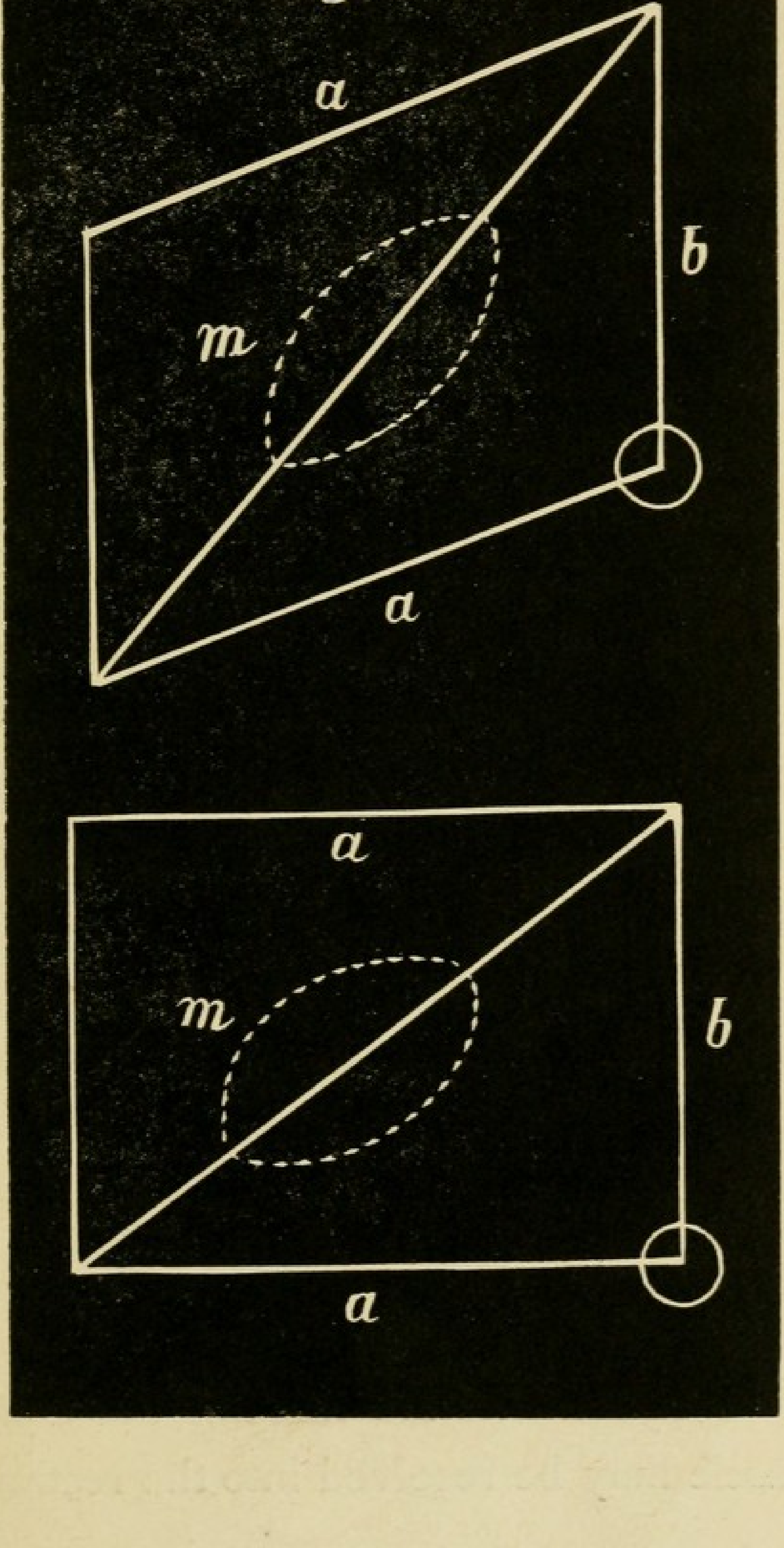
The fulcrum is at rest and has no relative motion: The power and weight describe circles, whose radii are the power-arm and the weight-arm of the lever: Hence, the velocity of the power is proportional to the length of the power-arm, and the velocity of the weight is proportional to the length of the weight-arm of the lever.

Example:—Let the power-arm of the radial lever be 2 inches, the biceps brachii being the power; and let the weight-arm of the radial lever be 10 inches, the weight being 5 pounds: Then the power will be 25 pounds. Now suppose the power, in so far as it can balance the weight, be a tangible body: Then we shall have:

The energy of P: : $25 x 2^2 = 100$. (7.)

The energy of W: : $5 x 10^2 = 500$. (8.)

Fig. 2.



While the weight appears to manifest more energy than the power, it must be kept in mind that, in so far as myostatics is concerned, the power must be greater than the weight, in order to be able to move the weight: and as the weight moves, it accumulates energy from the power. Hence the weight, in the case supposed, manifests the energy it has obtained from the power of the contracting muscle. Hence, it must follow, that the energy gained by the weight under the circumstances must equal the energy expended by the contracting muscles—AND THAT IN EFFECT THE WORK DONE BY THE WEIGHT MUST EQUAL THE WORK DONE BY THE POWER.

7. The principle of the parallelogram of forces may be illustrated by Fig. 2.

(1.) As we shall resolve the forces of muscles into *rectangular components* Fig. 2, is made a rectangle.

(2.) In *myostatics* the force of the muscle *m* is resolved into the rectangular components *a* and *b*.

(3.) In *myokinetics* the force of the contracting muscle may be resolved into the rectangular components *a* and *b*. The velocity of the motion must also be considered, according to the principles above stated.

8. The inclined plane involves the principle of the rectangle of forces. For instance, when two bones meet at their articulation at an acute or an obtuse angle, one rests upon the other as a body on an inclined plane.

9. *Let F c i Fig. 3, be a movable bone, and o c a fixed bone, c being the joint. The muscle m has its origin at o, and its insertion at i. The force of the contracting muscle is resolved into the two components a and b: a acts in the direction i c and is a displacing component acting on the movable bone. But b acts in the direction i P and contains a* DISPLACING *and a* RETENTIVE *component. Now the force b acts at i and reacts at o in the direction o c: The fixed bone rests on the movable bone as a body rests on an inclined plane: The fixed bone tends to descend on the movable bone—which is impossible: Hence the movable bone tends to go upward under the fixed bone with the same force that the fixed bone tends to descend: And this force which is equal b is resolved into the compon-*

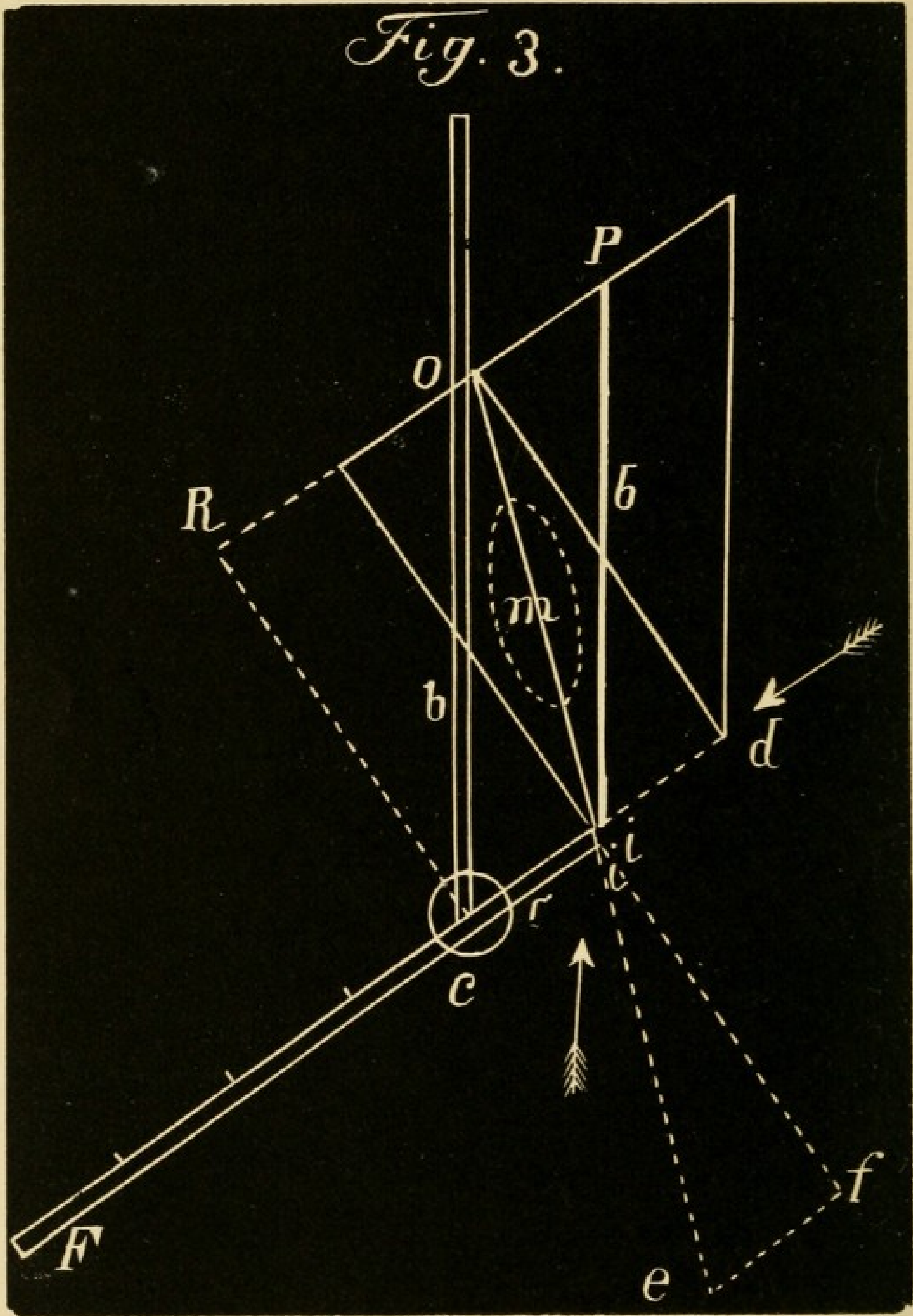


Fig. 3.

ents C R, or d o and c d: The component d o presses the movable bone against the fixed bone. The component d o is a MOVING *or* RETENTIVE *component. And the component c d is a* DISPLACING *component acting in the direction c d. But we have already a displacing component i c acting in the opposite direction, which will leave a displacing component equal i d. That is we must deduct from the component c i d the component i c which will leave the component i d. That will be the displacing component of the contracting muscle m. The lines o d and i d represent the* RECTANGULAR COMPONENTS *of the muscle. In a similar manner all* RECTANGULAR COMPONENTS *may be found.*

10. The wheel and axle act on the principle of the lever.

Example: The rotation of the skull on the top of the spinal column is an example of this principle.

11. The agents which move the human body are bones and muscles. The bones are passive agents, and the muscles are active agents.

12. Bones in regard to the action of muscles may be divided into *fixed* and *movable* :—

(1.) A fixed bone gives origin to the moving muscle—but does not move.

(2.) A movable bone gives insertion to the moving muscle—and is moved.

(3.) In some cases the movable bone becomes fixed, then the fixed bone may move.

(4.) When a muscle spans two joints and the interjacent bones, there may be one or two movable bones :—

(i.) One of the adjacent bones may move, when the other adjacent bone and the interjacent bone will be fixed.

(ii.) The two adjacent bones may move, when the interjacent bone will be the fixed bone :—

(iii.) One of the adjacent bones and the interjacent bone may move, when the other adjacent bone will be the fixed bone.

13. A movable bone may be a lever of the first, second, or third order :

Examples. (1.) The skull acted on by the posterior cervical muscles is a lever of the first order.

(2.) The foot acted on by the muscles of the tendo-Achillis is a lever of the second order.

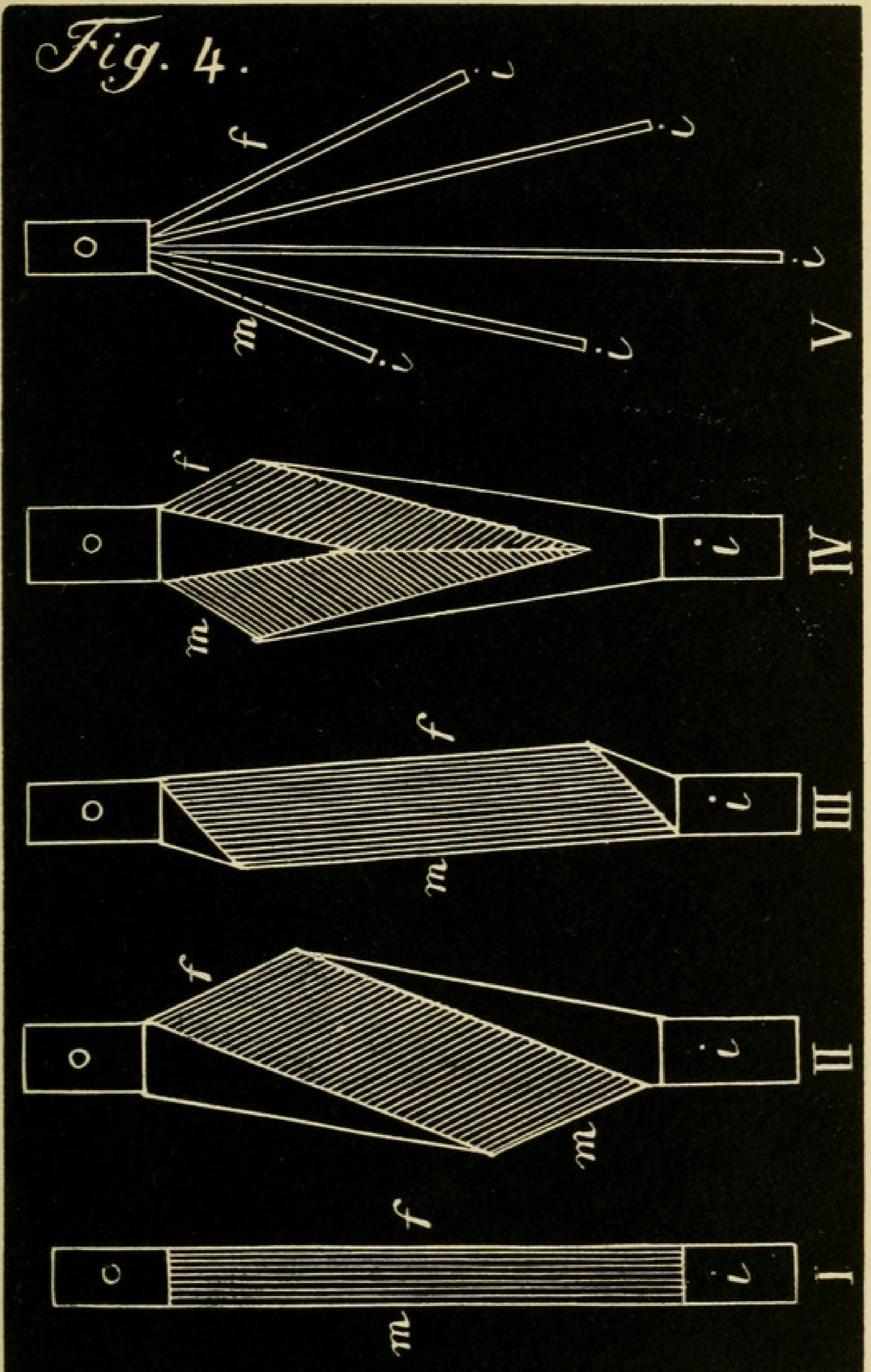


Fig. 4.

(3.) The radius acted on by the biceps brachii is a lever of the third order.

14. According to the direction of their fibres, muscles are of three kinds: *direct*, *oblique*, and *radiate*.

(1.) In a *direct fibred* muscle the fibres run in a longitudinal direction from the tendon of origin to the tendon of insertion, as is shown in I. Fig. 4.

(2.) In an *oblique fibred* muscle the fibres run in an oblique direction from the tendon of origin to the tendon of insertion, as is shown in II, III, IV, Fig. 4.

There are three kinds of oblique fibred muscles: The *short oblique* (II), the *long oblique* (III), and the *double oblique* (IV).

(3.) In the *radiate fibred* muscle the fibres run in radiate directions from a central tendon to various points of insertion (V).

Examples:—

(i.) The sartorius is a direct fibred muscle.

(ii.) The extensor proprius pollicis is a short oblique fibred muscle.

(iii.) The semimembranosus is a long oblique fibred muscle.

(iv.) The rectus femoris is a double oblique fibred muscle.

(v.) The diaphragm is a radiate fibred muscle.

15. In regard to motion and power as exhibited by muscles the following statements may be made :—

(1.) The longer the fibres of a muscle the more extensive is the motion it can make and the greater its power.

(2.) The power of a muscle increases as the number of its fibres increases: The muscle whose transverse section has the greatest area will have the greatest power.

(3.) Other things being equal, the proper use of a muscle will increase its power to a certain extent.

(4.) The volition can be made to act on part of the fibres of some muscles, as, for instance, the gluteus medius, or the pectoralis major.

(5.) The energy of a contracting muscle is proportional to the energy of the volition.

(6.) The firmness of a contracting muscle is proportional to the energy with which it contracts.

16. In a human body, whose entire weight is $143\frac{1}{2}$ pounds, the recent bones weigh $21\frac{1}{2}$ pounds, and the recent muscles weigh $77\frac{1}{2}$ pounds: and the weight of the bones is to the weight of the muscles as,

$$43 : 155;$$

and the weight of the muscles is to the weight of the body as,

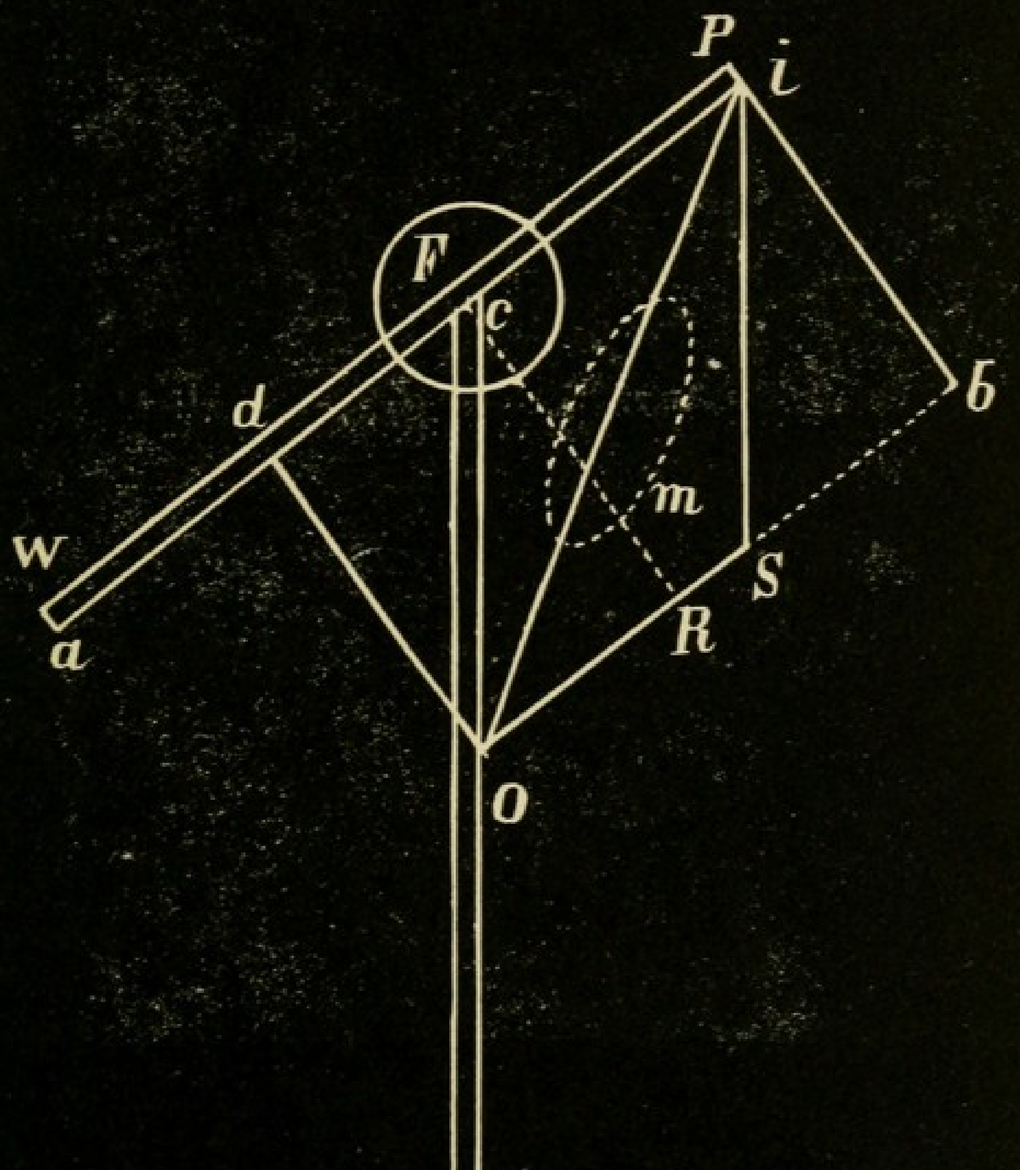
$$155 : 287.$$

It is easy to determine from the weights and the specific gravities of bones and muscles, *that, in the human body, the bulk of the muscles is more than six times the bulk of the bones.*

17. THE FORCE OF A CONTRACTING MUSCLE ACTING ON A BONY LEVER OF THE FIRST, SECOND, OR THIRD ORDER IS RESOLVED INTO TWO RECTANGULAR COMPONENTS.

(a) One of these components tends to move the movable bone, and may be called the *moving component*: (b) The same component tends to hold the movable bone and the fixed bone together, and may be called the *retentive component*. (c) The other of these components tends to displace the movable bone from the fixed

Fig. 5.



I. Order.

bone, and may be called the *displacing component* :—*The conformation of the joint may be such that the moving component is a displacing component* : *The moving component of the biceps brachii is a displacing component.*

18. The *long axis* of the contracting muscle, the *distance* in the long axis of the movable bone from the insertion of the contracting muscle to the centre of the joint, and the *distance* in the long axis of the fixed bone from the centre of the joint to the origin of the contracting muscle make the *sides* of a triangle, that may be called the *myodynamic triangle.*—In Fig. 5, o i c is the *myodynamic triangle.*

19. That angle of the myodynamic triangle included between the long axis of the contracting muscle and the long axis of the movable bone is important, and may be called the *myodynamic angle.* In Fig. 5, o i c is the *myodynamic angle.*

(a) *In the case of a bony lever of any order, the myodynamic angle is the guide to the magnitudes of the rectangular components of the contracting muscle.*

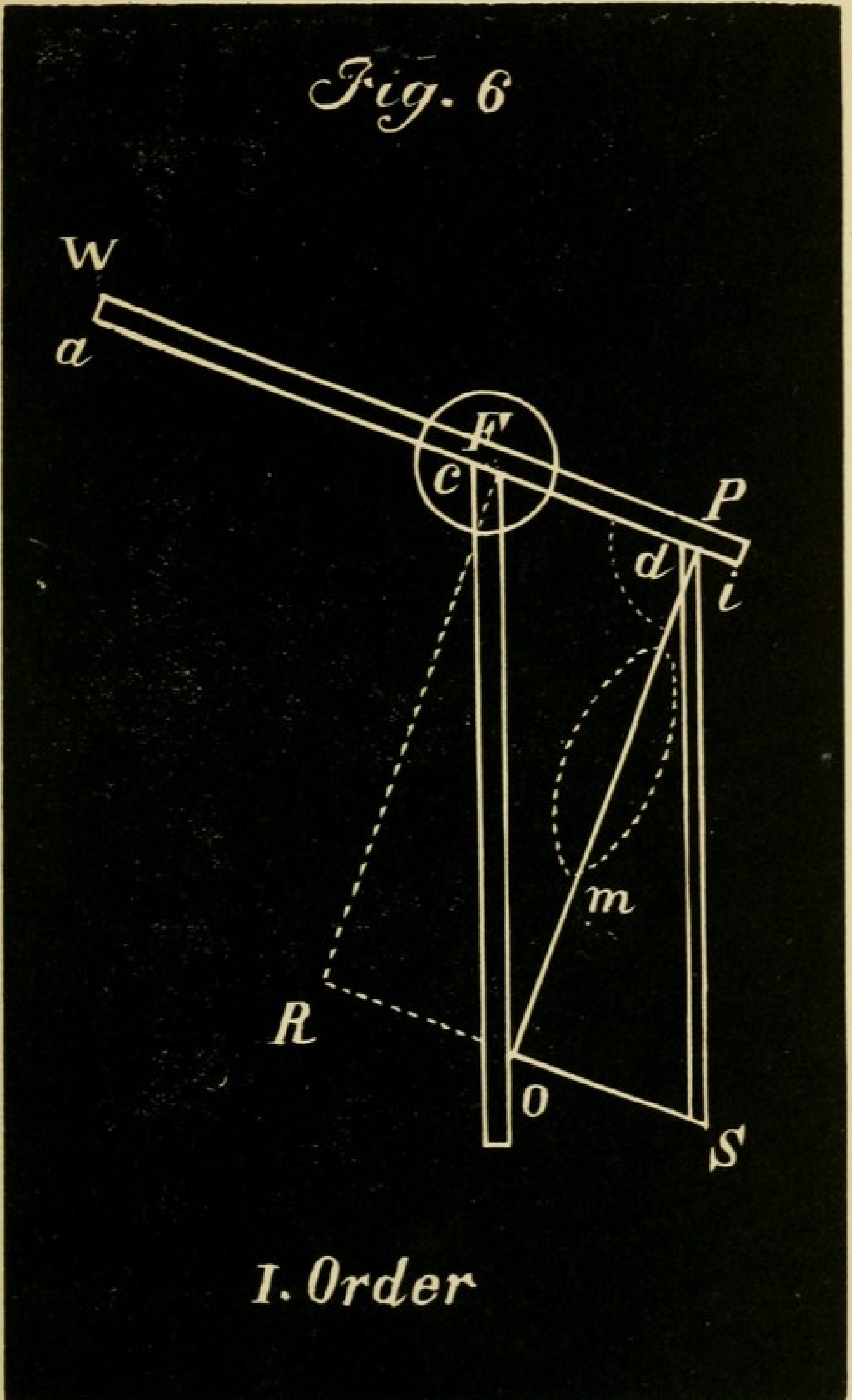


Fig. 6
W
a
F
c
P
d
i
m
R
o
S
I. Order

(b) The myodynamic angle must be *acute*, *right*, or *obtuse*, according to the extent of the contraction of the moving muscle.

20. The ulna may be an example of a bony lever of the first order: The humerus will be the fixed bone, and the triceps brachii will be the contracting muscle: The myodynamic angle will be between the triceps brachii and the ulna.

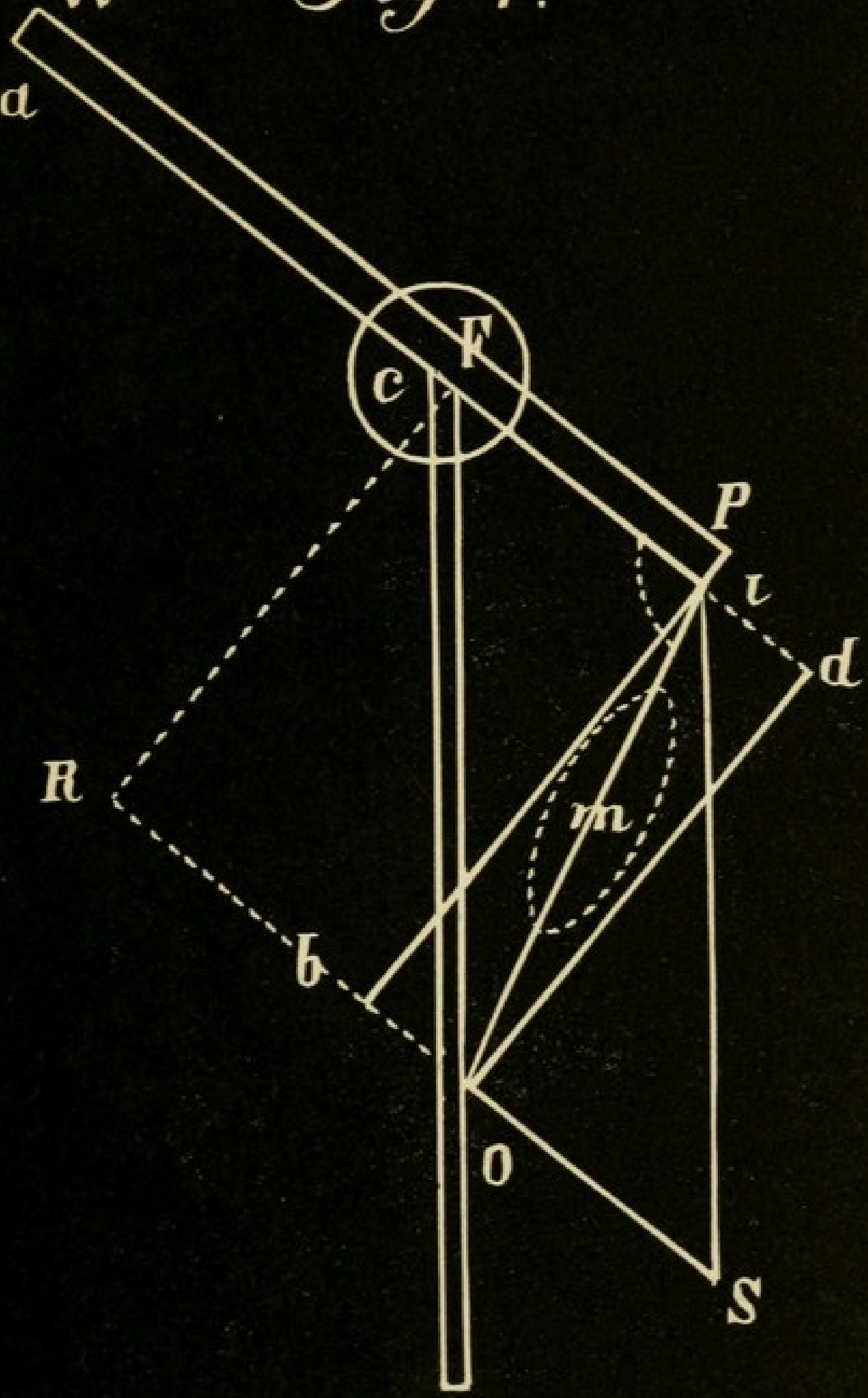
21. In a bony lever of the *first* order, let a c i be a *movable* bone, o c a *fixed* bone, c their joint, m the contracting muscle, whose origin and insertion are at o and i: See Figs. 5, 6, 7.

The power is at i, the fulcrum is at c, and the weight is at a. The myodynamic triangle is o i c. And the myodynamic angle is o i c.

(a) The myodynamic angle is *acute* in Fig. 5, *right* in Fig. 6, and *obtuse* in Fig. 7.

(b) From the origin of the contracting muscle draw a perpendicular to the long axis of the movable bone—prolonged if necessary, complete the rectangle o b i d, whose diagonal is the long axis of the contracting muscle: Also construct the rectangle d o R c, whose diagonal is the

Fig. 7.



1. Order.

long axis of the fixed bone from the origin of the contracting muscle to the joint.

(c) When the myodynamic angle is *right*, the long axis of the contracting muscle will be the perpendicular drawn from the origin of the muscle to the movable bone : The component o d will coincide with the long axis of the muscle ; and there will be one rectangular component. See Fig. 6. The component d c which is supposed to make part of the resultant m is exactly equal the component c d, which makes part of the resultant s i, or o c : and these components neutralize each other.

(d) When the myodynamic angle is *acute*, or *obtuse*, the perpendicular drawn from the origin of the contracting muscle to the movable bone will fall outside the long axis of the muscle, and there will be two rectangular components. See Figs. 5 and 7. The displacing component will be represented by the line i d.

22. A. When the myodynamic angle varies, the magnitudes of the rectangular components will vary. The following laws of variation in

the magnitudes of the rectangular components may be enunciated.

(1.) The *displacing* component (i d) of the contracting muscle will be a maximum, when the myodynamic angle is least, and will constantly diminish till the myodynamic angle is *right*,—when there will be no displacing component.

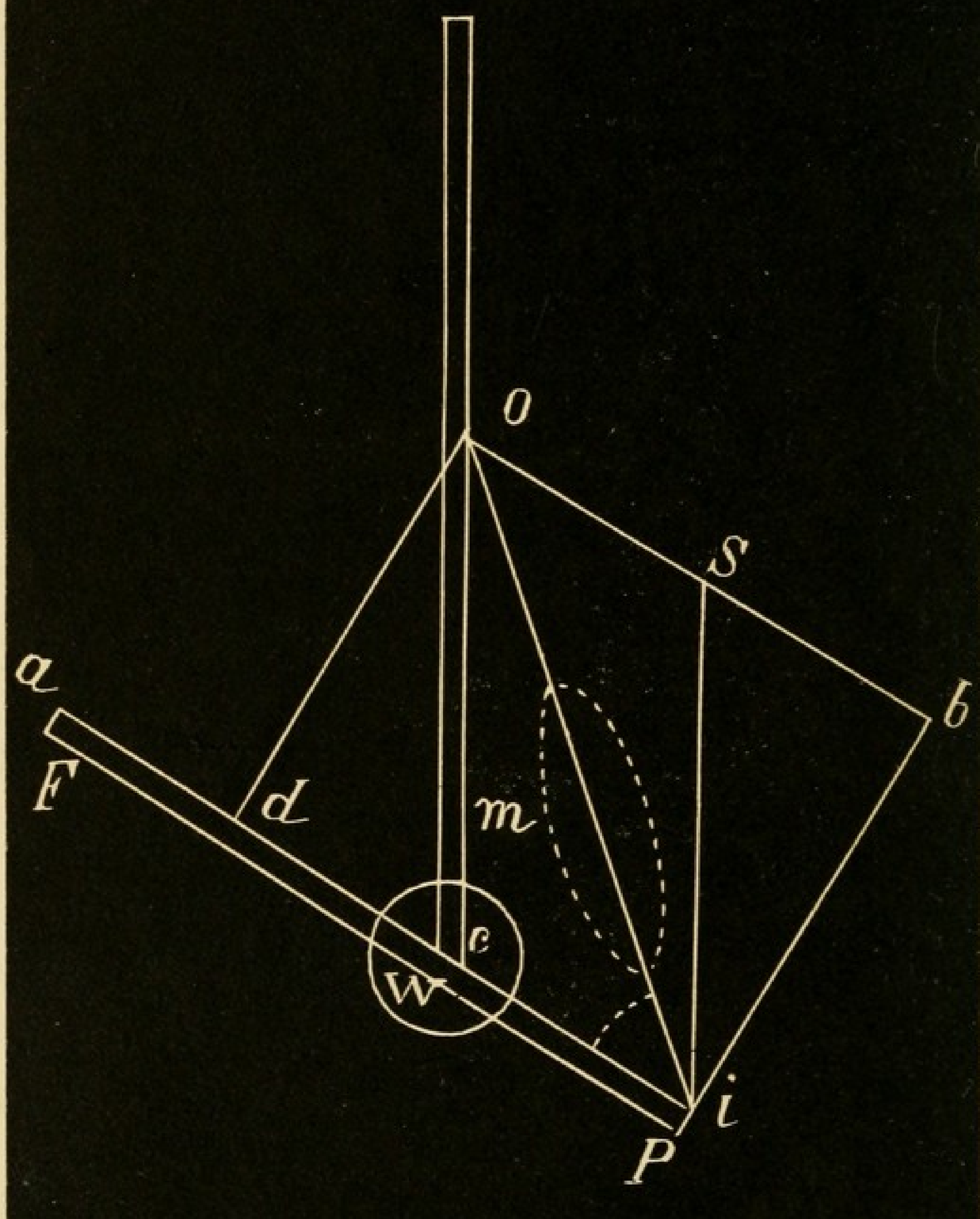
(2.) The *displacing* component (i d) of the contracting muscle will constantly increase from the *zero-point*—where the myodynamic angle is right—till the myodynamic angle is greatest.

(3.) The *moving*—or *retentive*—component (o d) of the contracting muscle will be a minimum, when the myodynamic angle is least, and will constantly increase till the myodynamic angle is *right*, when it will be a maximum.

(4.) The *moving*, or *retentive* component (o d) of the contracting muscle will constantly diminish from the maximum point—where the myodynamic angle is right—till the myodynamic angle is greatest.

22. B. In Figs. 5, 6, and 7, on the long axis of the contracting muscle construct the

Fig. 8.



II Order.

parallelogram o s i c, which shall correspond to and be twice as great as the myodynamic triangle :—

(1.) In Fig. 5, the components i c and c d co-operate in the direction i c d, making the entire displacing component equal i d : The whole force of the contracting muscle appears in the rectangular components.

(2.) In Fig. 6, the component d c and the component c d are antagonistic and equal, and therefore neutralize each other, so that there is no displacing component : The whole force of the contracting muscle appears in the moving component.

(3.) In Fig. 7, the component c d is greater than the component i c by the component i d, which is the displacing component : The whole force of the contracting muscle appears in the rectangular components.

23. In a bony lever of the *second* order, let a c i be a movable bone, o c, a fixed bone, c, their joint, m, the contracting muscle, whose origin and insertion are at o and i. See Figs. 8, 9, 10. The power is at i, the weight at c, and the

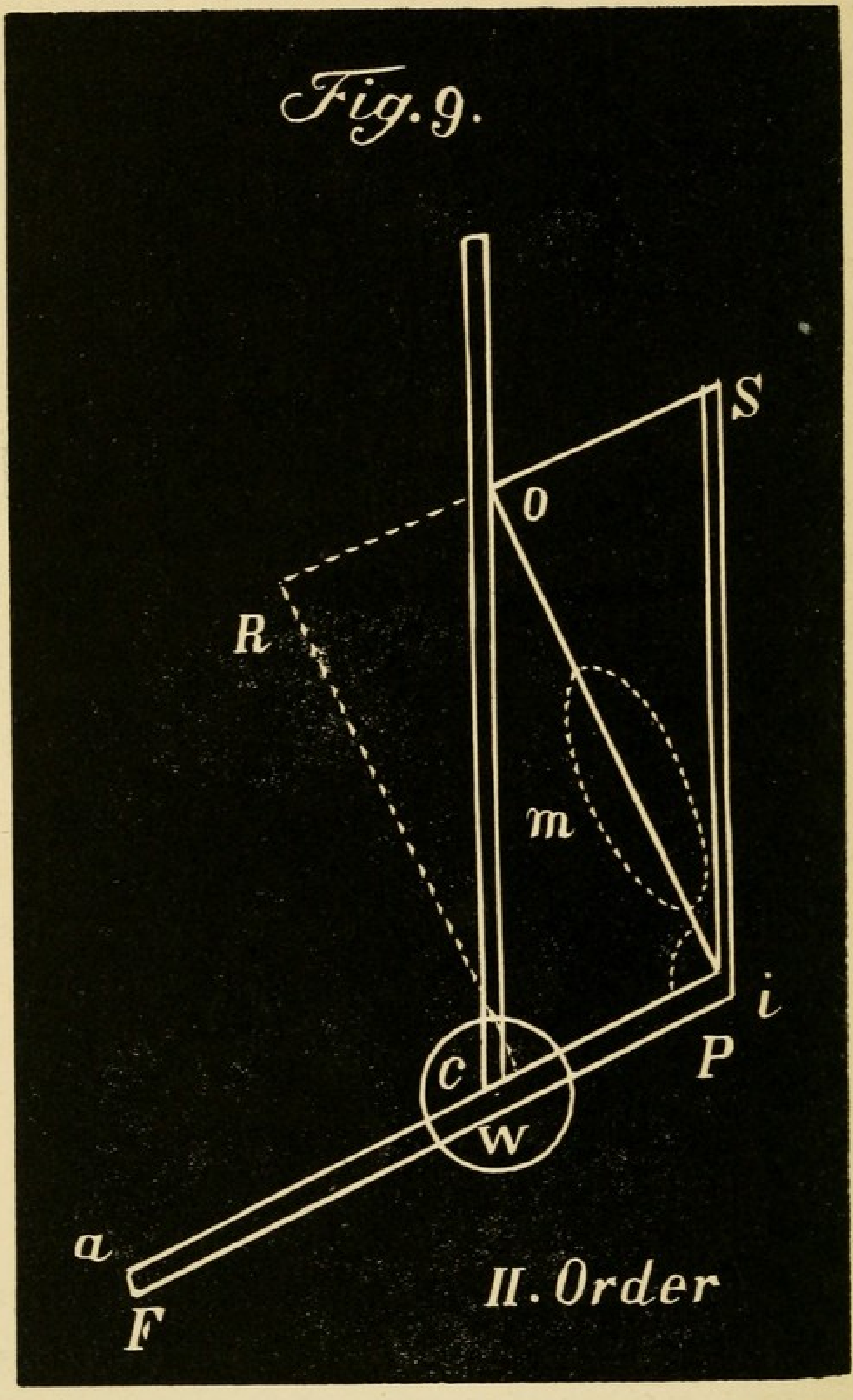


Fig. 9.
S
o
R
m
i
P
c
w
a
II. Order
F

fulcrum at a. The myodynamic triangle is o i c. And the myodynamic angle is o i c.

(a) The myodynamic angle is *acute* in Fig. 8, *right* in Fig. 9, and *obtuse* in Fig. 10.

(b) From the origin of the contracting muscle draw a perpendicular to the long axis of the movable bone—prolonged if necessary. Complete the rectangle o b i d, whose diagonal is the long axis of the contracting muscle.

(c) As before, when the myodynamic angle is *right*, there will be one rectangular component.

(d) Also as before, when the myodynamic angle is *acute* or *obtuse*, there will be two rectangular components.

24. A. When the myodynamic angle varies, the magnitudes of the rectangular components will vary. The laws of variation in the magnitudes of the rectangular components will be the same in a bony lever of the second order as in a lever of the first order: See 22, (1), (2), (3), (4).

24. B. In Figs. 8, 9 and 10, on the long axis of the contracting muscle construct the parallelogram o s i c, which shall correspond to and be

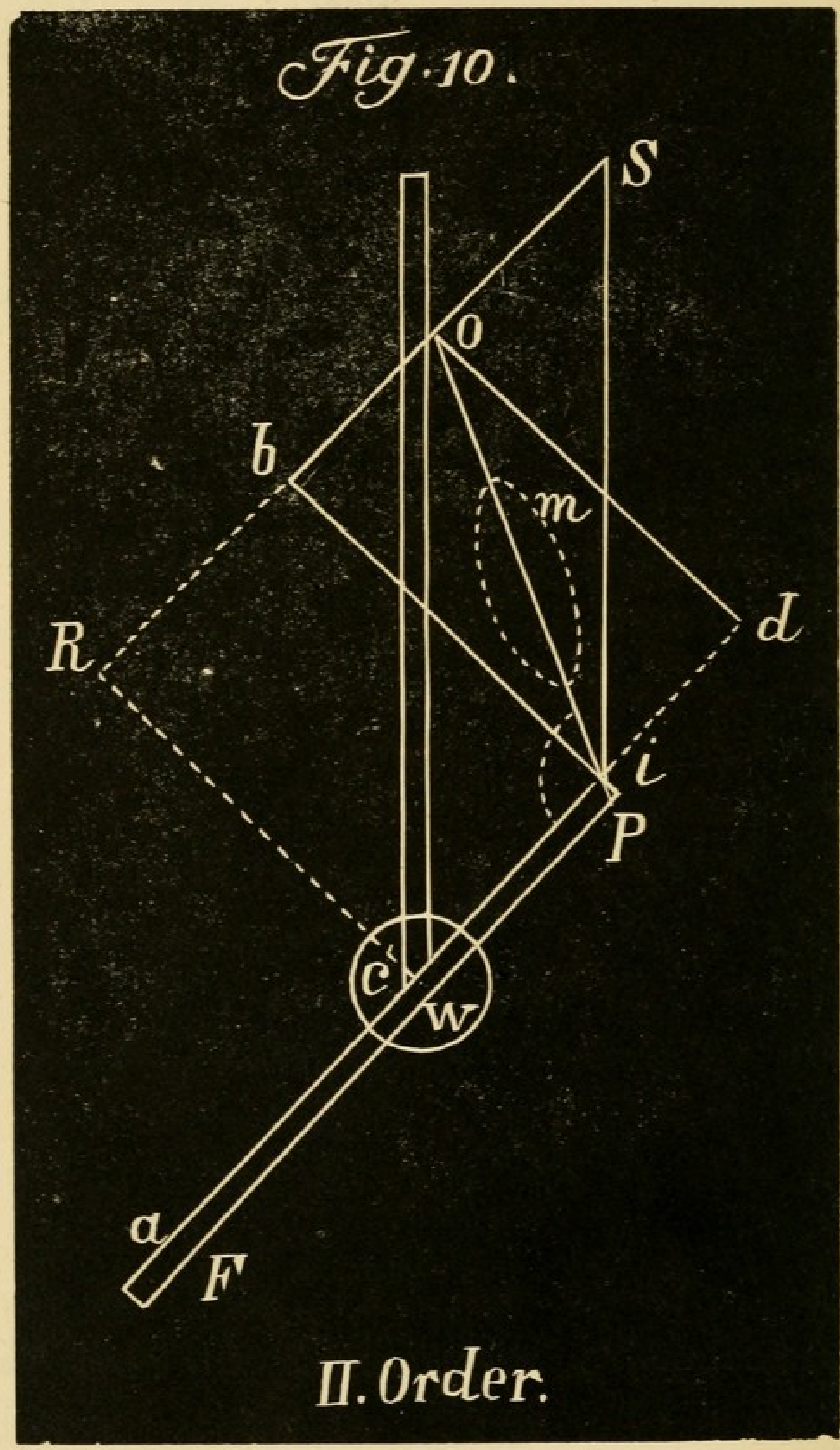


Fig. 10.
S
o
b
m
R
d
i
P
c
w
a
F
II. Order.

twice as great as the myodynamic triangle :—
Then the same conclusions may be drawn as in (1,) (2), (3), 22 B.

25. In a bony lever of the *third* order, let a c i, be a movable bone, o c, a fixed bone, c, their joint, m, the contracting muscle, whose origin and insertion are at o and i : See Figs. 11, 12, 13. The power is at i, the weight at a, and the fulcrum at c. The myodynamic triangle is o i c. And the myodynamic angle is o i c.

(a) The myodynamic angle is *acute* in Fig. 11, *right* in Fig. 12, and *obtuse* in Fig. 14.

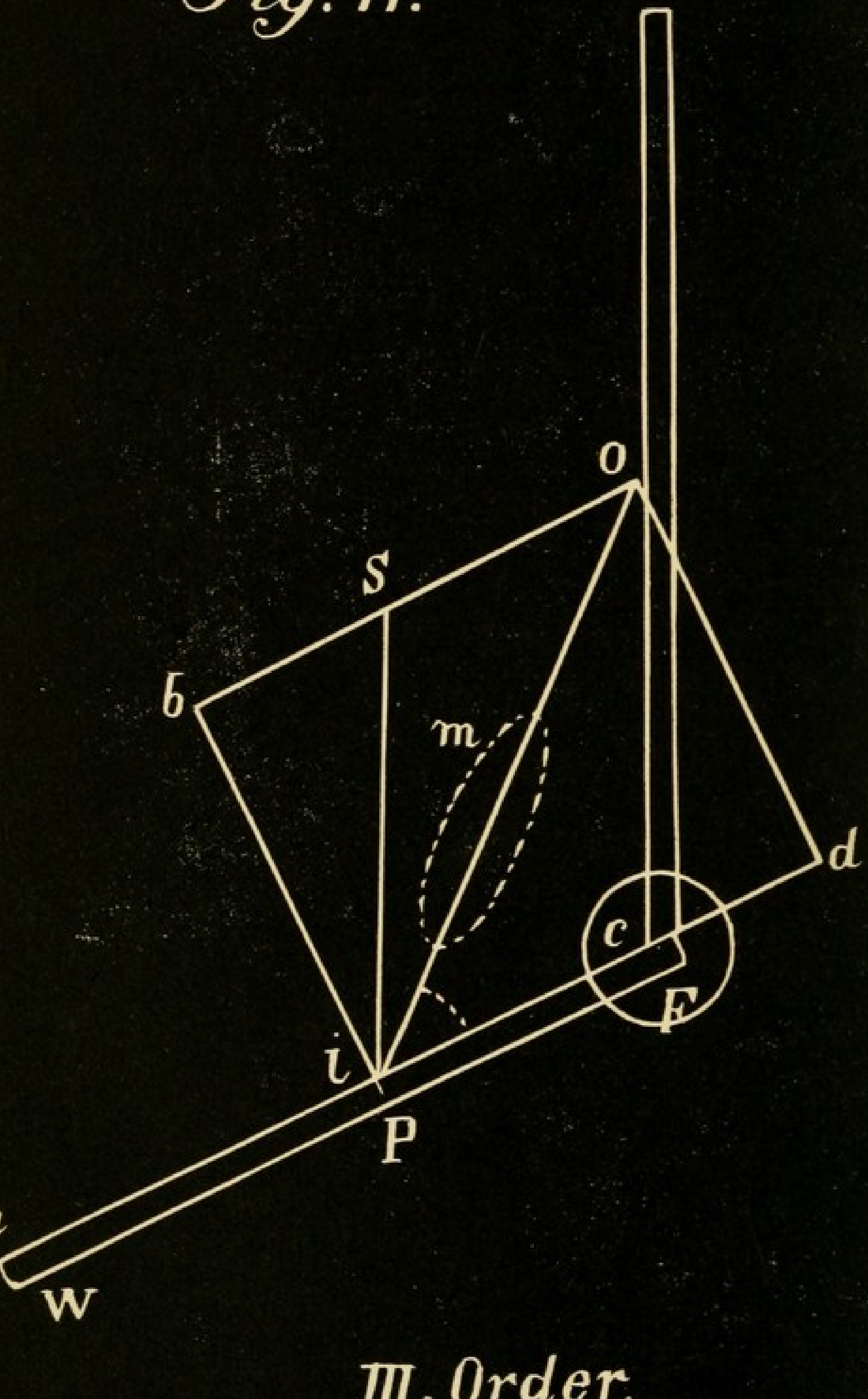
(b) From the origin of the contracting muscle draw a perpendicular to the long axis of the movable bone—prolonged if necessary. Complete the rectangle o b i d, whose diagonal is the long axis of the contracting muscle.

(c) Again as before, when the myodynamic angle is *right*, there will be one rectangular component.

(d) Also as before, when the myodynamic angle is *acute* or *obtuse*, there will be two rectangular components.

26 A. In this case also, when the myodynamic

Fig. 11.



III. Order.

angle varies, the magnitudes of the rectangular components will vary :—and the laws of variation in the magnitudes of the rectangular components will be the same as those of a bony lever of the first, or second order :—See 22, (1), (2), (3), (4).

26. B. In Figs. 11, 12 and 13, on the long axis of the contracting muscle construct the parallelogram o s i c which shall correspond to and be twice as great as the myodynamic triangle :—

(1.) In Fig. 11, the whole force of the contracting muscle appears in the rectangular components.

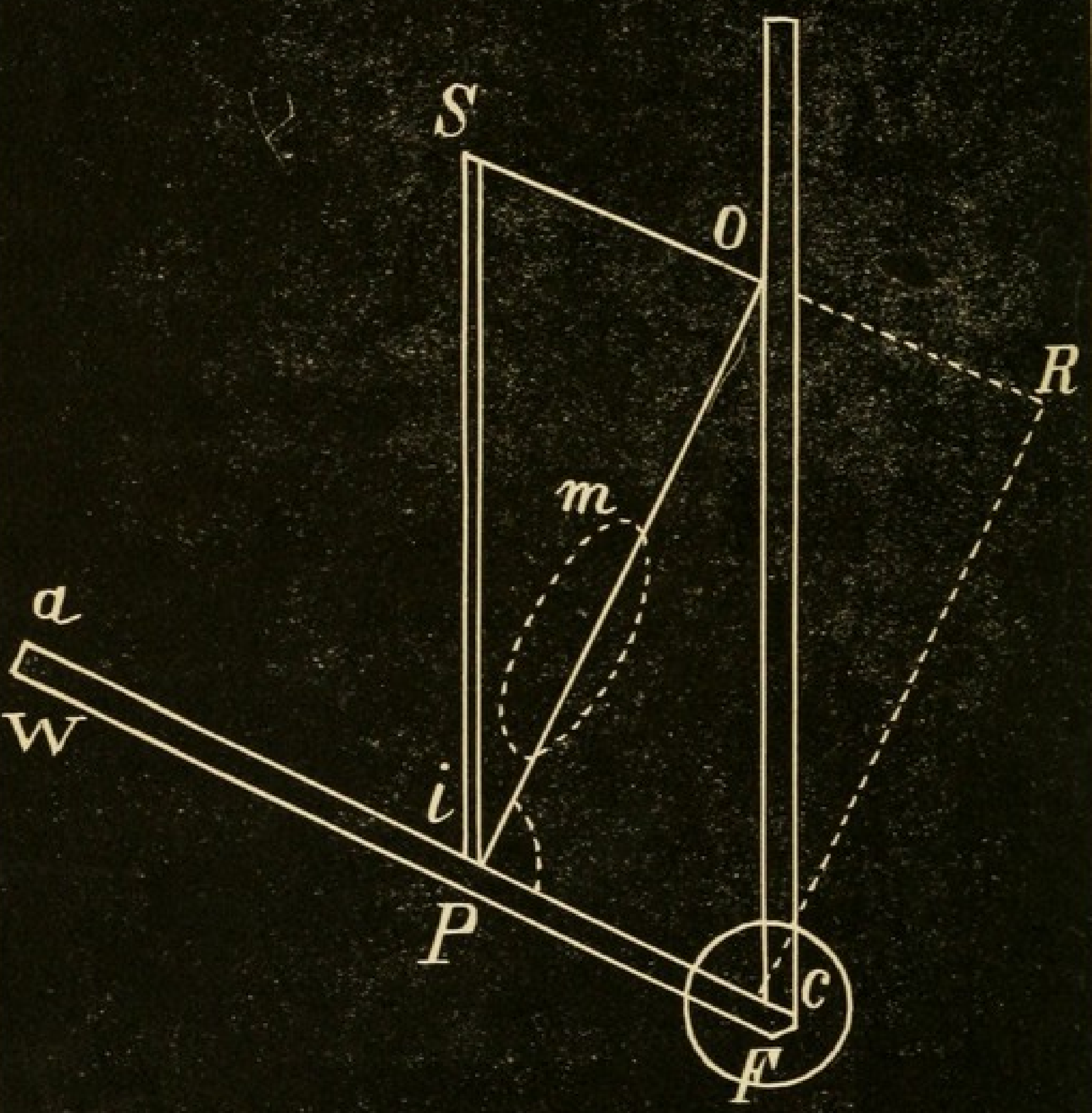
(2.) In Fig. 12, the whole force of the contracting muscle appears in the moving component.

(3.) In Fig. 13, the whole force of the contracting muscle appears in the rectangular components.

26. C. Rules for finding the rectangular components of a contracting muscle :—

(a) *Draw a line from the origin of the contracting muscle at right angles to and meeting the long*

Fig. 12.



III. Order.

axis of the movable bone, prolonged if necessary, and it will represent the moving, or retentive component.

(b) *Draw a line in the long axis of the movable bone from the insertion of the contracting muscle till it meets the line of the moving component at right angles, and it will represent the displacing component.*

27. Let i d and o d be the lines representing the rectangular components of the contracting muscle, whose long axis is o i: See Fig. 14. Let a and b be the rectangular components, and m the force of the contracting muscle.

(a) Then it is evident that we shall have the following proportions :

a : b : : d i : d o . . . (1);

a : m : : d i : i o . . . (2);

b : m : : d o : i o . . . (3);

(b) From these proportions we may derive the following equations :—

$$a = b \times \frac{d\,i}{d\,o} \quad \ldots \quad (1);$$

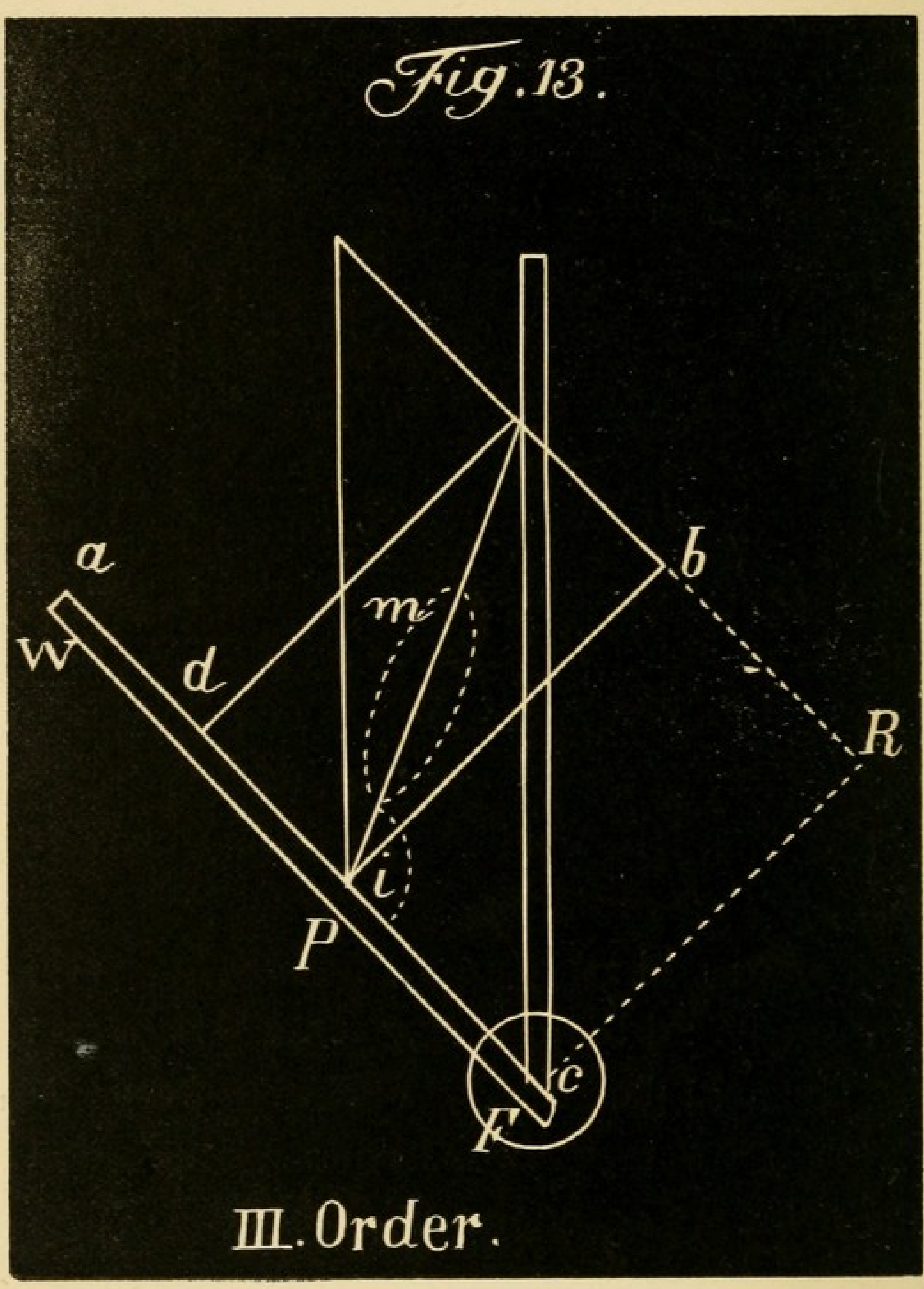


Fig. 13.
a
b
m
W
d
R
i
P
c
F
III. Order.

$$a = m \times \frac{d\,i}{i\,o} \quad . \quad . \quad . \quad . \quad (2);$$

$$b = a \times \frac{d\,o}{d\,i} \quad . \quad . \quad . \quad . \quad (3);$$

$$b = m \times \frac{d\,o}{i\,o} \quad . \quad . \quad . \quad . \quad (4);$$

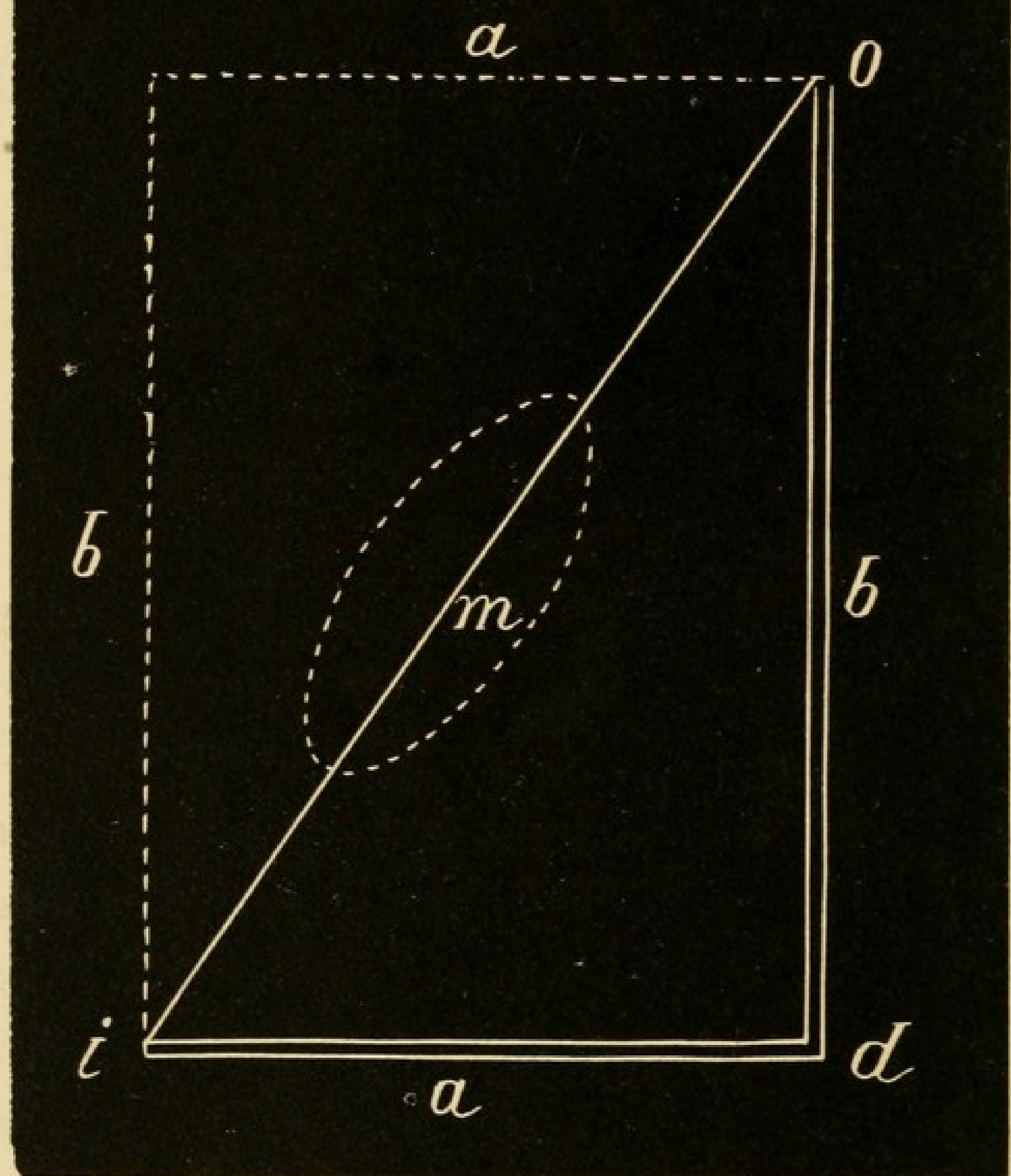
$$m = a \times \frac{i\,o}{d\,i} \quad . \quad . \quad . \quad . \quad (5);$$

$$m = b \times \frac{i\,o}{d\,o} \quad . \quad . \quad . \quad . \quad (6);$$

28. It will be convenient to call the right angled triangle o d i, Fig. 14, the *component triangle.* Hence, by the above formulæ, when two sides of the component triangle and one of the related forces are known, it is possible to find either of the other two forces. It will not be necessary to translate these formulæ into written rules.

29. A. In so far as the force of the contracting muscle is concerned, the *joint* between a movable bone and a fixed bone will be in a con-

Fig. 14.



dition of maximum stability, when the myodynamic angle is a right angle, in the case of any bony lever. But the stability of the joint becomes relatively less as the myodynamic angle differs from a right angle, in the case of any bony lever. The displacing component is a factor of instability, and is antagonized by the capsular ligaments.

29. B. In the case of any order of bony lever, the following general conclusions may be drawn :—

(1.) When the myodynamic angle is acute a greater part of the force of the contracting muscle will be a displacing component than when this angle is obtuse.

(2.) When the myodynamic angle is obtuse a greater part of the force of the contracting muscle will be a retentive component than when this angle is acute.

(3.) Hence with the same muscular force an obtuse myodynamic angle will afford conditions of greater stability to the joint than an acute myodynamic angle.

(4.) But other things being equal, a right-myo-

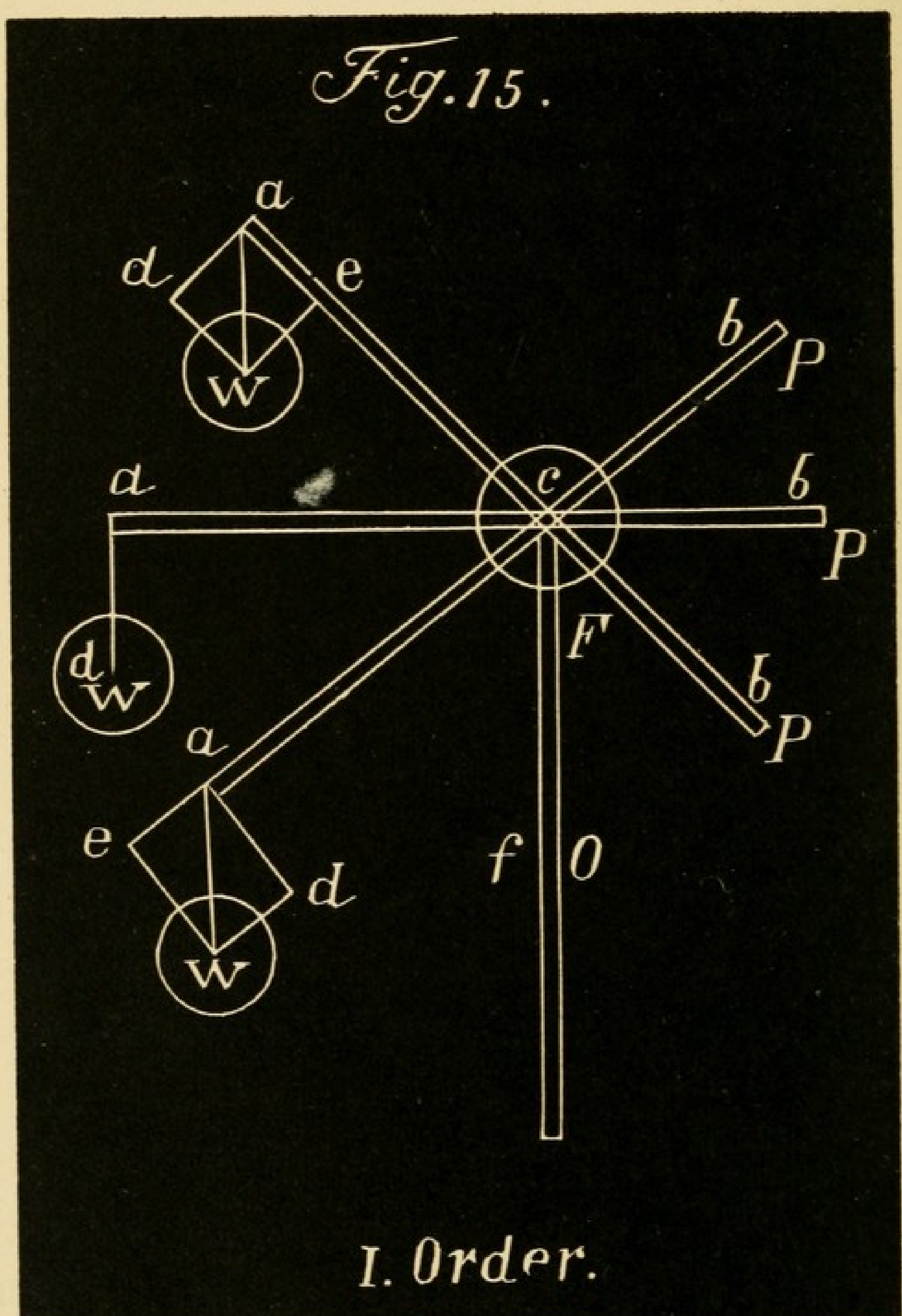


Fig. 15.

I. Order.

dynamic angle will give the most stable relations to a joint.

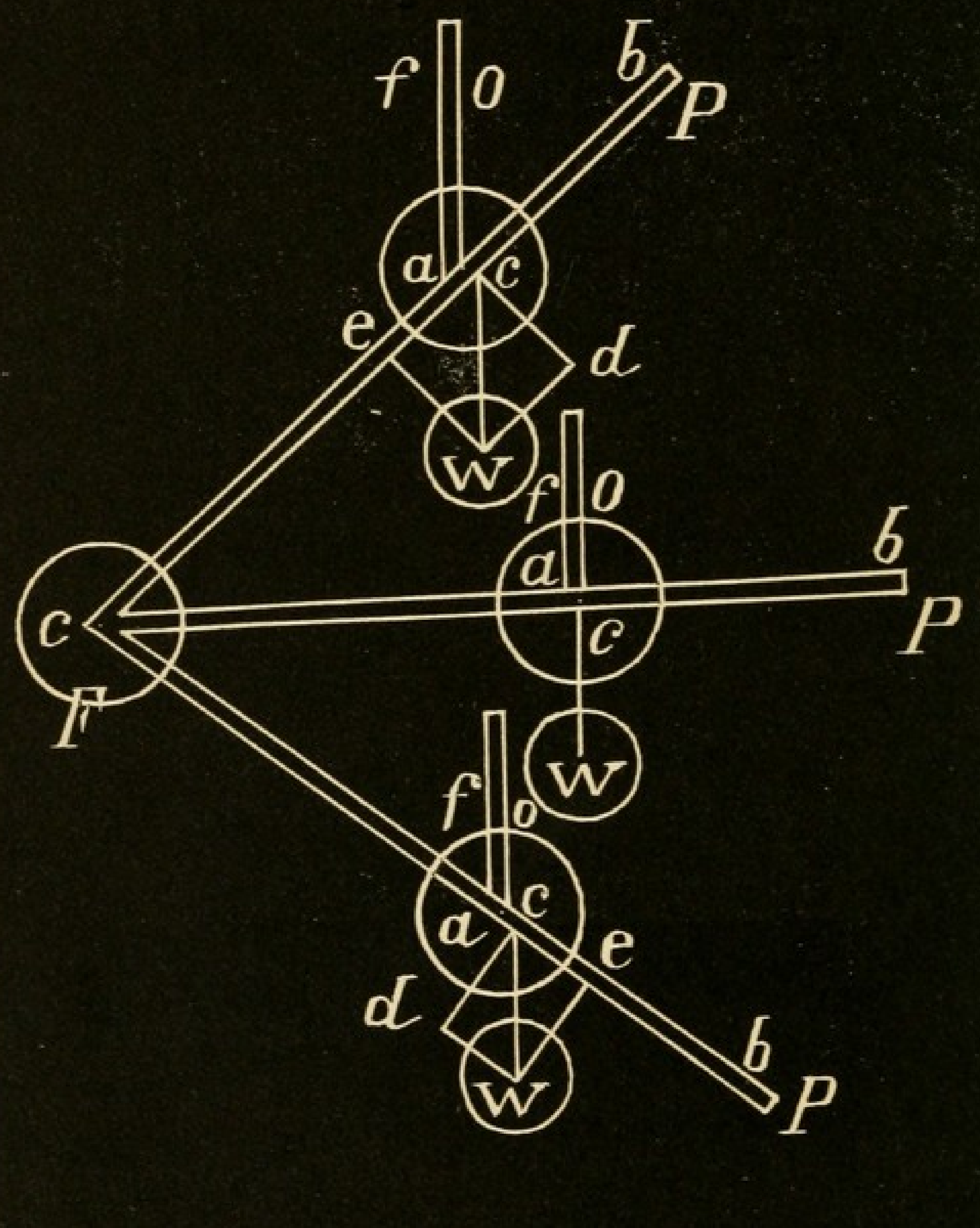
30. In myodynamics, when we have any order of bony lever, the force of the WEIGHT may be resolved into rectangular components.

(1.) One component of the weight acts at right angles to the long axis of the movable bone: as this component *resists* the moving component of the contracting muscle, it may be called the *Resisting component;* and as it aids in holding the movable bone against the fixed bone, it may also be called the *Retentive component.* See a d, Fig. 15.

(2.) The other component of the weight acts in the direction of the long axis of the movable bone: as this component tends to *displace* the movable bone from the fixed bone, it may be called the *Displacing component.* See a e, Fig. 15.

31. The two lines which represent the components of the weight are the base and perpendicular of a right-angled triangle—that may be called the *dynamic triangle.* One angle of this triangle is important, and may be called the *dynamic angle.*

Fig. 16.



II. Order.

32. In Figs. 15, 16 and 17, let f o c be the fixed bone, a c b the movable bone, and c their joint: in Figs. 15 and 16, the joint is in the continuity of the lever. Let P be the power, F the fulcrum, and W the weight, whose tendency is in the direction a w. On the line a w, as a diagonal, construct the rectangle a e w d, one of whose sides lies in the long axis of the movable bone—prolonged if necessary. *The dynamic triangle is a e w. The dynamic angle is included between the long axis of the movable bone—prolonged if necessary, and the line of the tendency of the weight, and is e a w.*

33. The dynamic angle is generally *acute.* It may be a *right-angle* at one point only—but is never greater than a right-angle.

34. In Figs. 15, 16 and 17, illustrating respectively levers of the first, second and third orders, the line a d represents the resisting component of the weight, and the line a e represents the displacing component of the weight.

35. In regard to the magnitudes of the *rectangular components* of the weight, the following conclusions may be drawn:

(1.) The resisting component of the weight is greatest, when the dynamic angle is a right-angle.

(2.) The resisting component of the weight is least, when the dynamic angle is the most acute.

(3.) When there is no dynamic angle, there is no resisting component.

(4.) The displacing component of the weight is greatest, when the dynamic angle is the most acute.

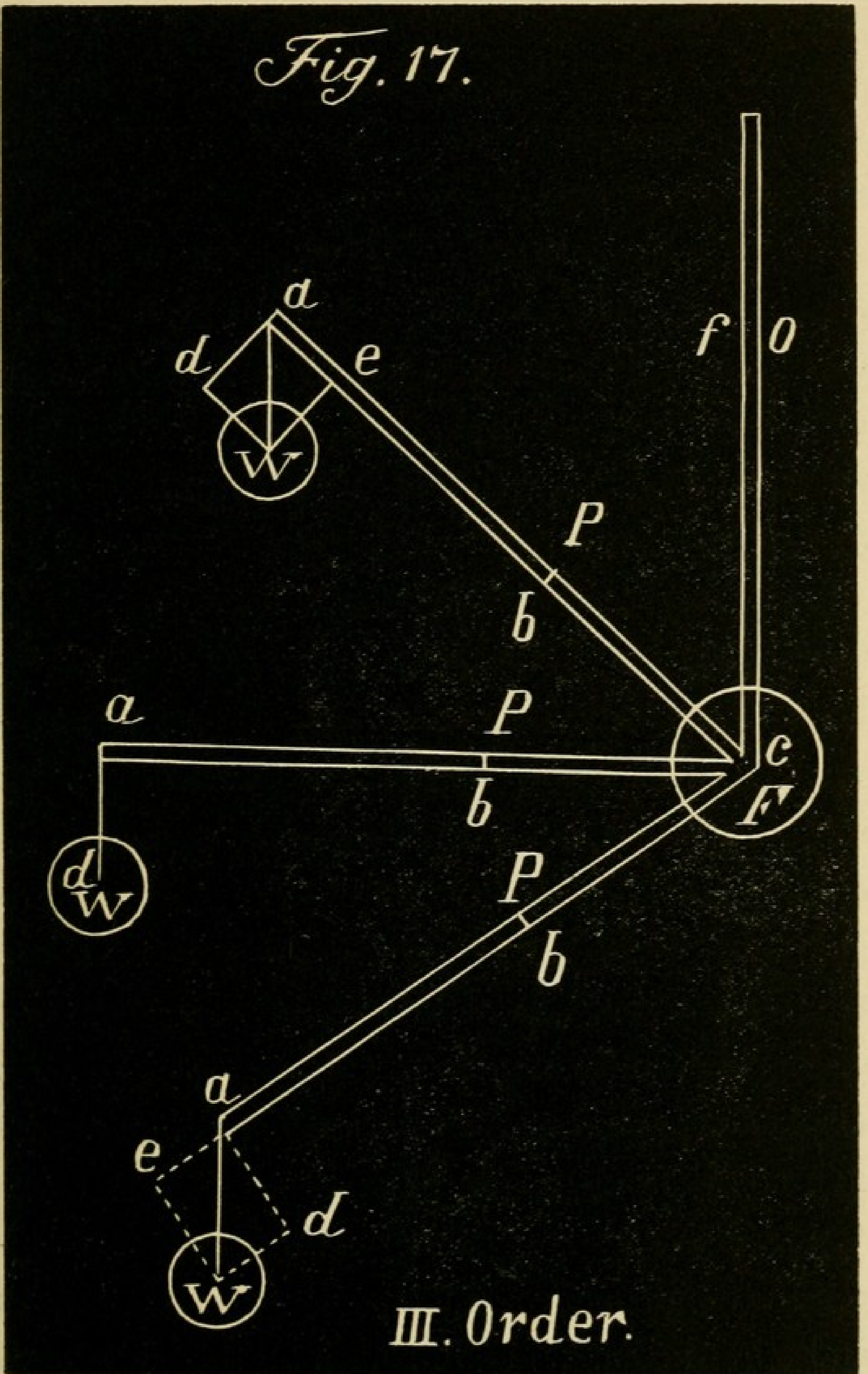
(5.) When the dynamic angle is a right-angle, the weight has no displacing component.

(6.) In general the resisting component augments up to a certain point and then diminishes in magnitude.

(7.) In general the displacing component diminishes up to zero and then augments in magnitude.

36. In so far as the force of the weight is concerned, the *joint* between a movable bone and a fixed bone is in a condition of maximum stability, when the dynamic angle is a right-angle, in the case of any bony lever. But the stability of the

Fig. 17.



III. Order.

joint becomes relatively less as the dynamic angle becomes less than a right-angle, in the case of any bony lever. The displacing component is a factor of instability.

37. By the formulæ of the component triangle, 27, (b), when two sides of the dynamic triangle and one of the related forces are known, it is possible to find either of the other two forces.—*The dynamic triangle is the component triangle of the weight.*

38. There are two important facts in regard to the structure of joints that ought to be remembered :—In myodynamics (a) the ligaments always and (b) the conformation of the joint sometimes antagonize the displacing components of the power and the weight. The crucial ligaments of the knee-joint and the conformation of the hip-joint are especially adapted to antagonize displacing components.—In the wrist joint the displacing components are small and the retentive components are large.

39. When the displacing components are successfully antagonized by the articular ligaments and the articular conformation, the forces of

these components are brought to bear on the joint-surfaces of the movable and fixed bones.

40. The combined effects of the rectangular components of the power and the weight on a bony lever of any order may now be considered.

(a) The following formulæ may be noted in regard to the three orders of the lever:

I. $P+W=F$ . . . . (1.)

II. $P+F=W$ . . . . (2.)

III. $F+W=P$ . . . . (3.)

In the above formulæ:

(i.) P is the *resultant* of the rectangular components of the *power*.

(ii.) W is the *resultant* of the rectangular components of the *weight*.

(iii.) F is the *resultant* of the rectangular components of the *fulcrum*.

(b) In this place it may be remarked that the rectangular components of the fulcrum may be analyzed in the same manner as the rectangular components of the power and the weight, in the case of any order of bony lever.

(c) In regard to the *moving* components of the power and the *resisting* components of the weight the following conclusions may be drawn:

(1.) In a bony lever of the I order:—The *moving* component of the power *plus* the *resisting* component of the weight equals the pressure of these components on the fixed bone.

(2.) In a bony lever of the II order:—The *resisting* component of the weight *minus* the *moving* component of the power equals the pressure of the components on the fulcrum.

(3.) In a bony lever of the III order:—The *moving* component of the power *minus* the *resisting* component of the weight equals the pressure of these components on the fixed bone.

(4.) The sum of the components acting at right angles to the ends of the bony lever equals the *resultant* component acting in the continuity of the lever.

(5.) *The moving and resisting components are conservative.*

(d) In regard to the *displacing* components of the power and the weight the following conclusions may be drawn:

(1.) In a bony lever of the I order:—i. Begin with an acute myodynamic angle, when the dynamic angle is also acute, and move the weight till the dynamic angle is a right angle:—See Fig. 15. During this motion the displacing components of the power and weight will *co-operate.*—ii. As the bony lever moves from the line where the dynamic angle is a right angle to the line where the myodynamic angle is a right-angle, the displacing components of the power and the weight will *antagonize.*—iii. As the bony lever moves from the line where the myodynamic angle is a right angle, the displacing components of the power and weight will *co-operate.*—iv. When the myodynamic triangle is right-angled at the joint, the resisting component of the weight equals the displacing component of the power.—This fact can be demonstrated by the myometer.

(2.) In a bony lever of the II order:—i. During the motion of the lever from the most acute myodynamic angle to the right-angled dynamic angle, the displacing components of the power and weight will *co-operate.*—ii. During the motion of the lever from the right-angled dynamic angle to the right-angled myodynamic angle, the displacing components of the power and weight will *antagonize.*—iii. After the lever moves from the line where the myodynamic angle is right-angled, the displacing components of the power and weight *co-operate.*—iv. When the myodynamic triangle is right-angled at the joint, the resisting component of the weight equals the displacing component of the power.

(3.) In a bony lever of the III order:—i. During the motion of the lever from the most acute myodynamic angle to the right-angled dynamic angle, the displacing components of the power and weight *antagonize.*—ii. While the lever is moving from the right-angled dynamic angle to the right-angled myodynamic angle, the displacing components of the power and weight *co-operate.*—iii. After the lever moves from the line of the right-angled myodynamic angle, the displacing components of the power and weight *antagonize.*—iv. Again, when the myodynamic triangle is right angled at the joint, the resisting component of the weight equals the displacing component of the power.

41. When the myodynamic triangle is right-

angled at the joint, the weight may equal the displacing component of the contracting muscle. The sides of the myodynamic triangle may be measured, and then it is easy to find the moving component as well as the entire force of the contracting muscle.

Example.—Let W=50: The displacing component of the contracting muscle=50. Let the sides of the component triangle be 2, 10, and 10.19 respectively: Then by the formulæ (3) and (5) 27 (b.)

$$\text{m-c} = 50 \times \frac{10}{2} = 250:$$

$$\text{And f-m} = 50 \times \frac{10.19}{2} = 254.75.$$

In which m-c is the moving component and f-m the entire force of the contracting muscle.

(A.) It is evident that the displacing component of the power is antagonized by the articular ligaments that connect the movable and the fixed bones: Hence the displacing component of the power is combined with the moving component of the power and presses the movable bone against the fixed bone as long as the articular ligaments remain unbroken.

(B.) It is also evident that the displacing component of the weight is antagonized by the articular ligaments that connect the movable and the fixed bones: Hence the displacing component of the weight is combined with the resisting component of the weight and presses the movable bone against the fixed bone as long as the articular ligaments remain unbroken.

(C.) A case might arise in which the entire force of the muscles that span a joint would act as a retentive force: for instance, when a weight is lifted by the hand in nearly the direction of the long axis of the fore-arm: in such a case the entire force of the weight would be a displacing force: and not only would the force of the muscles co-operate with the articular ligaments, but the force of the weight would antagonize the articular ligaments as well as the force of the muscles, unless the lifting muscles had the power to keep the weight from making tension on the ligaments.

(D.) A case might also arise in which the entire force of the weight would be retentive without the direct co-operation of the articular ligaments, for instance, when a weight is lifted nearly directly upward by the hand, having the long axis of the fore-arm and hand in a perpendicular position, the hand being above the fore-arm.

(E.) *When the displacing component is greater than the resistance of the articular ligaments, these ligaments must give way, and the movable bone will be dislocated.*

THE HAND AND THE WRIST-JOINT.

42. The hand can act as a lever of the first, second, or third order.

(1.) When the hand is extended and sustains a weight, it acts as a lever of the first order.

(2.) When the heads of the metacarpal bones rest on a solid surface, the hand acts as a lever of the second order.

(3.) When the hand is flexed and lifts a weight, it acts as a lever of the third order.

43. The hand lever is in myodynamic relation with the bones of the fore-arm through the muscles that span the wrist-joint. These muscles may be divided into four groups.

(1.) An *anterior group* containing the palmaris longus, the flexor carpi radialis, the flexor carpi ulnaris, the flexor sublimis digitorum, the flexor longus pollicis, and the flexor profundus digitorum.

(2.) An *outward group* containing the extensor carpi radialis longior, the extensor carpi radialis brevior, the three extensors of the thumb, and the flexor carpi radialis.

(3.) A *posterior group* containing the two carpo-radial extensors, the extensor carpi ulnaris, the extensor conmumis digitorum, the extensor minimi digiti, the extensor indicis, and the three extensors of the thumb.

(4.) An *inward group* containing the flexor carpi ulnaris and the extensor carpi ulnaris.

(5.) The muscles of the anterior group *flex*, those of the outward group *abduct*, those of the posterior group *extend*, and those of the inward group *adduct* the hand.

44. Some of the dynamic relations of the wrist-joint are important.

(1.) There is generally an inward and forward obliquity of the floor of the base of the radius of 10 or 15 degrees.

(2.) The tendons of the *flexors* meet the plane of the floor of the base of the radius at an angle somewhat greater than 10 or 15 degrees.

(3.) The tendons of the *extensors* of the thumb meet the plane of the floor of the base of the radius at an angle greater than 10 or 15 degrees.

(4.) The tendons of the *rest* of the *extensors* of the hand meet the plane of the floor of the base of the radius at an angle somewhat less than 10 or 15 degrees.

(5.) *The tendons that span the wrist-joint act as ligaments.* They come against the base of the radius and help prevent displacements of the hand.

(6.) The carpus moves forwards, outwards, backwards, and inwards in the concavity of the base of the radius.

45. The extent of the motions of the hand may be illustrated by the following measurements of a case:

(1.) From the long axis of the fore-arm the hand was *flexed* 70 degrees.

(2.) From the long axis of the fore-arm the hand was *abducted* 10 degrees.

(3.) From the long axis of the fore-arm the hand was *extended* 75 degrees.

(4.) From the long axis of the fore-arm the hand was *adducted* 35 degrees.

(5.) With external force the hand can be moved further in any direction than has just been noted.

46. In a certain case the dimensions of the hand-lever were as follows:

(1.) The entire length was 4 inches—the distance from the heads of the metacarpal bones to the base of the radius.

(2.) The distance from the heads of the metacarpal bones to the point where the force in the continuity of the lever acts was 3 inches.

(3.) The distance from the point where the force in the continuity of the lever acts to the carpal end of the lever was 1 inch.

47. In the case in which the dimensions of the hand-lever were measured, let the entire weight of the body—150 pounds—rest on a resisting surface through the heads of the metacarpal bones. The hand is now a lever of the second order: *The weight* of the body *equals the pressure of the carpus on the base of the radius.*—We have two equations, and two unknown quantities:

$150 + P = W$ . . . . (1.)

$4 \times P = 3 \times W$ . . . . (2.)

From these equations we find the values of P and W:

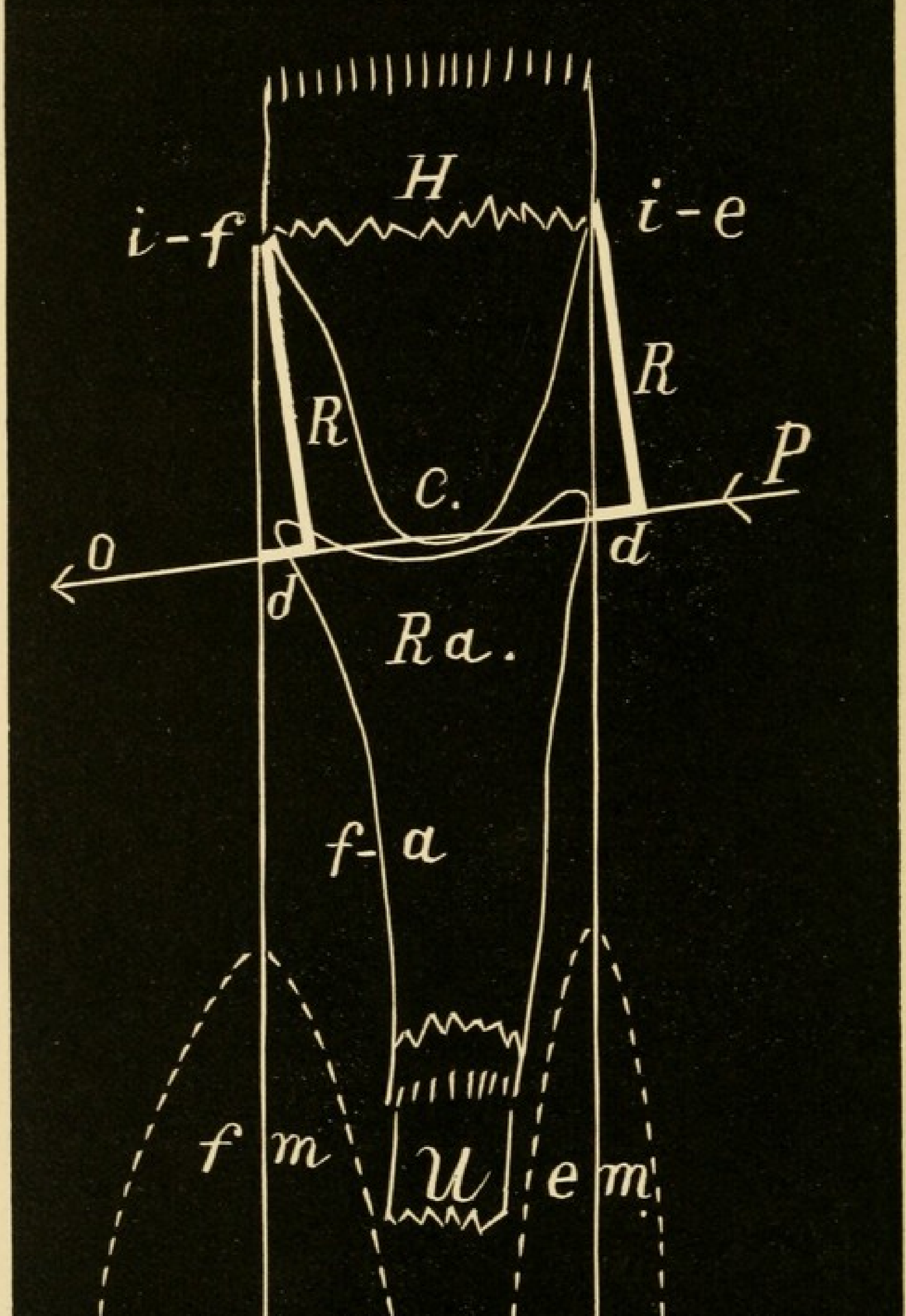
$P = 450$ pounds . . . . (3.)

$W = 600$ pounds . . . . (4.)

In this case: (1.) When the hand is extended the fulcrum is on the *palmar* aspect of the heads of the metacarpal bones; (2.) When the hand is flexed the fulcrum is on the *dorsal* aspect of the heads of the metacarpal bones.

48. In the next place, let the hand-lever, as a lever of the third order, having the same dimen-

Fig. 18.



sions as before, be flexed, and lift a weight of 50 Pounds. Then we shall have two equations:

$P = 4 \times W = 200$ . . . . (1.)

$F = P - W = 150$ . . . . (2.)

(1.) The force of the contracting muscles equals 200 pounds.

(2.) The pressure of the carpus on the base of the radius equals 150 pounds.

49. The myodynamic relations of the wrist-joint are conservative—even on the application of considerable external force :—

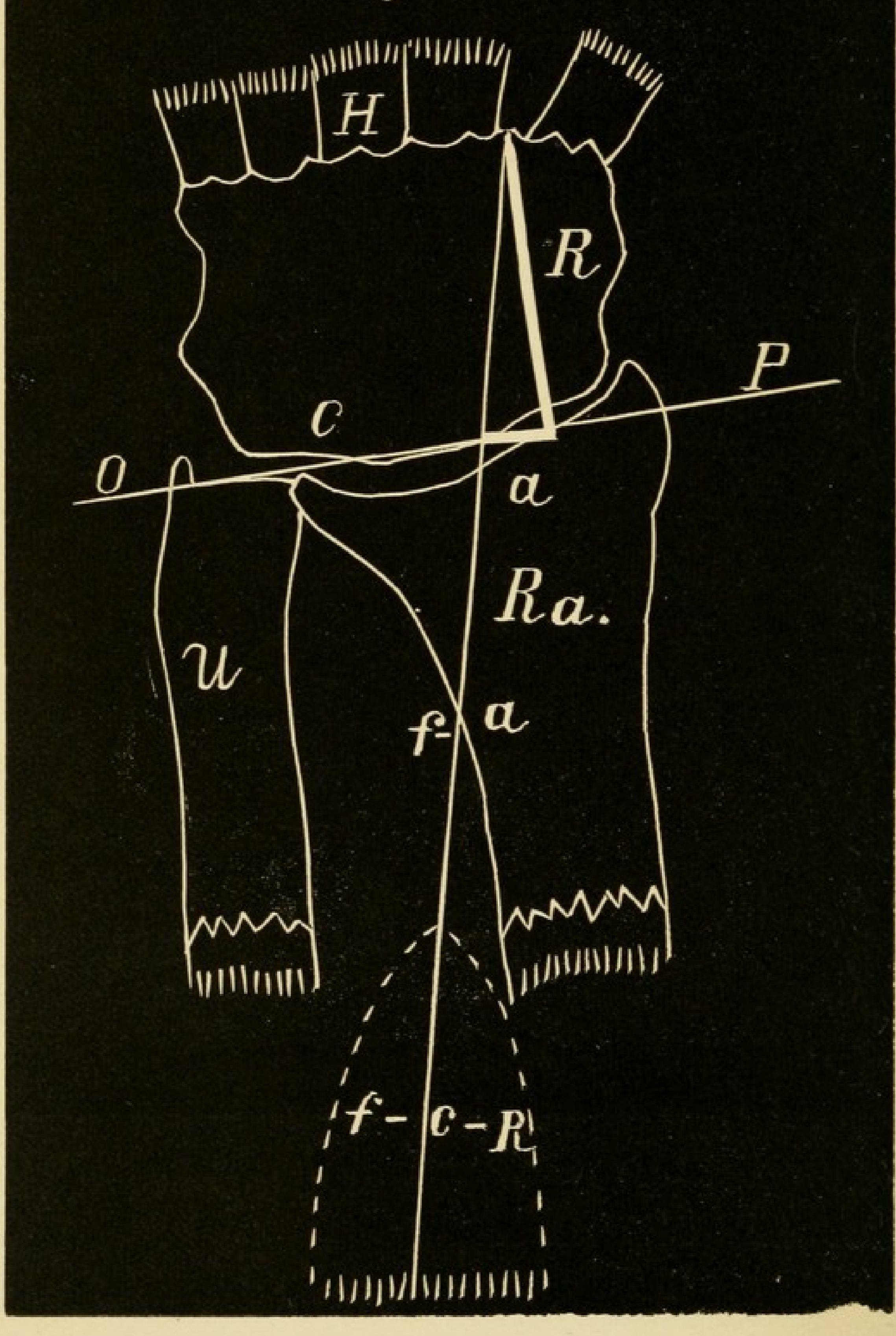
(1.) The hand is very rarely dislocated :

(2.) The base of the radius is frequently broken :

(3.) These conclusions agree with the practical observations of surgeons.—

Examples :—In Figs. 18 and 19, H=the hand; C=the carpus; R a=the radius; U=the ulna; f-a=the fore-arm; f-m=the flexors *on* the fore-arm; e-m=the extensors *on* the fore-arm; f-c-R=the flexor carpi radialis; P o= the plane of the base of the radius; R=a retentive component; and d=a displacing component: Fig. 18 is an outside view of the

Fig. 19.



wrist-joint; Fig. 19 is a front view of the wrist-joint:—By a simple inspection of the figures it can be seen how the *retentive components* of the muscles that span the wrist-joint preponderate over the displacing components of these muscles.

50. The retentive pressure of the muscles *on* the fore-arm is expended on the base of the radius. And sometimes in old age and after contusions and sprains the base of the radius is shortened and otherwise deformed by interstitial absorption. A condition of this kind will more or less resemble the results of a fracture of the base of the radius.

THE RADIUS AND THE RADIO-ULNAR-JOINT.

51. The base of the radius turns about the head of the ulna as a wheel turns about its axle, while the head of the radius turns on its own axis in a concavity of the base of the ulna. The radius turns inward and outward.

(1.) The inward turn of the radius is called *in-rotation*.

(2.) The outward turn of the radius is called *out-rotation.*

(3.) The arc of rotation of the radius is about 180 degrees.

52. When the fore-arm is completely extended the long axis of the ulna is nearly on a line with the long axis of the humerus.

(1.) Completely *supinate* the radius and the long axis of the fore-arm and the long axis of the humerus will meet forming an obtuse angle on the outside.

(2.) Completely *pronate* the radius and the long axis of the fore-arm will be quite on a line with the long axis of the humerus.

(3.) During the rotation of the radius a line drawn from the point of the styloid process to the upper end of the axis of the radial head will describe one-half of a cone: This may be called the *radial cone.*

53. The following dimensions of the radial cone were taken in a given case:—

(1.) The radius of the base of the radial cone was about one and three-fourths inches in length.

(2.) The altitude of the radial cone was about nine and one-fourth inches in length.

(3.) The slant height of the radial cone was about nine and two-fourths inches in length.

(4.) The axis of the radial cone prolonged downward will nearly coincide with the long axis of the ring-finger.

54. The following dimensions of the quadrangle of the fore-arm were taken in the same case :—

(1.) One side of the quadrangle was about one and three-fourths inches in length.

(2.) The other side of the quadrangle was about ten inches in length.

(3.) The proximal end of the quadrangle of the fore-arm is measured on the lower end of the humerus.

55. Flex the fore-arm so that its long axis meets the long axis of the humerus at right angles, and put the fore-arm in a position of *mid-rotation* :—

(1.) The plane of the bones of the fore-arm will be nearly *vertical.*

(2.) The long axis of the humerus will meet a vertical line in the plane of the fore-arm at an angle of about 135 degrees.

56. The muscles that *rotate* the fore-arm are divided into two groups:—The *pronators* and the *supinators*:—

(1.) The *pronators* of the fore-arm are—the *pronator quadratus*, the *pronator radii teres*, the supinator longus, the biceps brachii, the flexor carpi radialis, the flexor sublimis digitorum, and the flexor profundus digitorum.

(2.) The *supinators* of the fore-arm are—*The supinator brevis, the extensor ossis metacarpi pollicis, the extensor primi internodii pollicis, the extensor secundi internodii pollicis*, the supinator longus, the extensor carpi radialis langior, and the biceps brachii.

57. The supinator longus has three functions:—

(1.) It flexes the radius; (2.) it pronates the radius during the first part of in-rotation; (3.) it supinates the radius during the first part of out-rotation.

58. A muscle whose long axis runs in the direction of the diagonal of the quadrangle of

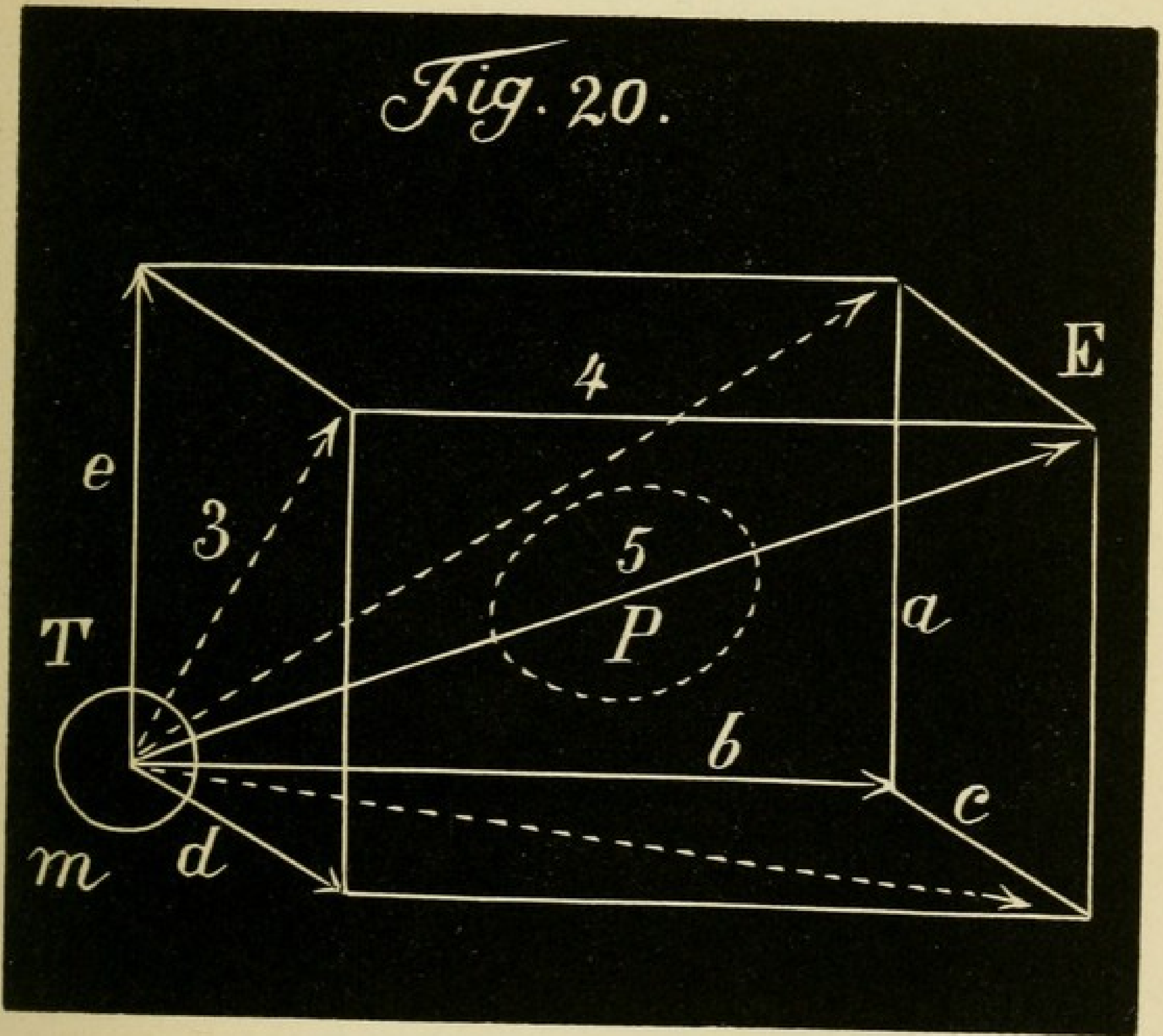


Fig. 20.

the fore-arm will have its force resolved into *four* components in so far as the elbow-joint is concerned, and into *three* components in so far as the radio-ulnar-joint is concerned :—See Fig. 20.

(1.) Let P be the contracting muscle, E its origin, and m its insertion : Construct on m P E the long axis of the contracting muscle, a rectangular parallelo pipedon. The force of P will evidently be resolved into the components a, b, and c:—(i) The moving component will be a ; (ii) the retentive component will be b in the case of the radius, and a in case of the ulna ; (iii) the displacing component will be a in the case of the radius, and b in the case of the ulna ; (iv) and the lateral displacing component will be c.

(2.) The component a equals the component e, and the component c equals the component d :—But e is a component making in-rotation of the radius, and may be called (i) a *rotating component* ; and this component tends to displace the radius from the ulna, and may be called the (ii) *rotating displacing component* ; while the component d tends to hold the radius against the ulna, and may be called the (iii) *lateral retentive component.*

59. The resultant of e and d is marked 3 in the figure :—and the resultant of 3 and b, or of e, d, and b is marked 5 in the figure : Hence, the force of P, that is, 5, is resolved into 3, and 4 : So that the lines 3 and 4 represent the two general rectangular components.

60. The *lateral retentive* components of the inrotators of the fore-arm are greater than the rotating components : Hence these muscles act in a conservative manner in so far as the radio-ulnar joint is concerned.

61. A special group of muscles supinating the radius comprises—the supinator brevis, the extensor ossis metacarpi pollicis, the extensor primi internodii pollicis, and the extensor secundi internodii pollicis. These muscles run obliquely across the quadrangle of the fore-arm, and have—

(1.) Retentive components acting on the radius in a proximal direction.

(2.) Lateral components acting from without inward.

(3.) The lateral components will be resolved into *rotating* and *retentive* components :—(a) The *retentive components* will hold the radius against the ulna :—(b.) The *rotating* components will rotate the radius.

(4.) The lateral retentive components of the special supinators are greater than the rotating components of these muscles.

(5) Hence, the forces of the special outrotators of the fore-arm act in a conservative manner in so far as the radio-ulnar joint is concerned.

62. *The function of the supinator longus deserves special attention.*

(1.) In the first place, when the fore-arm is completely extended, the *origin* of the supinator longus will be nearly in a line with the axis of the radial cone, and as the radius rotates in-and-out, the long axis of the supinator longus will coincide nearly with the slant-height of the radial cone :—*So that, under the circumstances, the supinator longus will not be a strong rotator.*

(2.) In the second place, flex the fore-arm until it makes a right angle with the arm, and let the ulna be fixed in this position: As the radius rotates completely in-and-out, the insertion of the supinator longus will describe a semi-circle, and it is evident that the top of this semi-circle will be nearer the origin of the supinator longus than any other points. Hence, under the circumstances, the supinator longus will shorten from complete supination to mid-rotation, and elongate from mid-rotation to complete pronation; but all the time the supinator longus will act as a flexor of the forearm.

(3.) In the third place, the moving component of the supinator longus tends to displace the radius from the ulna—especially the base of the radius from the head of the ulna.

63. The supinator longus is properly a flexor of the radius—even as much as the biceps brachii:

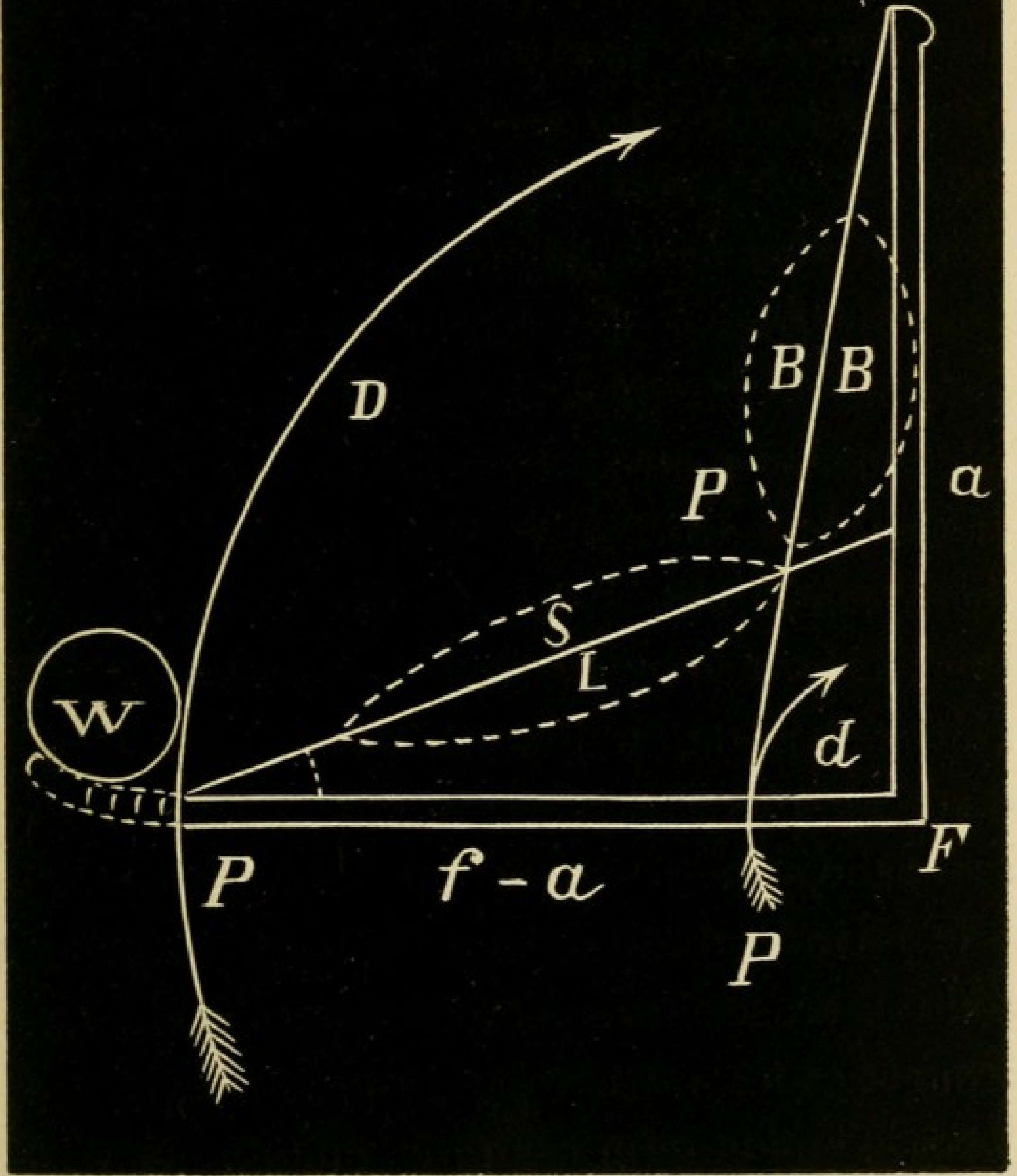
(1.) In a given case, the length of the radius was nine inches, and the length of the power-arm of the bony lever was one and one-fourth inches—the power being the biceps brachii. The force of the biceps brachii must be 360 pounds to lift 50 pounds.

(2.) In the same case, the distance of the origin of the supinator longus from the head of the radius was about four inches: Let the dynamic triangle be right angled at the joint—*the force of the supinator longus must be only 122 pounds to lift 50 pounds.* Now, if we suppose that, on the average, the supinator longus can lift twice as much as the biceps brachii, then it will follow that the supinator longus can lift as much, on the average, as the biceps brachii and the brachialis anticus. See Fig. 21.

(3.) But, in a given case, according to the above calculations, the supinator longus can lift nearly three times as much as the biceps brachii. The weight is lifted by means of the hand in each instance.

(4.) It must be remembered, however, that the biceps brachii has a greater transverse section than the supinator longus, and, in this respect, can exert more power than the latter muscle. The biceps brachii makes motion—the supinator longus applies force.

Fig. 21.



THE FORE-ARM AND THE ELBOW-JOINT.

64. The bones of the fore-arm can act as a lever of the first, second, or third order.

(1.) Elevate the arm and lift a weight with the hand; the triceps brachii will move the ulna and carry along the radius, making the bones of the fore-arm a lever of the first order.

(2.) Rest the hand on a resisting surface, as a fulcrum, and the bones of the fore will be a lever of the second order, whose power comes from the triceps brachii. It is evident that the mechanical principles involved in these two cases are similar, the weight and the fulcrum only changing places, while the power continues to act at the same point.

(3.) Under the action of the biceps brachii and the brachialis anticus, the bones of the fore-arm act as a lever of the third order.

65. The fore-arm has three motions:

(1.) The rotation of the fore-arm has already been described.

(2.) The fore-arm moves forward and backward about 130 degrees: *Flexion* and *extension*.

(3.) In early life the fore-arm moves outward and inward, sometimes as much as 15 degrees: *Abduction* and *adduction*—a lateral ginglymus.

66. The elbow joint has two essential parts:

A. (1.) The ulno-numeral articulation is a hinge-joint, and the greater sigmoid cavity of the ulna always embraces the trochlea of the humerus.

(2.) The radio-humeral articulation is a hinge-joint and *a ball-and-socket-joint*, having a shallow socket in the head of the movable bone, and a small head on the fixed bone. The radius has only *semi-circumduction*, which, in so far as the ulna is concerned, is rotation.

B. (1.) The distal end of the humerus, from the grove of the trochlea outward, is nearly transverse to the long axis of the humerus.

(2.) The *lip* of the trochlea projects downward about 30 degrees from the transverse diameter of the condyles of the humerus. This lip antagonizes the inward lateral displacing components of such muscles as are attached to the internal condyle, and run obliquely downward and outward across the quadrangle of the fore-arm.

67. The muscles that span the elbow joint may be divided into three groups :

(1.) The *rotators* of the fore-arm have already been enumerated.

(2.) The *flexors* of the fore-arm are : (i.) The supinator longus, the biceps brachii, and the brachialis anticus. (ii.) The pronator radii teres, and the flexors *on* the fore-arm, and the long carpo-radial extensor.

(3.) The *extensors* of the fore-arm are : (i) The triceps brachii and the supinator brevis. (ii) The extensors *on* the fore-arm.

(a.) The flexors *on* the fore-arm and the extensors *on* the fore-arm have indirect moving components acting on the radius and ulna.

(b.) A muscle that spans two joints can make the intermediate bone a fixed bone, and the adjacent bones movable bones. One of the adjacent bones may be the fixed bone, and the other two movable bones.

68. In the next place, the following proposition can be proved :

The muscles that directly and indirectly flex the forearm are more powerful than those which directly and indirectly extend the forearm.

I made transverse sections of the upper limb of a muscular male, whose cadaver had been preserved for dissection. First: I made a transverse section of the fore arm three inches above the wrist joint: (1) The section of the muscles on the dorsal aspect showed an area of about one and one-eighth square inches; and (2), the section of the muscles on the palmar aspect showed an area of about two square inches. Second: I made a transverse section of the fore-arm four inches below the elbow joint: (1) The section of the muscles on the dorsal aspect showed an area of about two square inches; (2) the section of the muscles on the palmar aspect showed an area of about four and one-half square inches. Third: I made a transverse section of the middle of the arm: (1) The section of the muscles on the dorsal aspect showed an area of about two and one-half square inches; and (2), the section of the muscles on the palmar aspect showed an area of about three and one-half square inches.

69. From the above measurements may be drawn the following conclusions—namely,

I. In the lower part of the forearm the volume of the muscles on the posterior aspect is to the volume of the muscles on the palmar aspect as 9 : 16.

II. In the upper part of the fore-arm the volume of the muscles on the posterior aspect is to the volume of the muscles on the palmar aspect as 4 : 9.

III. In the middle of the arm, the volume of the muscles on the posterior aspect is to the volume of the muscles on the palmar aspect as 5 : 7.

IV. In general, the volume of the muscles on the palmer aspect of the upper limb is nearly twice as great as the volume of the muscles on the posterior aspect of the same limb. The ratio may vary from the above estimate.

70. It is well known that the proper use of a muscle will increase its power up to a certain

point. And the muscles on the palmar aspect of the upper limb are used more than the muscles on the dorsal aspect of the upper limb, because the former are habitually made to overcome greater resisting forces than the latter. *Hence, the flexors of the upper limb are more powerful than the extensors.*

71. (a.) When the radius is completely extended the radio-humeral joint is conserved by :

(1.) The retentive components of the supinator longus and the biceps brachii.

(2.) The retentive components of the pronator radii teres and the supinator brevis.

(b.) And the superior radio-ulnar joint is conserved by the *lateral* retentive components of the pronator radii teres and the supinator brevis.

72. When the radius is semiflexed :

(1.) The displacing component of the biceps brachii will be large.

(2.) The displacing component of the pronator radii teres will be relatively small.

(3.) The retentive component of the supinator longus will be large, and its moving component will not act as a displacing component.

(4.) *The special ab-ductors* of the hand—that is, *the two carpo-radial extensors*—will have large retentive components :—

So that the radio-humeral joint will be in a comparative condition of conservatism.

73. When the radius is completely flexed :

(1.) The greater parts of the forces of the biceps brachii and of the brachialis anticus will be displacing components.

(2.) But these displacing components will be antagonized by parts of the forces of the supinator longus, the supinator brevis, the special abductors of the hand, and other muscles that span the elbow-joint and have their origin on the lower end of the humerus. In this respect, the radio-humeral joint is in a conservative relation; and the ulno-humeral joint has conservative myodynamic relations in any position of the fore-arm except one—namely,

74. When the fore-arm is flexed about 25 degrees. The co-operation of a resisting force against the palm of the hand and the *displacing* components of the muscles enumerated below will dislocate the ulna and the radius :—

The triceps brachii, the flexors *on* the fore-arm, the extensors *on* the fore-arm, the supinator longus, and the pronator radii teres. It is evident that the supination of the radius aids in causing this dislocation.

75. This dislocation is the more possible, because the shaft of the ulna is almost wholly, as it were, back of the condyles of the humerus, and because the coronoid process, at times, is somewhat readily lifted from the trochlea by the impact of violence and the force of displacing components:—when the radius is carried with the ulna, assisted by displacing muscular components.

76. In regard to the stability of the elbow-joint, the following statements may be made:

(1.) When the fore-arm is completely extended, the radio-humeral joint is in a condition of maximum stability.

(2.) When the fore-arm and the arm meet at a right angle, the ulno-humeral joint is in a condition of maximum stability.

(3.) The elbow-joint has less stability than the wrist-joint.

77. In a given case, it was found that,

(1.) During flexion of the fore-arm, the insertion of the biceps brachii approached its origin about three inches.

(2.) During flexion of the fore-arm, the insertion of the supinator longus approached its origin about seven inches.

(3.) This shows that the supinator longus has more intrinsic motion than the biceps brachii: It can contract more.

78. In any case, when the biceps brachii moves a weight in the hand, the weight moves as much further than the bicipital tubercle of the radius as the weight-arm of the bony lever is longer than the power-arm. See Fig. 21. The proportion is as follows: W–F : P–F : : D : d : In which D = the distance which W moves, and d = the distance which P moves.

(1.) While the weight is moving, it can do more work at any one moment than the power of the biceps; because the energy of the weight is proportional to the square of its velocity; while the energy of the power is proportional to the square of its velocity; and because the excess of energy in the biceps necessary to move the weight *accumulates* in the weight.

(2.) The simple fact is, that the molecular motion of the biceps is correlated into the molar motion of the radius and the weight; and, as molar motion represents energy, there is no loss of muscular force.

THE HUMERUS AND THE SHOULDER-JOINT.

79. The humerus may act as a lever of the first, second, or third order:

(1.) The transverse diameter of the tuberocities of the humerus acts as a lever of the first order when moved by the rotators. The in-rotators of the arm may be the power, and the out-rotators may be the weight.

(2.) The supraspinatus can act on the humerus so as to make it a lever of the second order, when the weight of the body is put more or less on the head of the humerus, and consequently on the outside of the elbow.

(3.) The pectoralis major, for instance, makes the humerus a lever of the third order.

80. The motions of the arm may be arranged under four heads :

(1.) The arm can move inward and outward about 90 degrees—*adduction* and *abduction*.

(2.) The arm can move backward and forward about 135 degrees—*extension* and *flexion*.

(3.) The arm can rotate inward and outward about 90 degrees—*in-rotation* and *out-rotation*.

(4.) The arm can move around to the right or to the left 360 degrees—*circumduction*.

81. The muscles that move the arm may be grouped according to the direction of these motions :

(1.) The *adductors* of the arm are the pectoralis major, the teres major, the teres minor, the subscapularis, the infraspinatus, and the latissimus dorsi.

(2.) The *flexors* of the arm are the biceps brachii, the coraco-brachialis, the pectoralis major, and the anterior part of the deltoid.

(3.) The *abductors* of the arm are the deltoid and the supraspinatus.

(4.) The *extensors* of the arm are the triceps brachii, the posterior part of the deltoid, the infraspinatus, the teres minor, the teres major, the subscapularis, and the latissimus dorsi.

(5.) The *out-rotators* of the arm are the teres minor, the infraspinatus, the supraspinatus, and the posterior part of the deltoid.

(6.) The *in-rotators* of the arm are the subscapularis, the pectoralis major, the anterior part of the deltoid, the teres major, and the latissimus dorsi.

(7.) The *circumductors* of the arm comprise, in one way or another, all the muscles that span the shoulder-joint and move the arm.

82. In an average-sized specimen of an adult humerus, the following measurements were made :

(1.) The entire length was about 13 inches.

(2.) The length of the anatomical neck was about three-eighths of an inch.

(3.) The depth of the head was about five-eighths of an inch.

(4.) The diameter of the head was about one and three-eighths inches.

(5.) The long axis of the humerus met the plane of the base of the head of the humerus at an angle of about 45 degrees.

83. In the same case, the following observations were made:

(a.) The external condyle and the greater tuberosity of the humerus pointed in the same direction.

(b.) The internal condyle pointed in the same direction as a line on the head of the humerus midway between the neck behind and the bicipital grove in front.

(c.) The greatest conjugate diameter of the glenoid cavity of the scapula was about one and one-fourth inches; while the greatest transverse diameter was about one and five-eighths inches.

(d.) The acromion projected about two inches beyond the glenoid cavity.

(e.) The coracoid process of the scapula projected somewhat above and in front of the glenoid cavity.

(f.) The strong coraco-acromial ligament completed the roof over the upper end of the humerus.

84. In general, the plane of the floor of the glenoid cavity of the scapula, or its conjugate diameter, runs somewhat backward from the transverse plane of the body, while the transverse diameter of this cavity is nearly parallel with the long axis of the body. *The surface of the cavity looks forward and somewhat outward.* The head of the humerus rests on this plane. Are there any muscular components that tend to displace the head of the humerus from the glenoid cavity of the scapula? In the meantime, let the mobility of the scapula, in regard to the chest-wall, be kept in mind. And let it also be kept in mind that the extensive motion of the humerus is facilitated by the comparatively large articular surface of its head and by the comparatively small articular surface of the glenoid cavity of the scapula.

85. Some of the muscles that span the shoulder-joint have small displacing components acting on the humerus:

(1.) The supra spinatus has no displacing components acting on the humerus. The anterior part and the posterior part of the deltoid may have displacing components acting on the humerus.

(2.) The infraspinatus, the subscapularis, and the teres minor may have downward displacing components acting on the humerus.

(3.) The coraco-brachialis and the short head of the biceps brachii and the long head of the triceps brachii may have small inward displacing components acting on the humerus.

86. Some of the muscles that span the shoulder-joint have large displacing components acting on the humerus. These are the pectoralis major, the teres major, and the latissimus dorsi, and the deltoid:

(1.) The lower part of the pectoralis major deserves special attention: (i) It has a large myodynamic angle giving a large displacing component acting downward. (ii) It pulls almost directly inward and forward, in the direction of the conjugate diameter of the glenoid cavity. (iii) Hence, the lower part of the pectoralis major has a predominant displacing component acting on the humerus, forward, inward, and downward.

(2.) For reasons that are plain, the upper part of the pectoralis major has a large inward and forward displacing component.

(3.) The teres major and the latissimus dorsi act nearly in the same direction and have large displacing components acting on the humerus, downward, inward, and somewhat backward.

(4.) When the arm is *abducted* the deltoid will have a large displacing component acting on the humerus. This results from the fact that then the deltoid pulls nearly in a line with the conjugate diameter of the glenoid cavity of the scapula.

(5.) When the arm is abducted, the triceps brachii, by means of its scapular origin, on account of the direction of the plane of the glenoid cavity, will have a considerable displacing component, acting forward, inward, and downward, on the head of the humerus.

(6.) *Hence, it will appear that the shoulder-joint, under some myo-dynamic relations, is in a condition of remarkable instability.*

(7.) It may be noted that the arm can only be abducted to a right angle with the body.

(8.) If the arm is rotated inward, the head of the humerus will turn under the acromion, and the arm can then be elevated so as to come more directly upward.

87. There are some points of dynamic importance to add to the facts above stated :

(1.) Let the elbow meet with a resisting surface—acting as a *power*—abducting the arm until the great tuberosity of the humerus comes against the acromion. Let the acromion be the weight—then the resistance of the lower portion of the capsule will represent the fulcrum—which may practically give way and let the head of the humerus out of the socket. *The humerus, under the circumstances, will be a lever of the second order*—and, on account of the length of the power-arm and on account of the comparative shortness of the weight-arm, will apply great force to the capsule. Also the prominent part of the head of the humerus will be brought nearer the lower border of the socket, and so be more apt to slip off into the axilla. And the adductors of the arm will be put on the stretch, and will have their displacing components augmented, which may be looked upon as so much weight to be added to the resistance of the acromion, and thus the displacement of the head of the humerus into the axilla will be doubly assured—on the principle of a lever of the second order.—

(2.) But, if the displacing components of the adductors and the resistance of the acromion be looked upon as the power, the principle of a lever of the third order will be involved, and the fulcrum will be overcome :—which is the lower and internal portion of the capsular ligament.

88. The following problem may now be solved :—*To determine, in a given case, the strain on the inner and lower portion of the capsule of the shoulder-joint.*—It will be convenient at present to consider the humerus a lever of the first order.—

(1.) Let the power-arm of the lever be ten inches long—the distance from the elbow-joint to the acromion. Let the weight-arm of the lever be two inches long—the distance from the inner and lower portion of the capsule to the acromion.

In this case the acromion will be the fulcrum. Let the force applied to the distal end of the humerus equal 100 pounds. Then,

$$2 : 10 = 100 : 500.$$

Hence, so far, the strain on the capsule will equal 500 pounds.

(2.) Again, let the power-arm of the lever be ten inches long—the distance from the elbow-joint to the insertion of the adductors of the arm. Let the weight-arm of the lever be two inches long—the distance from the inner and lower portion of the capsule to the insertion of the adductors of the arm. In this case the insertion of the adductors of the arm will be the fulcrum. But the force, as supposed, applied to the distal end of the humerus, equals 100 pounds. Then, again,

$$2 : 10 = 100 : 500.$$

Hence, also, so far the strain on the capsule will equal 500 pounds.

(3.) Therefore, under the circumstances, the capsule of the shoulder-joint receives a strain equal to 1000 pounds. And it may happen that the greater part of this strain acts as a displacing force, tending to put the head of the humerus into the axilla. Such a result takes place from time to time.

91. The conformation and the muscular relations of the shoulder-joint above and behind are eminently conservative. The conformation and the muscular relations of the shoulder-joint below and partly in front are notably non-conservative. These conclusions agree with the observations of surgeons in regard to dislocations of the humerus.

THE FOOT AND THE ANKLE-JOINT.

92. The foot acts as a lever of the second order.

In the first place, the following points are to be noted: (1.) The ankle-joint is a hinge-joint. The foot has *flexion* downward and backward, and *extension* upward and forward. (2.) The lateral motion of the foot (which is principally inward) takes place at the subastragaloid joint.

(3.) The two malleoli protect the sides of the ankle-joint. (4.) The extensor tendons are held down by the annular ligament which, to some extent, plays the part of a pulley. (5.) The tendo-Achillis is also, to a limited extent, held down by the annular ligament. (6.) The astragalus glides and turns backward and forward under the tibio-fibular arch. (7.) The muscles of the tendo-Achillis are especially used for locomotion; they are lifting muscles. (8.) The tibialis posticus, the flexor communis digitorum, the flexor longus pollicis, the peroneus longus, and the peroneus brevis are especially used to flex, abduct, evert, and invert the foot.

93. (a.) The *extensors* of the foot are the tibialis anticus, the extensor longus pollicis, the extensor longus digitorum, and the peroneus tertius. When the extensors lift the anterior part of the foot, the foot is a lever of the third order.

(b.) The *flexors* of the foot are the tibialis posticus, the flexor longus digitorum, the flexor longus pollicis, the muscles of the tendo-Achillis, the peroneus longus, and the peroneus brevis.

(c.) The *adductors* of the foot are the tibialis anticus, the tibialis posticus, the flexor longus pollicis, the flexor longus digitorum, and the muscles of the tendo-Achillis.

(d.) The *abductors* of the foot are the extensor communis digitorum, the peroneus tertius, the peroneus brevis, and the peroneus longus.

94. It must be kept in mind that the gastrocnemius spans both the knee-joint and the ankle-joint, arising from the condyles of the femur and inserted into the os calcis. The important practical relation here consists in the fact that the gastrocnemius can not be completely relaxed without flexing the leg on the thigh and the foot on the leg. This fact will appear to advantage in the reduction of dislocations of the foot, and in the setting of broken bones of the leg.

95. When the foot is completely extended, the tendons of the extensors are held down by the annular ligament, and the direction of traction is downward and backward, so that the extensors, under the circumstances, will have strong displacing components, and at the same

time the special flexors of the foot, as they pass around the malleoli, will have strong displacing components. The displacing components of both sets of muscles will act downward and backward; but the muscles of the tendo-Achillis, during this time, will have a strong displacing component acting upward and forward, and counteracting the displacing components of the special flexors and the extensors of the foot.

96. From the point of complete extension the foot can be flexed about forty-five degrees. In any position of the foot, the extensors and special flexors have marked displacing components acting backwards. But when the tendo-Achillis meets the long axis of the foot at right angles, the muscles of this tendon will not have a displacing component; all the energy of the muscles will be motor and retentive.

97. The displacing components of the adductors of the foot will tend to displace the rest of the foot from the astragalus; but the connections of the subastragaloid joint are very strong, and the malleolus internus will be apt to give way, under the application of great force, when

the displacement will occur at the ankle-joint, complicating a dislocation with a fracture.

98. In this place, it is proper to determine whether or not the *foot* acted on by the muscles of the tendo Achillis is a *lever* of the *second order*. Under the circumstances, it has already been shown by transposing terms that the foot involves the principles of a lever of the first order. This would be true of any lever of the second order. In a lever of the second order, *the weight is somewhere in the continuity of the lever*, the power is at one end, and the fulcrum is at the other end of the lever. The body is certainly the weight *to be moved*, and it rests on the continuity of the lever: The muscles of the tendo-Achillis act on one end of the lever—this is the power; the other end of the lever rests on some resisting surface—and this is the fulcrum. Here we have all the conditions of a lever of the second order. Hence, we conclude that the foot is a lever of the second order. But the weight *to be moved*—that is, the weight of the entire body—is only part of the entire force

acting on the continuity of the lever. The *entire force* is the *pressure* exerted by the weight of the body on the astragalus under the dynamic conditions; and that is, as the mechanical facts show, the weight of the body plus the contractile force of the active muscles, expressed in the same units as the weight of the body. So much for the foot-lever.

99. It is possible to verify this conclusion by assuming the foot to be: (1.) A lever of the first order. (2.) A lever of the second order:

In a given case, the distance from the *ball* of the foot to the center of the ankle-joint is five inches, the distance from the center of the ankle-joint to the insertion of the tendo-Achillis is two and one-half inches, and the weight of the body is 150 pounds. Now, it is evident that there will be a pressure of 150 pounds on the *ball* of the foot when the muscles of the tendo-Achillis lift the body:

(1.) The weight-arm of the lever X the weight = the power-arm of the lever X the power: That is—

$$2\tfrac{1}{2} \times P = 5 \times 150 : \quad . \qquad (1.)$$

Hence,

$$P = 300 : \quad . \quad . \quad . \qquad (2.)$$

Therefore,

$$W = 450 : \quad . \quad . \qquad (3.)$$

The pressure on the tibio-fibular arch is 450 pounds.

While $$F = 150 : \quad . \quad . \quad . \qquad (4.)$$

(2.) Again, the weight-arm of the lever X the weight = the power-arm of the lever X the power. That is :—

$$7\tfrac{1}{2} \times P = 5 \times W : \quad . \qquad (5.)$$

Also, $$P + 150 = W : \quad . \qquad (6.)$$

Equating (5) and (6).

$$7\tfrac{1}{2} \times P = 5 \times P + 750 : \qquad (7.)$$

Hence, $$P = 300 : \quad . \quad . \quad . \qquad (8.)$$

And $$W = 450 : \quad . \quad . \qquad (9.)$$

The result is the same as before. *Hence the foot is a lever of the second order.*

(3.) It appears, then, that the foot is a lever of the second order, that the ordinary lifting force of the muscles of the tendo-Achillis is 300 pounds, and that the habitual pressure on the astragalus, or on the tibio-fibular arch, is from 150 to 450 pounds. Yet the pressure on the astragalus, at times, must be much greater than 450 pounds. This is especially the case when external violence is added to muscular force.

100. Let the foot-lever be extended as far as possible; from the origin of the contracting muscles, taken collectively, let fall a perpendicular to the long axis of the foot prolonged forward: The distance from the foot of this perpendicular to the insertion of the contracting muscles will show a large displacing component, acting forward and upward. But it must be kept in mind that the annular ligament, under which the tendons of the muscles in question run, modifies this theoretical conclusion. It will appear that the myodynamic angle made by any one of these muscles will always be *acute*. *And hence, the displacing component would act backward and downward, and would be represented by a line drawn from the insertion of the contracting muscles in the long axis of the foot till it meets a perpendicular drawn from the annular ligament, where it passes over the tendons.*

101. (a.) Surgeons have found the foot dislocated backward more frequently than forward.

The dynamic relations of the muscles that span the ankle-joint and move the foot accord with the facts of observation. The backward displacing components preponderate over the forward displacing components.

(b.) The foot is dislocated outward more frequently than inward. The following dynamic relations will explain this fact: The long axis of the leg at the tibio-fibular arch meets the conjugate axis of the foot at a considerable angle, going down to the supporting surface on which the foot rests, near the inner side of the foot, the conjugate axis of the foot deviating outward from above downward. On account of this outward obliquity of the foot, when the foot forcibly meets a resisting surface, the force of reaction will be resolved so as to afford a considerable displacing component acting outward. The deltoid ligament is apt to be ruptured, or the internal malleolus may be broken off, and the fibula may be broken above the ankle-joint.

102. (A.) Fig. 22 represents the tibia, fibula, astragalus, and os calcis, as seen from behind—one-half natural size. The line a j b is in the

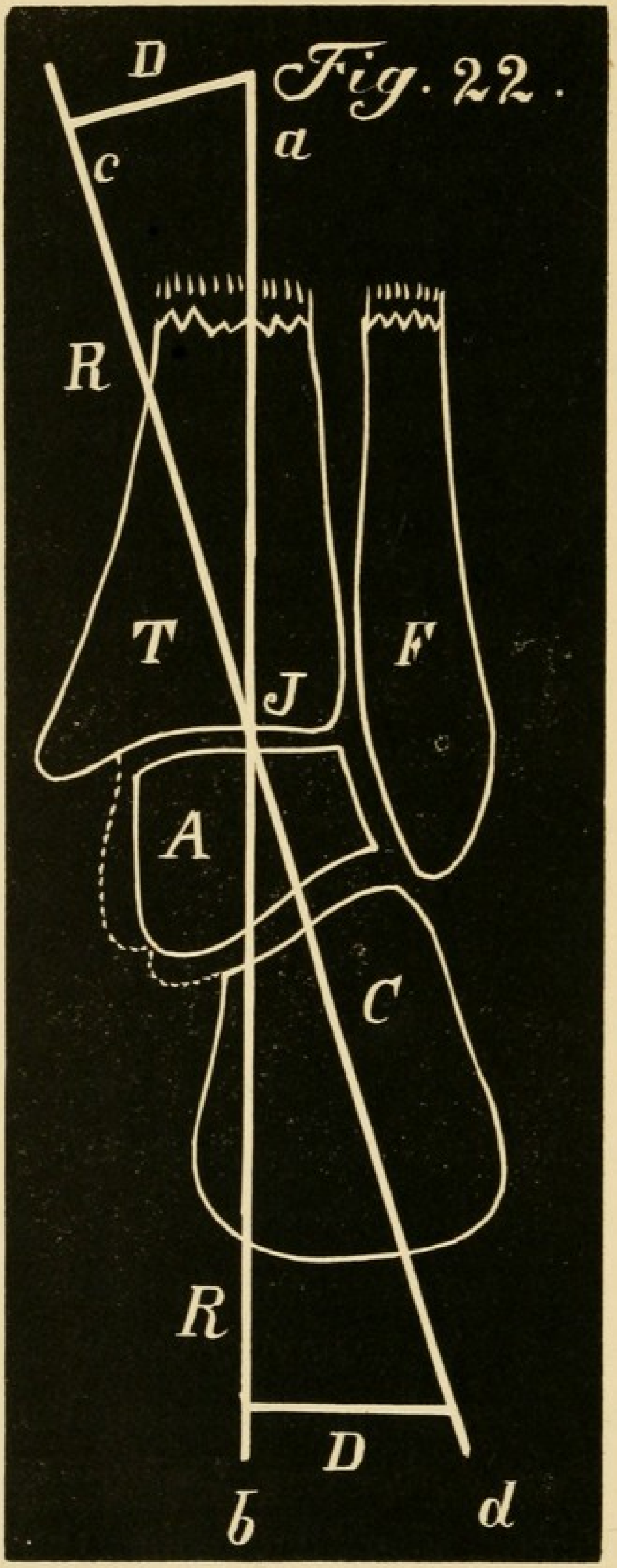


Fig. 22.
D
c
a
R
T
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b
d

long axis of the tibia, and the line d j c is in the conjugate diameter of the tarsus: These lines meet at the angle b j d The line b j represents the retentive pressure of the tibio-fibular arch on the astragalus, and the line b d represents the inward displacing force due to the obliquity of the tarsus: because the right angled triangles d j b and a j c are similar—D : R : : D, : R. I have treated a dislocation of the foot, complicated with Potts' fracture, in which the sole cause was the displacing component marked D in the Fig., a heavy weight having fallen on the top of the knee, when the foot rested on the ground and the leg was perpendicular to the foot: The force applied in this case must have been very great.

102. (B.) Fig. 23 represents an inside view of the bones of the foot with the lower end of the tibia: d A B is the plantar arch, and P–F is the plantar fascia. The astragalus A is the key-bone of the arch, having the weight nearer the posterior than the anterior pillar. When the heel is raised the weight of the body rests on the anterior pillar, and when the toes are

raised the weight of the body rests on the posterior pillar. The plantar fascia is very important in the construction and mechanism of the foot; so much so, when it is too long or too short, the function of the foot is more or less disturbed.—The sub-astragoloid joint has already been noticed. The medio-tarsal joint is where the os calcis and astragalus meet the cuboid and scaphoid bones, and is a ginglymus, having considerable flexion and extension. The medio-pedal joint is where the os calcis, the cuboid bone, and the fourth metatarsal bone meet the astragalus, the scaphoid, and external cruciform bones, and the third metatarsal bone, and runs longitudinally through the foot. The joint between the head of the astragalus and the scaphoid bone resembles a ball-and-socket joint, and facilitates inversion of the foot, as the os calcis glides inward under the astragalus, the latter bone only moving backward and forward as the foot is flexed and extended.—The foot is admirable for its strength and adaptation, but its usefulness is often diminished by neglect and ignorance.

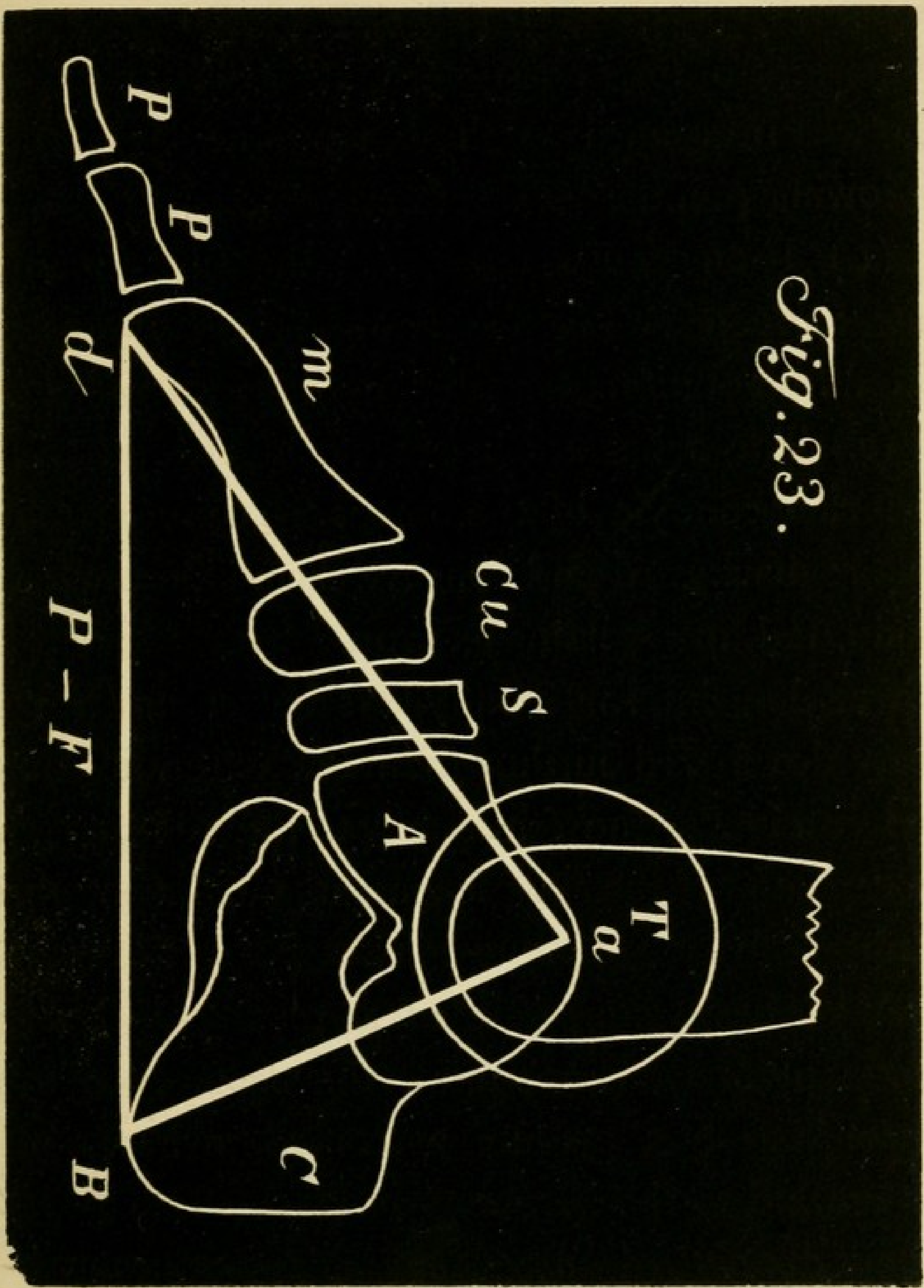


Fig. 23.

THE LEG AND THE KNEE-JOINT.

103. In regard to the knee-joint, note the following points :

(1.) The articular surface of the tibia for the internal condyle of the femur is concave and fitted for rotation.

(2.) The articular surface of the tibia for the external condyle of the femur is convex from before backward and concave from side to side, and fitted for a gliding motion.

(3.) The internal condyle is larger and projects downward further than the external condyle. Hence, the femur meets the tibia so as to make an obtuse angle on the outside of the limb.

(4.) The oblique fasciculus of the posterior ligament of the knee-joint runs from the posterior part of the external condyle inward and downward to the inner aspect of the tibia—*and limits the out-rotation of the leg.*

(5.) The anterior crucial ligament runs from the inner and front side of the spine of the tibia upward, backward, and outward to the inner and back part of the external femoral condyle—*and limits the in-rotation of the leg, and prevents displacement of the tibia backward.*

(6.) The posterior crucial ligament runs from the depression behind the spine of the tibia upward, forward, and inward to the outer and fore part of the internal femoral condyle—*and limits out-rotation of the leg, and prevents displacement of the tibia forward.*

(7.) The leg has *flexion*, *extension*, and *rotation*:—The flexion and extension of the leg takes place through an arc somewhat less than two right angles. The leg can be rotated through an arc of about fifteen degrees. The rotation of the leg takes place around the center of the tibial socket for the internal condyle of the femur—the external socket of the tibia gliding backward and forward under the external condyle of the femur. This motion can be clearly shown when the leg meets the thigh at a right angle.

104. The muscles that span the knee-joint

may be grouped, according to their function, as follows :—

(1.) The *extensors* of the leg are the muscles of the quadriceps extensor.

(2.) The *flexors* of the leg are the semi-tendinosus, the semi-membranosus, the biceps cruris, the popliteus, the gracilis, the sartorius, and the gastrocnemius.

(3.) The *out-rotators* of the leg are the biceps cruris and the sartorius.

(4.) The *in-rotators* of the leg are the semi-tendinosus, the semi-membranosus, the popliteus, the gracilis, and the sartorius.

105. (1.) The rectus femoris, the sartorius, the semi-tendinosus, the semi-membranosus, the gracilis, and part of the biceps cruris span both the knee-joint and the hip-joint.

(2.) The vastus internus, the vastus externus, the popliteus, and part of the biceps cruris span the knee-joint.

(3.) The gastrocnemius spans both the knee-joint and the ankle-joint.

106. The muscles that span the knee-joint may make the femur the fixed bone and the

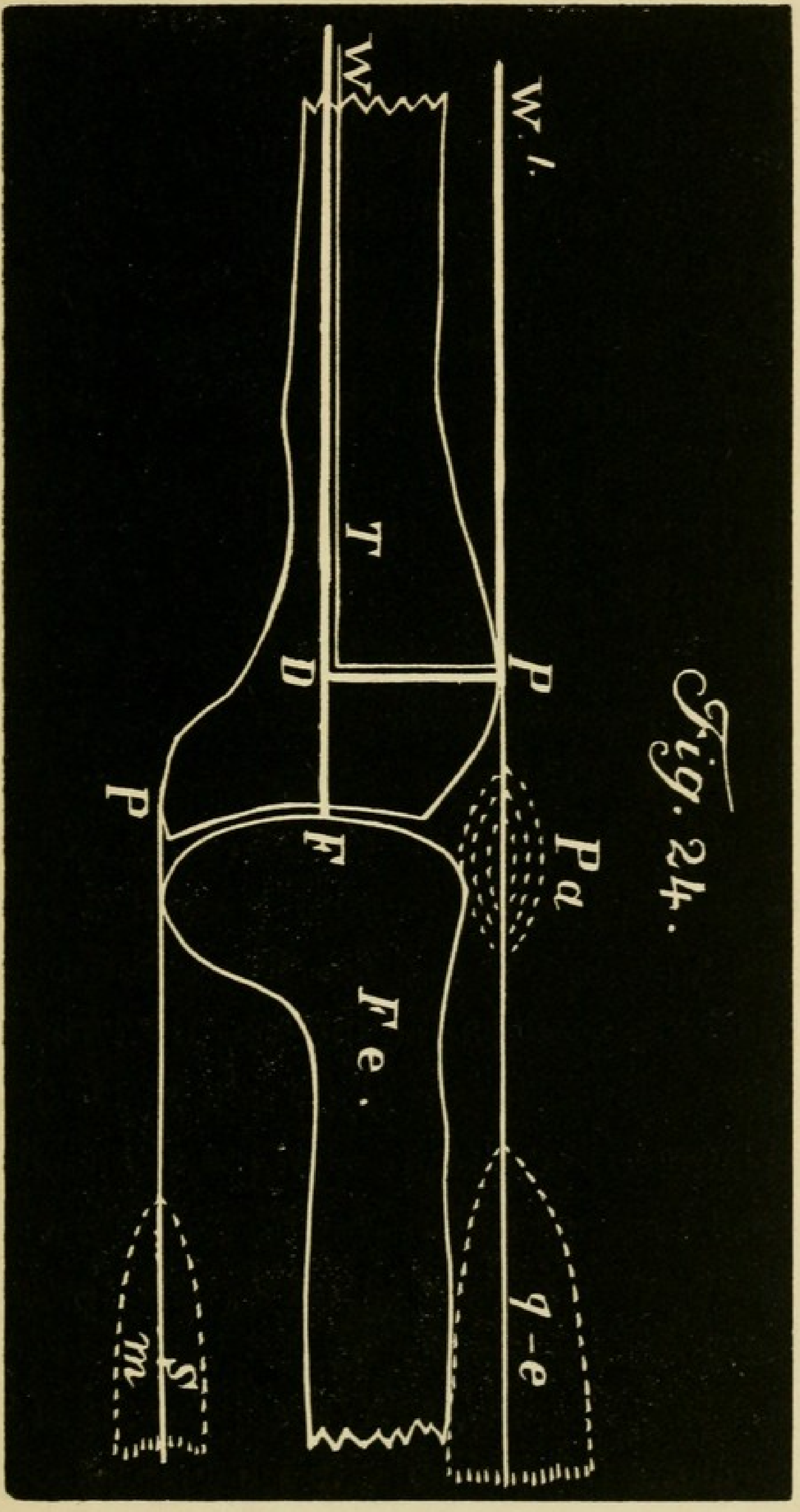


Fig. 24.

tibia the movable bone—or the tibia the fixed bone and the femur the movable bone. The muscles that span both the knee-joint and the hip-joint may make the femur the fixed bone and the tibia and the pelvis the movable bones.

107. See Fig. 24: Pa is the patella; q–e is the quadriceps extensor; Fe is the femur; and T is the tibia: Draw the line W'P–D F having a right angle at P and D: P is at the insertion of the tendo-patellæ, and F is where the tibia and femur come in contact. The distance P D is about two inches, and the length of the tibia is about fourteen inches: and W D P is a bent lever of the first order, whose fulcrum is D F. Let the lower end of the femur rest on a resisting surface, and let a weight of fifty pounds be placed on the lower end of the tibia —always acting in the direction P D of the power-arm of the lever. By the principles of the lever:

$$2 \times P = 14 \times 50 \quad . \qquad (1.)$$

Hence, $$P = 350 \quad . \quad . \quad . \qquad (2.)$$

But, $$F = P + W = 400 \quad . \qquad (3.)$$

Therefore, the pull of the quadriceps equals

350 pounds, and the pressure on the joint-surfaces equals 400 pounds. It may be remarked, that the tendency of the weight is put on the joint surfaces by means of the articular ligaments, and is thus added to the retentive action of the quadriceps :—The *static* work of the bone is greater than the *kinetic* work of the muscle.

108. See Fig. 25: The description is the same as before—except that the tibia and the femur meet at a right angle. The condyles of the femur meet the base of the tibia further back than in the previous instance. The distance P D is somewhat more than two inches—but let us say two inches. The distance D C is about four inches. The component triangle is P D C. The rectangular components are to each other as 2 : 4, and, since the weight is fifty pounds, the component D C equals 350 pounds, and the component P D equals 175 pounds. These two components will be resolved from the force of the quadriceps—which will equal 391 pounds. But D C is a retentive as well as a moving component; while P D is a displacing component,

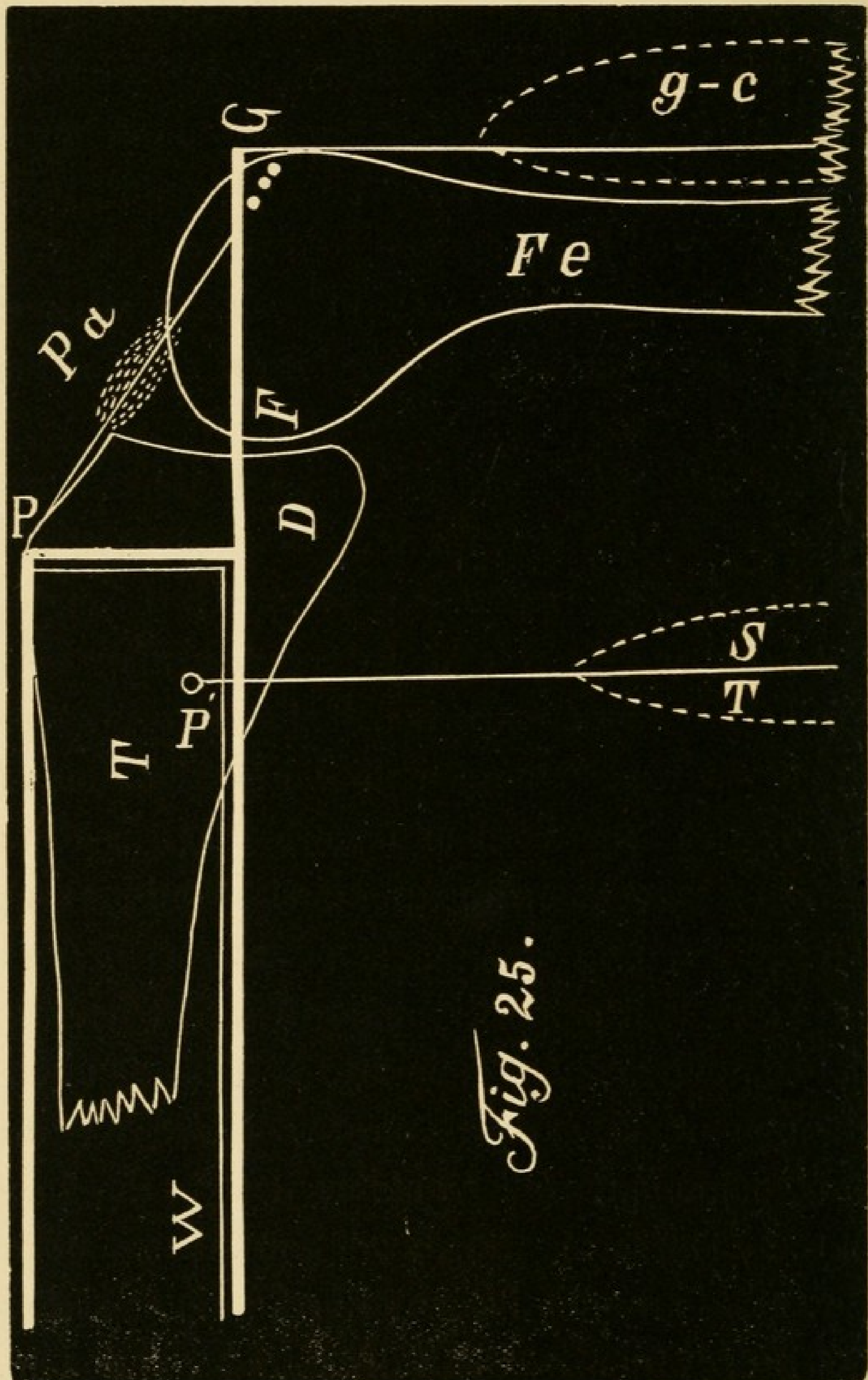


Fig. 25.

and is resisted by the anterior crucial ligament, and thus has its force brought on the joint-surfaces, so that the two rectangular components hold the fixed and movable bones together with a force equal 391 pounds.—Add to this the weight of 50 pounds, and the mutual pressure of the joint-surfaces of the tibia and femur equals 441 pounds.

109. See Fig. 26: The description is the same as in the first instance—except that the femur and the tibia meet at an acute angle. The bent lever is P d W, having a fulcrum F d. The myodynamic angle is C P D—the conjugate axis of the base of the tibia prolonged being one side of the component triangle. In this case the rectangular components are equal. The moving component D C equals 350 pounds as before, when the weight equals 50 pounds, and the displacing component P D equals 350 pounds. The force of the quadriceps, from which the two equal rectangular components are resolved, is therefore equal 494 pounds—and the pressure of the condyles of the femur on the base of the tibia would be 544 pounds.

110. If now the weight of the body be put on the tibia as a lever, the tibia will have the same dynamic relation to the femur as the foot has to the bones of the leg, and the tibia will be a lever of the second order.

(1.) In case the body is erect, and on the supposition that there is no action of the muscles that span the knee-joint, the weight of the body minus the weight of the legs will rest on the bases of the tibiæ; and the muscular force required to maintain the body erect at the knees must be added to this weight.

(2.) Let the body weigh 150 pounds, and let it rest on the tibial levers meeting the femora at right angles: The pressure on the joint-surfaces would be over 1200 pounds: on two condyles the pressure would be 600 pounds: and on one condyle the pressure would be 300 pounds.—But, if the weight of the body rested on one leg, the pressure on two condyles would be 1200 pounds; and the pressure on one condyle would be 600 pounds.

(3.) It appears that, as the myodynamic angle C P D decreases or becomes less than a right

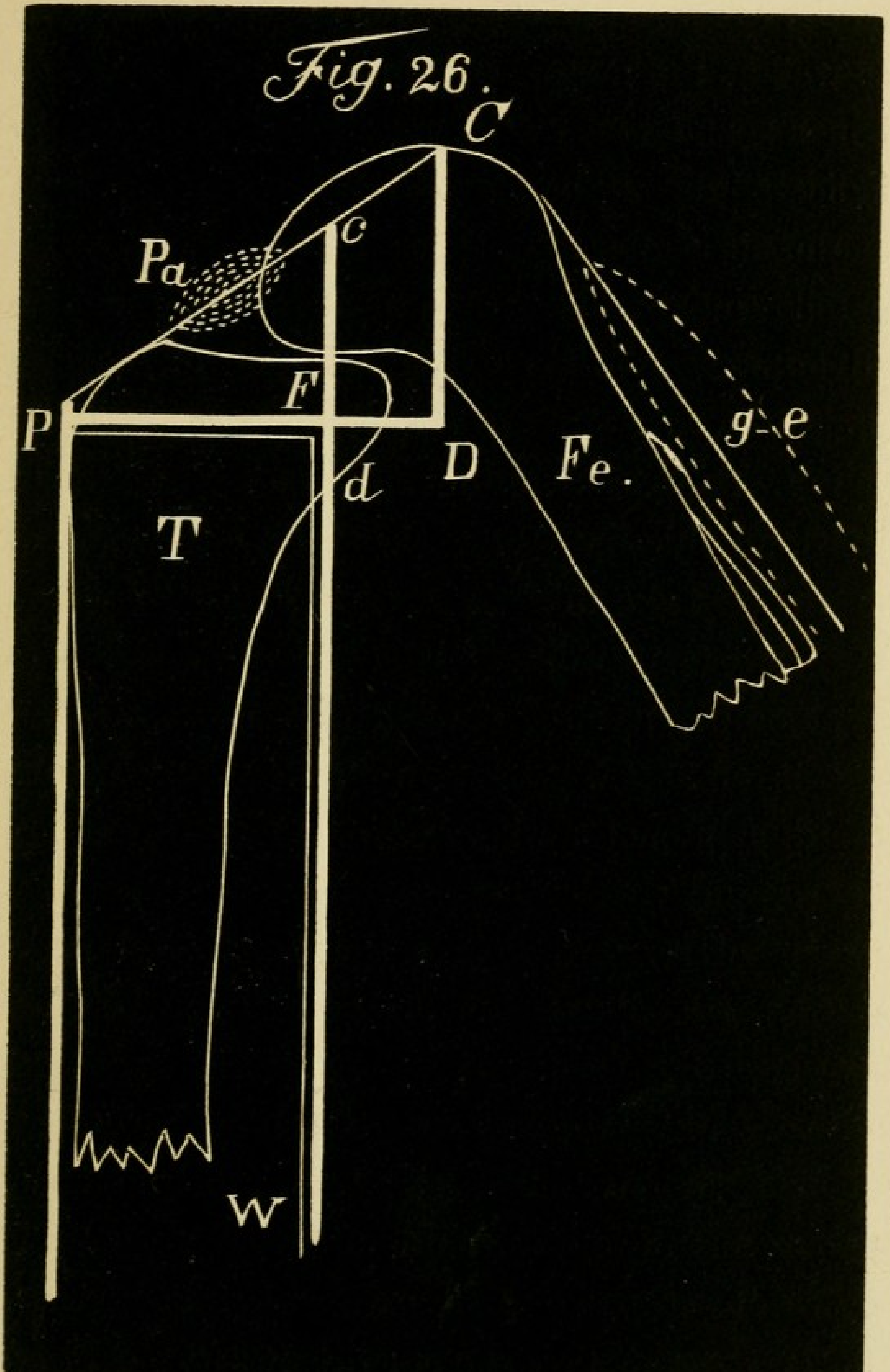


Fig. 26.
C
c
Pa
F
P
D
d
T
Fe.
g-e
W

angle, the force of the quadriceps must increase as well as the mutual pressure of the ends of the bones: and these facts take place in the order indicated during flexion of the leg. The patella augments the myodynamic angle: Hence the patella makes the quadriceps act to greater advantage, and relatively diminishes the mutual pressure of the ends of the bones.

111. These conclusions may be demonstrated substantially by the following experimental means: Take the bones of the lower limb, as they are articulated in a *skeleton*, and fasten a dynamometer to the upper end of the patella by means of a string: when the leg is extended, the dynamometer will have its index at a certain figure, and as the leg is constantly flexed by means of its own weight, the index of the dynamometer will as constantly point to a greater figure.

112. When the leg is completely extended, the semi-membranosus has a larger moving component than the semi-tendinosus, because it acts on a longer power-arm: See P' s–m, Fig. 24. But when the tibia meets the femur at a right

angle, the semi-tendinosus has a greater moving component than the semi-membranosus, because it acts on a longer power-arm: See Fig. 25. Hence, during the first part of flexion of the leg, the semi-membranosus is the more powerful agent; and during the second part of flexion of the leg, the semi-tendinosus is the more powerful agent.—In these instances the tibia becomes a lever of the third order. When the leg is extended, the moving components are *retentive*: but when the leg is semiflexed, the moving components are *displacing*.

113. a. In a given case the following measurements were made:—

(1.) From the center of rotation of the leg about the internal condyle (which is the fulcrum) outward to a point in a line drawn directly upward from the insertion of the biceps cruris, the distance was about two and one-half inches: This would constitute the power-arm of a lever, whose power is the biceps cruris.

(2.) From the same center of rotation inward to a point in a line drawn directly upward from the inner part of the semi-membranosus the distance was about one-half inch.

(3.) Hence, other things being equal, the outrotating power of the biceps cruris is five times as great as the in-rotating power of the semi-membranosus.

(4.) And, as the insertion of the semi-tendinosus is relatively nearer the center of rotation of the tibia, the semi-membranosus has a greater in-rotating power than the semi-tendinosus.

b. In the same case the following measurements were also made:—

(1.) The distance from the knee-joint to the insertion of the biceps cruris was about one-half inch.

(2.) The distance from the knee-joint to the insertion of the semi-tendinosus was about two and one-half inches.

(3.) Hence, other things being equal, the semi-tendinosus has five times the flexing power of the biceps cruris.

114. In fact, the special rotating antagonist to the biceps cruris is the popliteus:—The

popliteus pulls on the external condyle and in-rotates the leg.

115. In those cases of triple displacement of the leg, on account of disease: (1.) The out-rotation is due to the biceps cruris; (2.) The flexion is due to the semi-membranosus and the semi-tendinosus; (3.) The sub-luxation is due to the semi-membranosus, the biceps cruris, and the semi-tendinosus.

116. Some general conclusions may now be made in regard to the stability of the knee-joint, when the leg is in different positions:—

(1.) The condition of maximum stability of the knee-joint is when the leg is completely extended, for then the retentive components of all the muscles that span the knee-joint have a maximum magnitude. This condition of stability of the knee-joint gradually diminishes until the tibia nearly meets the femur at right angles.

(2.) The condition of minimum stability of the knee-joint is in the vicinity of semi-flexion of the leg. The displacing components of the muscles that span the knee-joint are very great in the vicinity of complete flexion—except those of the gastrocnemius and the popliteus :—And when the leg is meeting the thigh at an acute angle, the popliteus and the gastrocnemius will antagonize the ham-string muscles and thus contribute to the stability of the knee-joint: Besides, the tibia, if displaced backward, would soon come against the femur, and so a complete dislocation would be prevented.

THE FEMUR AND THE HIP-JOINT.

117. In regard to the hip-joint, the following points are to be noted: (1.) The hip-joint is a ball-and socket joint; (2.) The socket is deep; (3.) The head of the femur is two-thirds of a spheroid; (4.) The average length of the femoral head is about one and two-tenths inches; (5.) The average length of the femoral neck is about one and four-tenths inches; (6.) The average lateral diameter of the trochanters at the junction of the femoral neck is about one and five-tenths inches; (7.) The average distance from

the apex of the femoral head in the long axis of the femoral neck to the outer surface of the great trochanter is about four inches; (8.) The neck of the femur generally meets the shaft at an obtuse angle from above downward; the neck may, however, be depressed till it meets the shaft at a right angle—or even an acute angle—especially in old age; (9.) The length of the adult femur is about seventeen inches.

118. The two following facts are worthy of record—namely,

(1.) One of the lower limbs is generally about one-fourth of an inch longer than the other,—constituting normal *a-symmetry* of the lower limbs.

(2.) When the upper point of measurement is the superior anterior spine of the ilium,—*abduction* shortens the measurement of the lower limb,—*adduction* lengthens the measurement of the lower limb.

(3.) Hence, other things being equal, that lower limb will measure longer than its fellow, which is on the side of the pelvis that is tilted upward.

119. The motions of the femur are—*adduction, flexion, abduction, extension, in-rotation, out-rotation*, and *circumduction* :—

(i.) The *adductors* of the femur are—The proas magnus, the iliacus, the pectineus, the gracilis, the adductor brevis, the adductor longus, the adductor magnus, the quadratus femoris, the obturator extensus, the semi-membranosus, the semi-tendinosus, the biceps cruris, and the inferior part of the gluteus maximus.

(ii.) The *flexors* of the femur are—The anterior part of the gluteus minimus, the psoas magnus, the iliacus, the pectineus, the gracilis, the adductor brevis, the adductor longus, the sartorius, the tensor vaginæ femoris, the rectus femoris, and the obturator externus.

(iii.) The *abductors* of the femur are—The gluteus minimus, the gluteus medius, the gluteus maximus, the tensor vaginæ femoris, the sartorius, the pyriformis, and the rectus femoris.

(iv.) The *extensors* of the femur are—The gluteus maximus, the biceps cruris, the semi-membranosus, the semi-tendinosus, and the adductor magnus.

(v.) The *in-rotators* of the femur are—(1.) The gluteus minimus; (2.) The gluteus medius; (3) the tensor vaginæ femoris; (4.) The vastus externus; (5.) The vastus internus; (6.) The crureus; (7.) The rectus femoris; (8.) The gracilis; (9.) The semi-membranosus; (10.) The semi-tendinosus; (11.) The iliacus; (12.) The psoas magnus; (13.) The pectineus; (14.) The adductors.

(vi.) The *out-rotators* of the femur are—(1.) The gluteus minimus; (2.) The gluteus medius; (3.) The gluteus maximus; (4.) The pyriformis; (5.) The obturator internus and the gemelli; (6.) The obturator externus; (7.) The quadratus femoris; (8.) The biceps cruris; (9.) The sartorius; (10.) The abductors; (11.) The pectineus; (12.) The iliacus; (13.) The psoas magnus.

(vii.) The *circumductors* of the femur are all the muscles that span the hip-joint.

120. It ought to be especially noted that the origin of the obturator externus is considerably below its insertion, so that this muscle tends—(1.) to prevent the shaft of the femur from going

upward when the femoral neck is broken; (2.) to prevent upward dislocation of the femur:— Also the obturator internus will have similar, though less marked, functions.

121. The biceps cruris, the semi-membranosus, the semi-tendinosus, the gracilis, the sartorius, and the rectus femoris span the hip-joint and the knee-joint. The gluteus maximus, the gluteus minimus, the gluteus medius, the tensor vaginæ femoris, the psoas magnus, the iliacus, the pectineus, the adductor magnus, the adductor longus, the adductor brevis, the obturator externus, the triceps rotator, and the pyriformus span only the hip-joint.—*The sartorius flexes, out-rotates, and abducts the thigh: and flexes the leg.*

122. The shaft of the femur does not rotate directly on its own axis; it rotates indirectly, as it moves forward and backward under the action of rotator muscles. When the femoral neck is broken, the shaft of the femur can rotate directly on its own axis.

123. When the femur is flexed and extended, the femoral neck will rotate nearly on its own

axis. The head and neck of the femur may be looked upon as a lever. The entire femur is a *bent lever*. The *acetabulum* is the fulcrum. When the femur is the movable bone, the components of the muscles that span the hip-joint may be determined on the principle of a lever of the third order. When the body rests on the head of the femur, and is moved by the muscles that span the hip-joint, these muscles act on the pelvis as the power of a lever of the first order. The femur may be rotated about forty-five degrees. The femur may be adducted from a line parallel with the long axis of the body about thirty degrees. The femur may be abducted from a line parallel with the long axis of the body about thirty degrees. The lateral motion of the lower limb will therefore be not far from sixty degrees. The femur may be flexed till the thigh comes in contact with the surface of the abdomen. The femur can be extended so that the condyles will be somewhat back of the long axis of the body prolonged.

124. It requires a few words in regard to the

rotating function of *the* flexors of the thigh—that is, the psoas magnus and the iliacus :—

When the thigh is parallel with the long axis of the body, and when the femoral neck is of average length, and when the trochanter minor is of moderate length, the insertion of the flexors of the thigh, during in-rotation of the femur, will move forward and inward faster than backward and outward, inasmuch as the femoral neck makes a longer radius than the semi-diameter of the shaft of the femur plus the height of the trochanter minor : The same may be said when the thigh is abducted. Under the conditions named, the psoas magnus and the iliacus are in-rotators of the femur. But when the thigh is adducted, and when the trochanter minor is largely developed, so as to make a lever long enough, the psoas magnus and the iliacus are out-rotators of the femur. *These muscles are flexors of the thigh.*

125. The *triceps rotator* of the femur is made up of the gemelli and the obturator internus. In general, when the long axis of the femur and

the long axis of the body are parallel, the downward obliquity of the pull of the triceps rotator is about the same as the upward obliquity of the femoral neck: Hence, the downward displacing component of the triceps rotator will be about counteracted by the upward displacing tendency on account of the obliquity of the femoral neck.

126. When the femur is completely in-rotated, the rotating component of the triceps rotator will be small; but will increase in size during out-rotation of the femur, when the myodynamic angle will be at the maximum. On account of the conformation of the hip-joint, the triceps rotator will always have a large retentive and a small displacing component.

127. The anterior part of the gluteus minimus has four components: (1.) A moving component; (2.) A retentive component; (3.) A rotating component; and (4.) A displacing component:—In this case, the retentive component is always large—on account of the conformation of the hip-joint.

128. Let us now examine the dynamic rela-

tions of the triceps rotator and the inrotating part of the gluteus minimus by measuring a given case :—

(1.) From the insertion of the gluteus minimus to the insertion of the triceps rotator, the distance was one inch.

(2.) From the insertion of the triceps rotator to the head of the femur, the distance was two and one-half inches.

(3.) And from the insertion of the gluteus minimus to the head of the femur the distance was three and one-half inches.

129. Let the rotating component of the triceps rotator be the power, the rotating component of the gluteus minimus be the weight, and the pressure on the head of the femur be the fulcrum :—The lever will be of the third order : Let the fulcrum be fifty pounds.

Then : $P = W + 50$ . . . (1.)

And : $W = \frac{5}{2} \times F = 125$ . . (2.)

Hence $P = 175$ . . . . (3.)

130. These figures show :—

(1.) The rotating component of the gluteus minimus has a more advantageous position and dynamic relation than the rotating component of the triceps rotator.

(2.) The rotating component of the triceps rotator equals the rotating component of the gluteus minimus plus the pressure on the femoral head in the direction of the motion of the rotating component of the triceps rotator.

(3.) But when the articular ligaments and the conformation of the joint cause the combination of the muscular components under consideration, the pressure on the head of the femur is equal the sum of the contractile energy of the two muscles.

131. (a.) To a certain extent, a long femoral neck has favorable dynamic relations :—

(1.) This is true in regard to the lateral strain caused by the moving components of the contracting muscles.

(2.) This is not true in regard to the pressure caused by the entire force of the contracting muscles.

(b.) The weakest part of the femoral neck is at its junction with the head :—

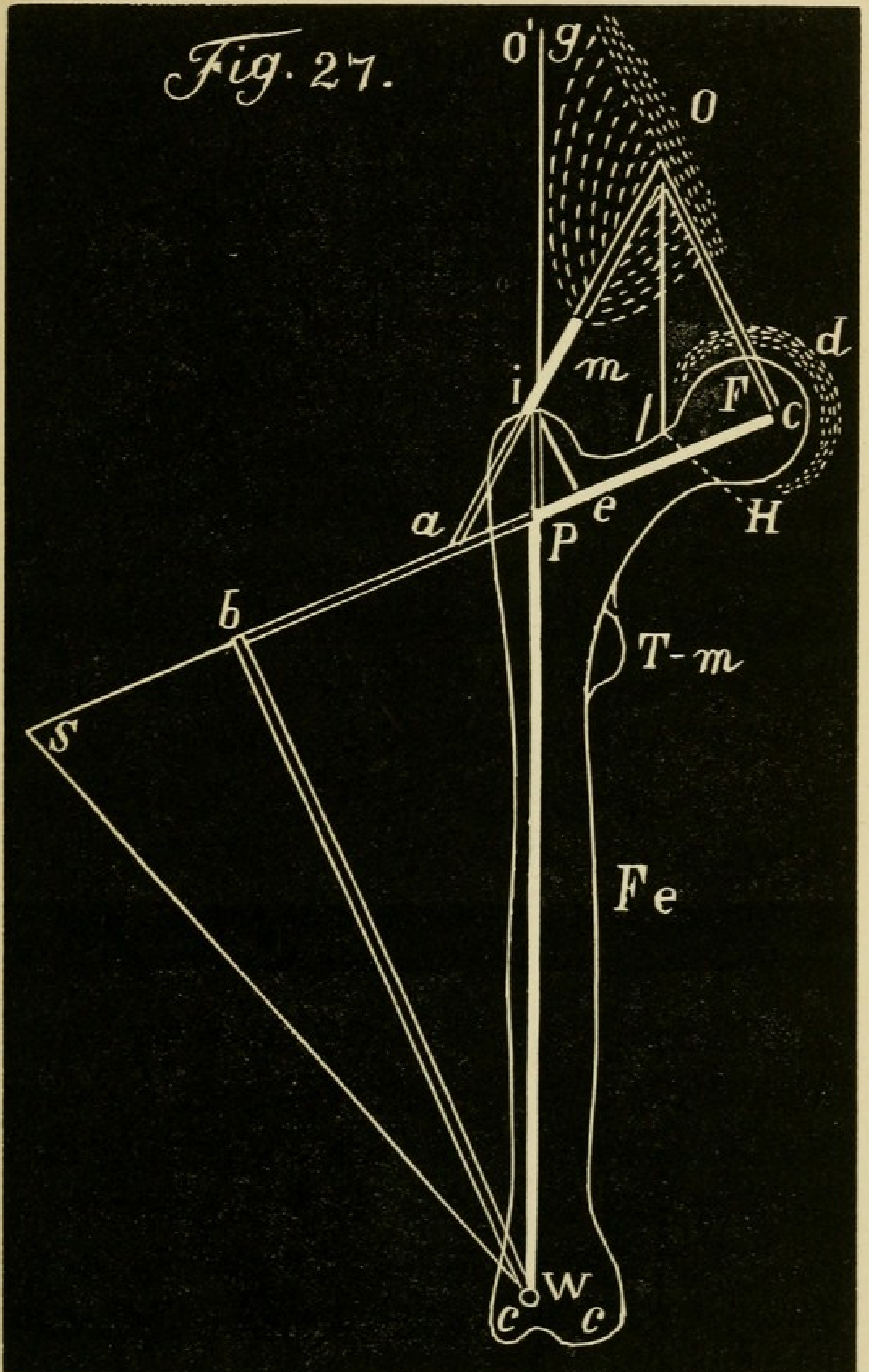
(1.) This fact agrees with the need of having the cervical lever of greater strength the nearer we get to the insertion of the muscles.

(2.) In this place, it may be remarked that the femoral neck of the female is oftener broken than the femoral neck of the male, and that the femoral neck of the female is not unfrequently broken near the femoral head.

132. The gluteus medius is favorably located to apply great force to the femoral neck :—

See Fig. 27 : Fe is the femur, which is a *bent lever ;* g m is the gluteus medius, whose origin and insertion are o and i ; H is the femoral head ; c c are the femoral condyles ; F is the fulcrum ; P is the power ; and W is the weight. The femoral neck is a lever of the third order under the action of the gluteus medius :—Prolong the long axis of the femoral neck—inward, if necessary, till it meets at d a perpendicular drawn from the origin of the contracting muscle —outward, till it meets a perpendicular drawn from the lower end of the femur ; and prolong the long axis of the contracting muscle till it meets at a, the prolonged axis of the femoral

Fig. 27.



neck :—The rectangular components of the contracting muscle will be a d and d o ; and a d will be a retentive component and d o will be a moving component. In a given case, as approximately measured, the retentive component a d was 9, and the moving component d o was 3 : Hence, the force of gluteus medius was 9.5 nearly.

133. Now let the weight of the lower limb pull directly downward in the direction i P W : draw i e perpendicular to P F : Then will i e and e p be the rectangular components of the force of the weight of the lower limb. But i e is a resisting component and e p is a displacing component ; and e p will tend to counteract the retentive component a d ; and i e will counteract the moving component d o : The force of i e will equal the force of d o ; but the force of e p will be less than the force of a d. Draw o H parallel to i p : Then will d H represent the force of e p :—This will reduce i e and o d, and p e and H d to the same denomination :—And then will a H represent the retentive component of the power and the weight acting on the

lever P F. And by careful comparative measurements and estimates of the lines and the forces they represent, it appears that the head of the femur is pressed into the acetabulum with a force at least twice as great as the weight of the lower limb, when that limb is freely suspended as above indicated under the action of the gluteus medius.

134. When the long axis of the gluteus medius is more vertical and runs in the direction o' i, then the moving component will be greater and the retentive component will be smaller. Also when the femoral neck meets the femoral shaft more nearly at a right angle, then, too, the moving component will be greater and the retentive component will be smaller. And, furthermore, when the pelvis is tilted outward so as to bring the origins of the glutei medius and minimus more directly over the trochanter major, any force acting downward in the long axis of the femur will antagonize the retentive components of these two muscles, and reduce the pressure between the femoral head and the acetabulum to a minimum. These dynamic

facts have important bearings in the treatment of hip-joint disease and fracture of the femoral neck.

135. If the weight acts on the lower end of the femur in the direction of b w—w b d being a right angle—then the entire weight will resist the moving component of the muscle: And the greater the weight, the greater the moving component of the muscle; but the greater the moving component of the muscle, the greater the retentive component of the muscle: Hence the greater the weight, the greater the pressure of the head of the femur on the surface of the acetabulum.

138. If the weight act on the lower end of the femur in any direction s w beyond the perpendicular w b, the rectangular components will be s b and b w: s b will be a retentive component, augmenting the action of the retentive component of the muscle, while b w will be a resisting component, antagonizing the moving component of the muscle: And the nearer the weight acts at right angles to the femoral shaft, the greater will be the retentive components.

139. The psoas magnus acts on the femur, making it a lever of the third order. In a given case, the following approximate measurements were made: (1.) The length of the femur was about seventeen inches, that is the weight-arm of the lever: (2.) The distance from the trochanter minor in the line of the rectangular component of the psoas magnus to the head of the femur was about four inches, that is the power-arm of the lever. See Fig. 20: T–m is the trochanter minor, and E is the ilio-pectineal eminence, while P is the distance between these two points: The rectangular components are 3 and 4, while the resultant is 5. The resultant expresses the entire force of the psoas magnus. Let the weight applied to the femoral condyles be twelve pounds: The formula for the femoral lever will be—

$$12 \times 17 = 51 \times 4 :—$$

Then the moving component of the psoas magnus would be fifty-one pounds: Divide this by three and multiply the quotient by four and it gives a retentive component of sixty-eight pounds: Multiply the same quotient (seventeen)· by five and it gives the entire force of the psoas magnus, which equals eighty-five pounds. And this means that the femoral head is pressed against the acetabular surface by the psoas magnus with a force equal eighty-five pounds :— Now, suppose the weight of the lower limb to be twelve pounds, and the weight of the body to be sixty pounds : and if the psoas magnus lifts the weight of the lower limb applied to the condyloid end of the femoral lever, it will press the hip-joint surfaces together with a force of eighty-five pounds : But if the weight of the body rests on one limb, it will press the hip-joint surfaces together with a force of only sixty pounds. The psoas magnus can do, under the circumstances, more work than the weight of the body.

140. Let the weight on the condyloid end of the femoral lever be twenty-four pounds :— Then the force of the proas magnus will be 170 pounds.—Let the entire force of the rest of the muscles that span the hip-joint be ten times as great as the force of the psoas magnus, then the

pressure of the surface of the femoral head on the acetabular surface will equal 1,700 pounds.

141. Some practical observations may be made in this connection :—

(1.) The myodynamic facts, as above explained, forbid us to treat the active conditions of hip-joint disease by permitting the patient to walk about—because walking about causes the muscles of the hip, even under surgical appliances, to contract—and we now know what great pressure these muscles can make on the surfaces of the hip joint.

(2.) If we put the patient on the back, and make extension of the lower limb on the affected side, we accomplish two important results: (a.) The side of the pelvis on the affected side is tilted downward, and that shortens the lower limb, when the measurement is made from the pelvis.—(b.) And the lower limb is pulled more in a line with the long axis of the glutei medius and minimus: *Thus diminishing pressure between the hip-joint surfaces by diminishing the size of retentive muscular components.*

142. In regard to the stability of the hip-joint two important statements may be made :—

(1.) The conformation of the hip-joint is such that, under all ordinary myodynamic relations, the muscles that span this joint have greater retentive than displacing components :—wherefore, the hip-joint is in a condition of myodynamic stability.

(2.) If the femur is moved in any direction, so as to bring the femoral neck against the brim of the acetabulum, the femur will become a lever of the first order, which will tend to lift the femoral head out of its socket when the powerful retentive components of the hip-joint muscles, will be turned into displacing components, so that external violence and muscular force will co-operate to dislocate the femur: Under the circumstances, the hip-joint is in a condition of dynamic instability.—And these facts agree with the practical observations of surgeons.

143. The femoral shaft has an arch which bends forward, and this throws the lesser troch-

anter somewhat backward. Let a normal femur be laid on a plane surface on its condyles, and its lesser trochanter and the femoral head will rise some distance above the plane surface: This brings the femoral head forward, or the internal condyle backward, just as the condyle or the head is looked upon as the fixed point. In another place I have shown how a fracture may derange this normal twist of the femur. Now, if the leg be completely extended, and a tape-line fixed over the femoral head and over the apex of the tibio-fibular arch, it will run directly over the long axis of the tibia, and also deviate from the long axis of the femur as it runs from the base of the tibia upward to the femoral head. And the meaning of this fact is this—that, as the weight of the body rests on the femoral head, it is, as a force, directly over the long axis of the tibia, and directly over the tibio-fibular arch, and also directly over the key-bone of the plantar arch. I have verified these facts by a number of observations and measurements.

144. I have also made some measurements

showing that the thigh is generally equal in length to the leg and vertical diameter of the foot: The height of the plantar arch and the length of the tibia make a lever of about the same length as the femur. Hence, when the foot-and-leg lever and the femoral lever are antagonistic, and have equal lever-arms, they are in a condition of dynamic equality, or perhaps it might be more correct to say that they are in equilibrium.

THE SKULL AND THE CRANIO-VERTEBRAL JOINT.

136. The condyles of the skull rest on the atlas, and the atlas rests on the axis; and the odontoid process of the axis is where the body of the atlas would be—if it had one. The skull has the following motions—namely,

(a.) (i.) Flexion; (ii.) extension; (iii.) right rotation; (iv.) left rotation; (v.) right adduction; (vi.) left adduction.

(1.) The *flexors* of the skull are: The rectus capitis anticus minor, the rectus capitis anticus major, the sterno-cleido-mastoid, and the accessory hyoid groups of muscles.

(2.) The *extensors* of the skull are: The rectus capitis posticus minor, the rectus capitis posticus major, the superior oblique, the trachelo-mastoid, the splenius capitis, the complexus, the biventer cervicis, and the trapezius.

(3.) The *right rotators* of the skull are: The left sterno-cleido-mastoid, the left trapezius, the right splenius capitis, the right trachelo-mastoid, the right rectus capitis posticus major, and the right rectus capitis anticus major.

(4.) The *left rotators* of the skull are: The right sterno-cleido-mastoid, the right trapezius, the left splenius capitis, the left trachelo-mastoid, the left rectus capitis posticus major, and the left rectus capitis anticus major.

(5.) The *right adductors* of the skull are: The right rectus capitis lateralis, the right superior oblique, the right trapezius, the right splenius capitis, the right trachelo-mastoid, and the right sterno cleido-mastoid.

(6.) The *left adductors* of the skull are: The left rectus capitis lateralis, the left superior oblique, the left trapezius, the left splenius capitis, the left trachelo-mastoid, and the left sterno-cleido-mastoid.

(b.) (i.) The flexion and extension of the skull take place mostly at the cranio-atloid joint. (ii.) The rotation of the skull takes place mostly at the atlo-axoid joint. (iii.) The adduction of the skull takes place mostly in the cervical spine below the axis and in the cranio-atloid joint.

(c.) The term *adduction* designates the fact that the head, as it is bent to the right or to the left, approaches the body on the side to which the movement is made. The term *ab-duction* would designate the fact that the head, as it is bent to the right or to the left, moves as a whole from the long axis of the body. Either term would be appropriate, though the former has been used.

137. The skull is a lever of the first order, in which: (1.) The *power* is derived from one or more muscles—assisted at times by the weight of some part of the head; and in which: (2.)

The *weight* is also derived from one or more muscles—assisted at times by the weight of some part of the head. For instance, when the head is flexed, the weight of the head will co-operate with the flexors in antagonizing the *power* of the extensors. (3.) In fact, any one group of muscles acting on the skull may be considered the power, while the antagonistic group may be considered the weight.

138. When the body and the head are in the upright position, all the motor muscles of the skull, above grouped, co-operate. The antagonistic groups of muscles are in equilibrium. *The moving components of the groups of muscles antagonizing are equal.*

(1.) The moving components of the right rotators equal the moving components of the left rotators. (2.) The moving components of the left adductors equal the moving components of the right adductors. (3.) The moving components of the flexors equal the moving components of the extensors.

Examples: (1.) The trachelo-mastoids will antagonize the sterno-cleido-mastoids. (2.) The right sterno-cleido-mastoid and the right trachelo-mastoid will antagonize the left sterno-cleido-mastoid and the left trachelo-mastoid. (3.) The rotating components of the right sterno-cleido-mastoid and the left trachelo-mastoid antagonize the rotating components of the left sterno-cleido-mastoid and the right trachelo-mastoid.

139. (1.) *The retentive components of the motors of the skull will co-operate, as well as the moving components. (2.) The displacing components of the antagonizing motors of the skull will also antagonize each other;* and, as the antagonizing groups have displacing components acting in different directions—that is, in opposite directions, these groups of displacing components will counteract each other, and the cranio-vertebral joint will be in a condition of permanent stability. (3.) And, in any case, the retentive components are greater than the displacing components of the head-motors.

THE MYOMETER.

136. It is now desirable to add some points of experimental evidence afforded by a machine that, for the sake of convenience, may be called a *myometer*. This machine is made as follows: (1.) A bar of wood five and one-half feet long, whose cross section is about one and one-half inch square, is morticed from side to side in two directions, for about five inches in the center, so as to leave a small quadrangular piece at each corner—the mortices, or slots, meeting at right angles. About an inch beyond the mortices on one end the bar is cut transversely by a saw, as far as the opposite side of the mortice, and then slit from the end down to the transverse saw cut. Then an opening is made down through to the mortices as large as the central opening of the two mortices. (2.) Another bar of wood about two feet long is made to fit into one of the mortices in the long bar; and an iron pin goes through the short bar transversely, and plays up and down in the other mortice. (3.)

In the long bar are fastened, on opposite sides: Two screw-eyes eighteen inches from the center of the mortices; two screw-eyes nine inches from the center of the mortices; two screw-eyes three inches from the center of the mortices. (4.) In the short bar are fastened, on opposite sides: Two screw-eyes eighteen inches from the pivotal pin; two screw-eyes nine inches from the pivotal pin; and two screw-eyes three inches from the pivotal pin on either side. (5.) A screw-eye is fastened into the thin part of the long-bar directly in a line with the long axis of the two transverse mortices. (6.) The long-bar will represent a fixed bone, and the short-bar will represent a movable bone: The short bar can be used as a lever of any order.

137. (1.) Select three spring-scales, which have equal resistances under equal tensions. To determine this point, hook the spring-scales together and make tension; if the scales have the same resistance, the indicators will always point to figures of equal value. The importance of this comparison is obvious.

(2.) The spring-scales are dynamometers :— One is used to show the pressure of the joint surfaces, one is used to show the force of the contracting muscle, and one is used to show the resistance to be overcome by the movable bone. That is, the dynamometers represent the power, the weight and the fulcrum. (3.) Also select two weights—one weighing one-half pound, the other two pounds. When the two bars, the screw-eyes, and the three spring-scales are properly put together, they constitute a *myometer*.

138. The first thing to do experimentally is to resolve the force of the dynamometer representing a muscle into its rectangular components. This may be done by the *myometer*. See Fig. 28. Let S b be the short bar, and L B be the long bar of the myometer. Let the dynamometer P represent a contracting muscle, and the dynamometer W represent the resisting weight. The points of insertion of the screw-eyes may be seen by an examination of the figure. Some experiments may now be made :

First. Let S c equal L c—that is, let the two

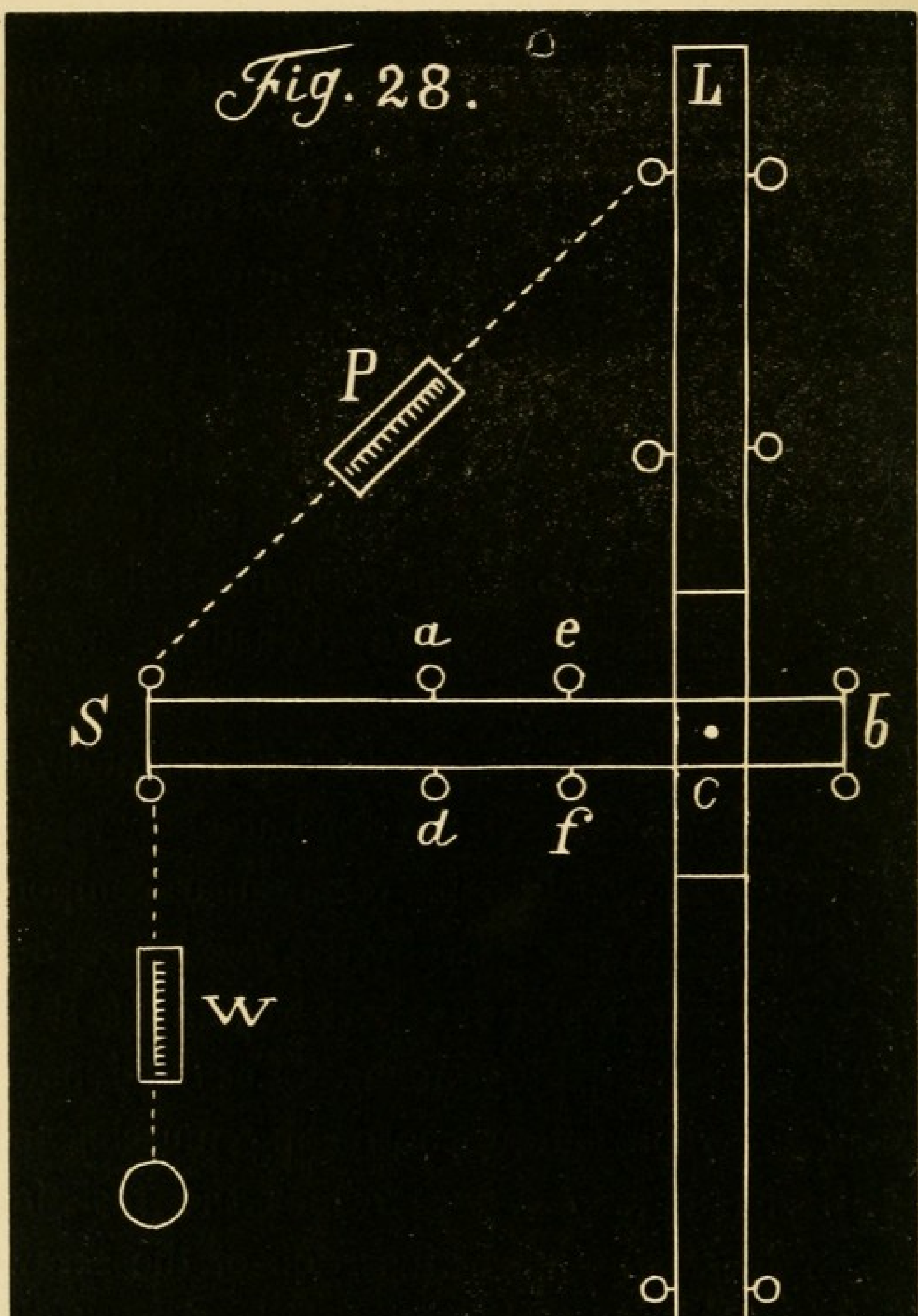


Fig. 28.
L
P
a
e
S
b
c
d
f
W
B

osseous sides of the myodynamic triangle be equal. And let the myodynamic angle equal forty-five degrees, when the weight puts the contracting muscle under strain. The dynamometer P is fastened to the screw-eyes at L and S, and the dynamometer W is fastened to the opposite screw-eye at S. Pull on the dynamometer W till the angle S C L is a right angle, and the indicator of the dynamometer P points to the figure 17, *then will the indicator of the dynamometer W point to the figures 12.* Each of the rectangular components will therefore be twelve pounds. Hence, P will have a moving component of twelve pounds, acting in the direction W S. According to theory, the sum of the squares of the two rectangular components equals the square of the resultant. Hence,

$$12^2 + 12^2 = 17^2,$$

which is very nearly correct, the result being

$$288 = 289.$$

And this is near enough for theory to agree with experiment.

Second. Let a c equal one half L C, and let the angle a c L equal a right angle, when the weight is applied to d. The dynamometer P is fastened to the screw-eyes at L and a, and the dynamometer W is fastened to the opposite screw-eye d. Pull on the dynamometer W till the angle a c L is a right angle, and the indicator of the dynamometer P points to the figure 14, *then will the indicator of the dynamometer W point to* $12\frac{1}{2}$ *nearly*. So that the other rectangular component will be $6\frac{1}{4}$ pounds nearly. And P will have a moving component of $12\frac{1}{2}$ pounds, acting in the direction d a. *Theoretically* $\overline{12\frac{1}{2}}^2 + \overline{6\frac{1}{4}}^2 = 14^2$. But $14^2 = 196$; and $\overline{12\frac{1}{2}}^2 + \overline{6\frac{1}{4}}^2 = 195\frac{5}{16}$. Theory and experiment very nearly agree in this instance.

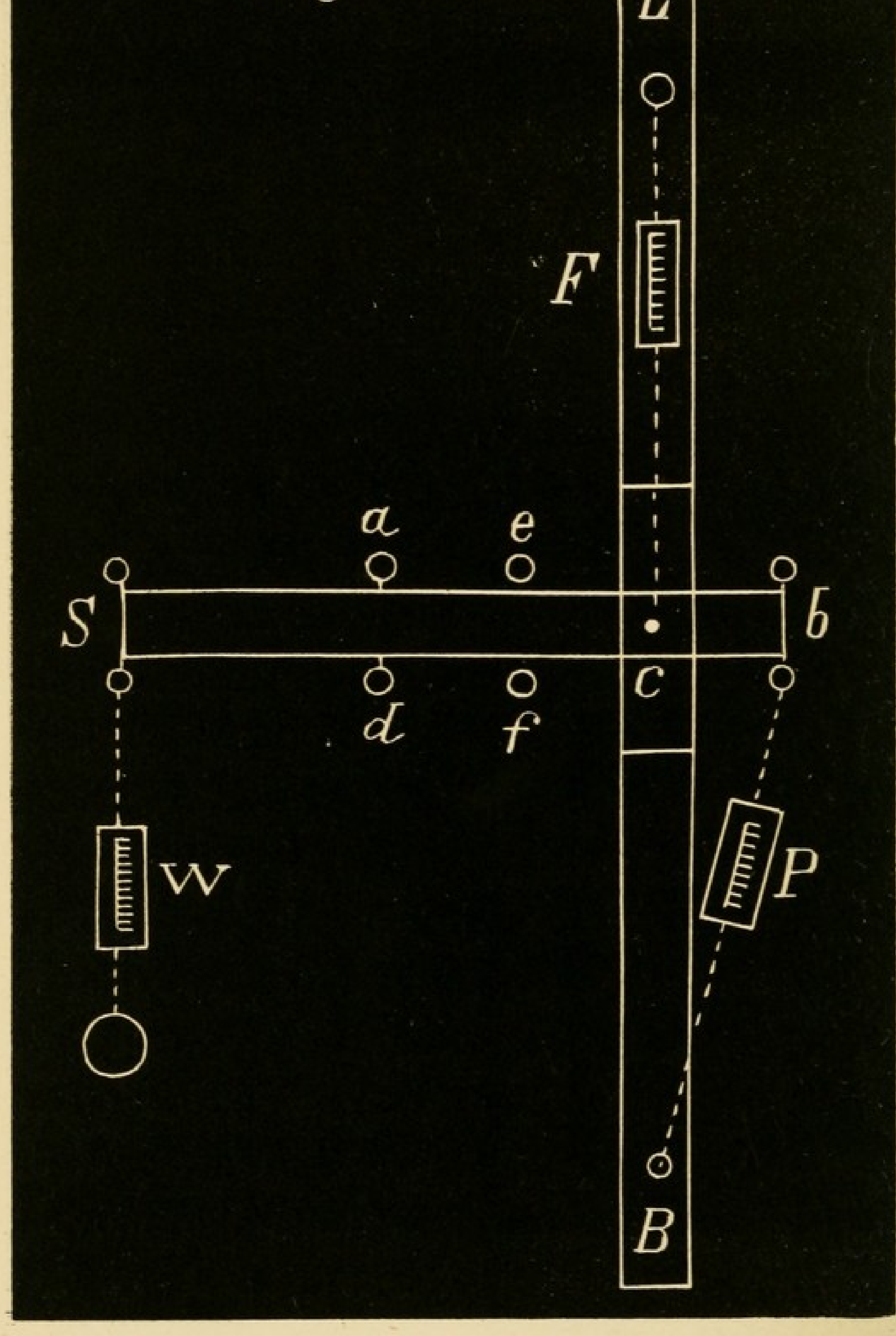
Third. Let e c equal one-sixth L c, and let the angle e c L equal a right angle when the weight is applied to f. The dynamometer P is fastened to the screw-eyes at L and e, and the dynamometer W is fastened to the opposite screw-eye f. Pull on the dynamometer W till the angle e c L is a right angle, and the indicator of the dynamometer P points to the figure

$18\frac{1}{4}$, *then will the indicator of the dynamometer W point to 18 nearly.* So that the other rectangular component will be 3 pounds. And P will have a moving component of 18 pounds, acting in the direction f e. *Theoretically* $18^2 + 3^2 = \overline{18\frac{1}{4}}^2$. But $\overline{18\frac{1}{4}}^2 = 333\frac{1}{16}$; and $18^2 + 3^2 = 333$. Experiment substantiates theory by agreeing with it very nearly.

139. (a.) *The second thing to do experimentally is to apply the principle of the lever to the resolution of the force of the dynamometer, representing the contracting muscle, into its rectangular components:* The principle is that the force in the continuity of the lever equals the sum of the forces acting at the ends of the lever.

(b.) Let S b (Fig. 29) be the short-bar of the myometer; let L B be the long-bar; let P be the dynamometer representing the muscle; let F be the dynamometer representing the pressure that one bone makes on the other; and let W be the weight. L B represents the fixed bone, and S b represents the movable bone: Then S b is a lever of the first order.

Fig. 29.



140. The power of the dynamometer P—or the force of the contracting muscle—is resolved into a moving and a displacing component. The moving component is a retentive component. *The displacing component is resisted by the articular ligaments, which put the stress of the displacing component on the joint-surfaces in addition to the stress of the moving component. Hence, the resultant of the moving and displacing components—that is, the force of the contracting muscles—will appear as stress on the joint-surfaces :*

(1.) For, if we could suppose that there is no myodynamic angle, plainly the force of the muscle and the force of the weight would be in the same direction, and their sum would constitute the pressure on the joint-surfaces.

(2.) Make the myodynamic angle *acute*, and it will be found, by the myometer, that the weight, plus the indicated figures on the dynamometer P will equal the indicated figures on the dynamometer F.

(3.) Make the myodynamic angle *right*, and it will be found, by the myometer, that the weight, plus the indicated figures on the dynamometer P, will equal the indicated figures on the dynamometer F: The dynamic angle will be acute, and the weight will have a resisting and a displacing component; the displacing component will be put on the joint-surface by the articular ligaments; the resultant of the resisting and displacing components—that is, the force of the weight—will appear as stress on the joint-surfaces.

(4.) Make the myodynamic angle *obtuse*, and it will be found, by the myometer, that the weight, plus the indicated figures on the dynamometer P, will equal the indicated figures on the dynamometer F.

141. Since the principle of the three orders of the lever is the same, it must follow that the conclusions, in regard to the resultants of the components of the power and weight acting on a bony lever as above enunciated in regard to the lever of the first order, are also true relatively in regard to the resultants of the components of the power and weight acting on a bony lever of the second or third order—that is,

the sum of the forces at the ends equal the force in the continuity of the lever.

142. In order to determine the resistance of cancellous bone, I have cut off the ends of long bones and subjected them to pressure. A few points in regard to these experiments are sufficient for our present purpose. The results are only approximate. The bone ends, in one case, will have more power of resistance than the bone-ends in another case. I make the following record in regard to the ends of a well-formed and apparently healthy femur :—

(1.) The head was cut off at its junction with the femoral neck, making two-thirds of a spheroid, whose diameter was about one inch and a half. It contained about 1.7 cubic inches of cancellous bone. The cut surface of the head was put on a resisting surface and pressure gradually applied to the top of the head by means of a steel lever. When the pressure was about 400 pounds, the top of the femoral head began to flatten, and continued to be depressed as more and more force was applied till pressure was about 2,200 pounds, when the femoral head had settled down one-half inch, had expanded on all sides to a diameter of an inch and three-fourths, and had about one-third *partially* broken off:—Let me call attention to the fact that this amount of pressure (2,200 pounds) is only a little greater than the amount of pressure (1,700 pounds) derived previously from a theoretical basis.

(2.) The neck and the greater part of the trochanteric region of the same femur were cut off, and subjected to pressure in the same manner as the head:—The base of the piece of bone was two and one-fourth inches by one inch and a half: The summit of the neck was about one inch in diameter. When the pressure was about 600 pounds the summit of the neck began to yield, and when the pressure was over 2,200 pounds, the summit of the neck had settled down about three-eighths of an inch, leaving the trochanteric region quite unchanged.

(3.) The condyles of the same femur were cut off transversely to the shaft of the bone:—The cut surface of the piece was about three inches by two inches: the depth of the internal condyle was one inch and a half, while the depth of the external condyle was one inch: This permitted pressure to be made only on the internal condyle. When the pressure was some 600 pounds the internal condyle gave way and settled to a level with the external condyle: And the two condyles then sustained a pressure of over 2,200 pounds. As the cut surface was not quite transverse antero-posteriorly, the condyles split nearly in two from side to side. It would appear, therefore, in this case, that one condyle would be inadequate to sustain the pressure of the quadriceps extensor, as obtained above, by theoretical considerations—namely, over 1,000 pounds—and that both condyles of the femur would be adequate to do the work required by the myodynamic relations.

143. The practical conclusions are: (1.) That, under ordinary conditions, the cancellous tissue of bone-ends can sustain the pressure applied to it by the daily use of the muscles. (2.) That the structural conditions of the bone-ends may so change, on account of disease or injury that the action of the muscles may cause absorp-

tion and deformity, (3.) That, when sufficient external violence is added to the force of contracting muscles, sound cancellous tissue may be more or less broken. (4.) That this broken cancellous tissue may be more or less impacted by having the plates and arches of bone interpenetrate and overlap.

144. Finally, attention may be drawn to the important bearing of myodynamics to fractures, dislocations, and orthopoedic surgery. A complete understanding of these three great departments of surgery can not be had without a knowledge of the PRINCIPLES OF MYODYNAMICS.

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