A STUDY OF MUSCLE FUNCTION IN THE FINGERS

Arris and Gale Lecture delivered at the Royal College of Surgeons of England
on
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by

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Fig. 1. Sir Charles Scarborough (*left*) delivering the Arris Lecture in 1649, with Mr. Arris, founder of the lecture, acting as his demonstrator.

THE ARRIS LECTURE, which became known as the Public Anatomy, was founded in 1646 by Mr. Edward Arris to encourage the teaching of the subject. He was a member of the Company of Barbers and Surgeons, and its Master in 1651. He became an Alderman of the City of London in the same year.

To-day is the 287th anniversary of his death on 28th May 1676.

The Gale's Anatomy, or the Osteology Lecture, was founded soon after the Arris, or Muscular Lecture, by Mr. John Gale of Bushey. The combined lecture is the most ancient foundation of this College.

There is a portrait, in the possession of the Company of Barbers, painted by Robert Fowler, which shows Sir Charles Scarborough delivering one of the first " Public Anatomies " in 1649, with Mr. Arris himself acting as his demonstrator (Fig. 1). The body was probably that of a criminal executed for felony, and the subject appears to be the muscles of the forearm and hand.

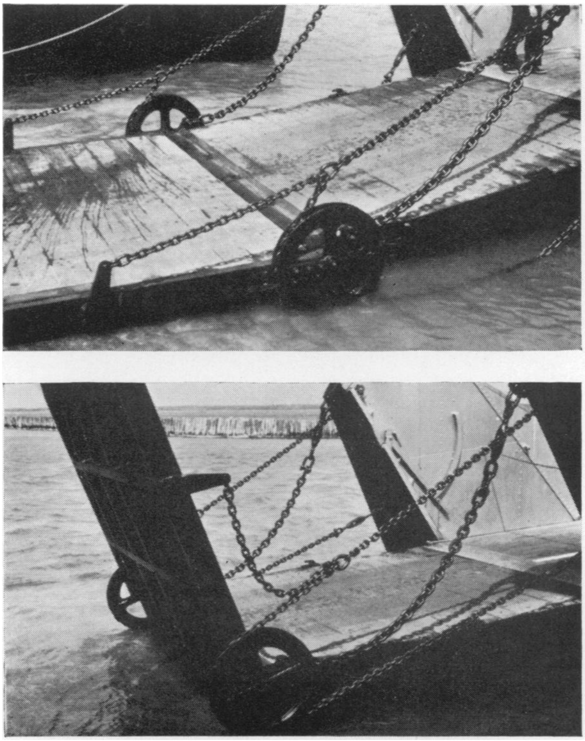


Fig. 2. The ramp of this car ferry is let down in two parts. The chain which pulls it up and lets it down has two attachments. One operates in flexion of the distal joint and the other in extension.

Anatomists will note that the attachment of the extensor muscles to the external epicondyle of the humerus is correctly shown.

At about the same time, Rembrandt painted his famous " Anatomy Lecture ", now in the Mauritshuis at the Hague. This shows Dr. Tulp, and his audience as well, and gives an indication of how the original Arris and Gale lectures must have been given—to a comparatively small audience round the body. It is claimed that the first body he ever lectured over was that of an Englishman.

In this famous picture the anatomy has gone astray, as the flexor muscles are shown arising from the external epicondyle.

This, however, must be put down to artistic licence, rather than to any erroneous understanding of anatomy in Leiden.

It is to Leiden that I am indebted for the foundation of my study, as it is based largely on the very extensive research of Professor Landsmeer of Leiden into the anatomy of the extensor expansion, and the mechanics by which the finger functions.

Many other sources have also been used, but the origin of the whole study was the electro-myographic work of Dr. Kenneth Backhouse (Backhouse and Catton, 1954).

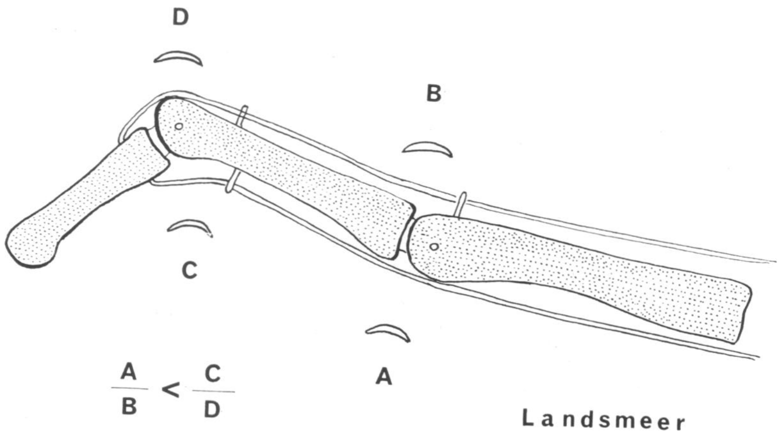


Fig. 3. Landsmeer's articulated chain. For explanation see text.

I would like to start by illustrating one of my main points with these pictures of the car ferry that runs from Lymington to the Isle of Wight (Fig. 2). The vessel represents the metacarpal, and the front lets down with a ramp, consisting of two phalanges, with a metacarpo-phalangeal and an interphalangeal joint. The " muscle " which works this operates by a " tendon " which has a double attachment. Whereas in extension the tension is applied to the distal " phalanx ", it will be seen that in the flexed position it is applied more proximally.

I consider that this applies to many of the muscles in the hand, with the tension applied at different attachments in different positions.

The articulated chain

Landsmeer (1955) suggested using an articulated chain to study the movement of the fingers (Fig. 3). A simple model consisting of three bones and two joints has been constructed.

He showed mathematically that to control both joints in all positions at least three muscles are necessary; either all three bi-articular, or two bi-articular and one monarticular.

A hinge joint has two end positions, e.g. flexion and extension, but only one of these is a functional end-position. Which of the two terminal positions of each joint is the " functional end-position " depends mathematically on the ratio $\frac{a}{b} : : \frac{c}{d}$, the symbols representing the excursions of the tendons over the joints as shown in the diagram.

In the finger, $\frac{a}{b}$ is less than $\frac{c}{d}$, largely because the value of c is so much greater than that of d:

(1) because of the construction of the proximal interphalangeal joint with the volar plate, making the flexor tendon travel a longer path, and

(2) because the excursion of the flexor tendon due to the flexion of the distal interphalangeal joint is also added to c.

As a result of this value of the ratio, the " functional end-position " in the finger is flexion of the interphalangeal joint and hyperextension of the metacarpo-phalangeal joint.

Thus the finger under the influence of the two long muscles only will collapse into this position, which will be recognized as the position of clawing.

Modifications in the system. This simple system of three bones and two joints is complicated in the fingers by three factors:

(1) There is another bone and joint to be considered, the distal phalanx, and the distal interphalangeal joint.

(2) The two long bi-articular muscles moving the chain are both complicated: the flexors in so far as there are two tendons, and the extensor expansion, by reason of its complicated tendon plexus, and its multiple attachments.

(3) There are two sets of additional muscles, which stabilize the system, the distal and the proximal wings. The distal wings are served by the lumbricals and the distal interossei, which are bi-articular muscles, and the proximal wings are served by the proximal interossei, which are essentially mon-articular muscles.

The volar long muscle, the flexor tendon complex

There are three points about the flexor tendon complex that are of particular interest (Fig. 4).

The perforation of the superficialis by the profundus has several valuable results. The superficialis divides into two strap-like bands which wind round the outside of the profundus tendon, come together, decussate, and are attached to the opposite sides of the shaft of the middle phalanx. The profundus is not entirely cylindrical. Where it passes through the superficialis, it is flattened from side to side. Beyond this point, where it passes over the proximal interphalangeal joint, it is flattened from front to back (Martin, 1958).

Secondly, the excursions of these muscles are of interest. The tendons make a short smooth circle in flexion, but in extension they run a sinuous course, which makes the excursion greater than if they ran a straight course through the finger in extension.

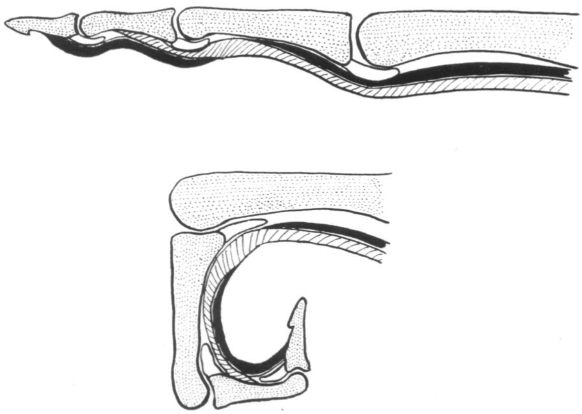


Fig. 4. Diagrammatic lateral views of the flexor tendons in extension and flexion, showing the sinuous curves in extension and the smooth curve in flexion.

The total excursion in a middle finger may be as much as 45 mm., but it will be seen from Table I that the difference between the excursions of the two tendons is very small in spite of the fact that the deep tendon runs over three joints and the superficial tendon only two.

This is due to the fact that when the superficial tendon is beneath the deep tendon at the proximal interphalangeal joint it is very thin, and the deep tendon is not very much farther from the centre of rotation. At the metacarpo-phalangeal joint, however, the profundus tendon is beneath the superficial tendon and is thicker, and the superficial tendon has to make a greater arc, because it is farther from the axis of rotation.

As a result of this, the two tendons do not move very much in relation to each other.

TABLE I

EXCURSIONS OF TENDONS IN MILLIMETRES

	Superficial tendon	*Deep tendon*
Distal interphalangeal joint.. ..	0	5
Proximal interphalangeal joint ..	16	17
Metacarpo-phalangeal joint ..	26	23
Total	42	45

The third point of interest is that made by Dr. Charles Long of Cleveland, Ohio, last year, when he showed that in free unresisted movements of the fingers, it was quite often impossible to record activity in the superficial flexors (Long, 1962).

All the free unresisted movements of the fingers are to a very large extent carried out by the deep muscle, and not by the superficial. As soon as any power is required, then the superficial muscle comes into action very strongly.

The dorsal long muscle—the extensor expansion

The extensor system in the fingers is complicated, not by duplication, but by the multiplicity of its attachments (Fig. 5).

The extensor expansion consists basically of a central tendon, which divides into three parts over the dorsum of the proximal phalanx. The median band goes to the base of the middle phalanx, and the two lateral bands rejoin beyond the proximal interphalangeal joint to form the terminal tendon.

This system is joined by thee pairs of components:

(*a*) Landsmeer's ligaments. (More fully, the oblique parts of the retinacular ligaments of Landsmeer (1949).)

(*b*) The distal wing tendons, a lumbrical on the radial side and usually a palmar interosseous on the ulnar side.

(*c*) The proximal wing tendons, usually served by dorsal interossei.

The terms distal and proximal wing tendons are introduced to indicate the insertion patterns of the intrinsic muscles. The classical dorsal and palmar interosseous description is not entirely satisfactory when describing their insertions, and hence their actions.

The distal components, Landsmeer's ligaments (Fig. 6)

These arise from the fibrous flexor tendon sheath in front of the proximal interphalangeal joint, pass over the side of the middle phalanx, and join the terminal tendon behind the axis of the distal interphalangeal joint.

They thus pass from in front of one joint, to behind the other, and act as a link system between the two joints, holding them theoretically at the same angle throughout the movement.

They are important for the function of a triphalangeal finger, with a limited number of muscles. They link the movements of the two interphalangeal joints so that they can be flexed by one muscle, the flexor profundus, and extended by one muscle, the extensor, subject to some stabilization by the short muscles.

Essentially they keep the two joints at the same angle: that is, when the distal interphalangeal joint is flexed to 90°, the proximal interphalangeal joint is also flexed to 90°, and as the proximal joint is extended, at least in the first half of extension, the distal joint is also extended, by Landsmeer's ligaments, as it is through them that the tension of the median band is passed on to the distal phalanx.

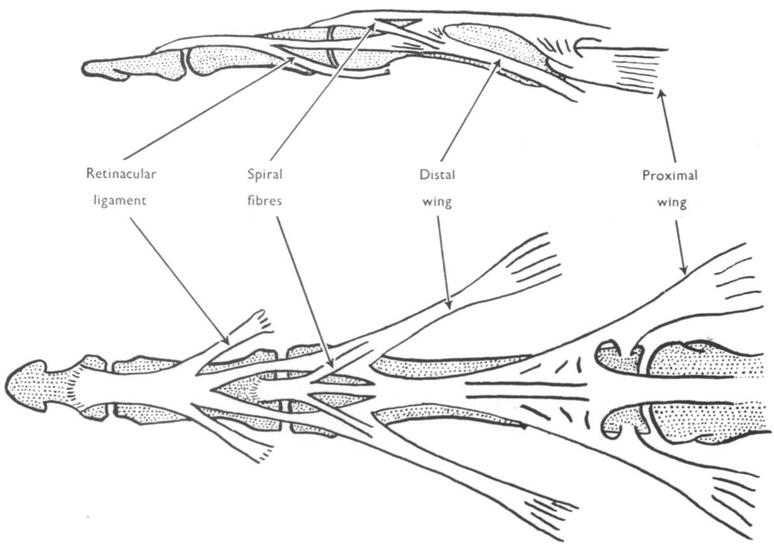


Fig. 5. Diagrams of the extensor expansion showing the central tendon and the paired components. In the dorsal view the proximal phalanx is drawn abnormally long to improve the clarity of the diagram.

However, this is not the whole story. Due to the shape of the joints, which are eccentric, the finger is longer in flexion, and this ligament is tense in the flexed position.

If the proximal interphalangeal joint is held firmly extended, the distal interphalangeal joint can be flexed through about 45°, which means that the Landsmeer's ligaments must be sufficiently lax to allow this movement, in the extended position of the proximal interphalangeal joint. In the flexed position of the interphalangeal joints, this laxity disappears and the distal interphalangeal joint is extended from the fully flexed position to the position of 45° by means of the ligaments.

If the ligaments were completely tense throughout the movement, supplementary muscles for this joint would not be necessary. However, the ligament is lax in the last 45° of extension, due to the asymmetry of the joints, and the movement is completed by the combination of the long extensors and the distal wing tendons. It might be more accurate to describe this structure, not as a ligament, but as a further attachment of the extensor expansion.

The middle pair of components, the distal wing tendons, lumbricals and palmar interossei

Figure 7 shows a dissection made by slicing a hand between two fingers, and looking at the radial side of the finger. The lumbrical tendon can be seen passing through the lumbrical pulley at the distal end of the lumbrical canal. It is somewhat distorted because the finger is extended, and the dead muscle relaxed.

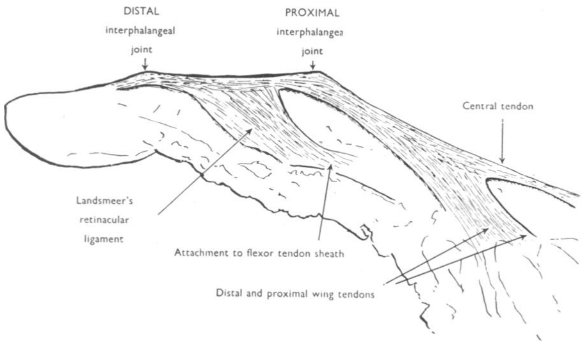


Fig. 6. Drawing of a dissection of the extensor expansion to show the attachment and extent of the retinacular ligament.

The pulley is made up by a condensation of the various fasciae of the hand: the palmar fascia, the anterior interosseous fascia, the dorsal fascia of the web, and Cleland's ligaments (Cleland, 1877). Through this pulley the lumbrical passes from the flexor compartment of the palm to the extensor compartment of the finger.

As a result of this pulley, the tendon of the lumbrical approaches the expansion at a constant angle, in spite of the relative alteration in alignment between the lumbrical muscle and the expansion which takes place when the metacarpo-phalangeal joint is moved.

The pulley also separates the tendon functionally from the proximal wing tendons.

After passing through this pulley the tendon has a bifid attachment. Most of the tendon fans out to join the lateral band of the central tendon, working on the distal joint. The remainder passes, as the spiral fibres, to be attached to the base of the middle phalanx.

In flexion of the interphalangeal joints, these lateral bands slide sideways over the proximal interphalangeal joints, and make a short cut over the joint, sufficient to allow enough excursion of the terminal tendon for flexion of the distal joint at the same time.

The diagram of the expansion in flexion (Fig. 8) will show this point, and also that pulling on the lateral bands by the lumbrical in this position could only cause further lateral movement and be unable to extend the distal joint.

As a further result of the eccentricity of the interphalangeal joints the tension of the lumbrical or ulnar wing tendon will be applied by the spiral fibres to the base of the middle phalanx in flexion, thus allowing the muscle

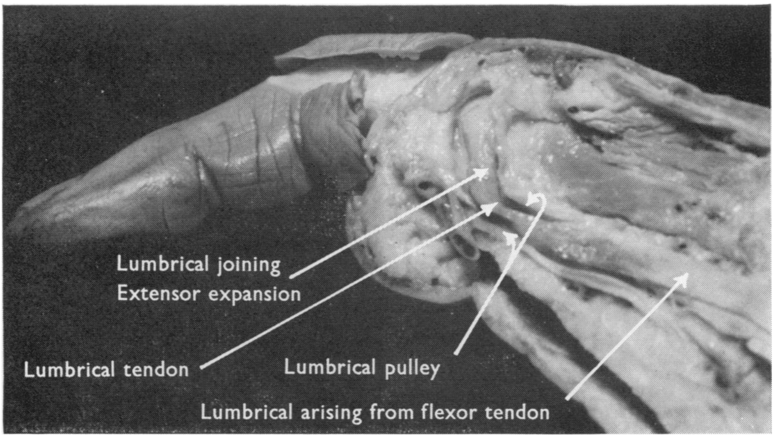


Fig. 7. A dissection of the lumbrical pulley. The pulley is constituted by the junction of the dorsal and palmar deep fasciae. The wing is here a little distorted as the extensor tendon is in the extended position, but the lumbrical is relaxed.

to cause extension of the proximal interphalangeal joint directly, in conjunction with the central tendon, and of the distal interphalangeal joint indirectly by means of the now tense ligaments of Landsmeer.

Further, the tension will be released from the lateral tendons. If it were to continue in this position lateral tears of the expansion would be caused of the type met with in the Buttonhole deformity.

The muscle on the opposite side of the finger to the lumbrical has exactly the same attachment, and was described by Landsmeer as the ulnar wing tendon. These two tendons should be known collectively as the distal wing tendons. The muscle serving the ulnar wing, usually what is now known as a " palmar interosseous", should be known as a " distal interosseous."

The tension of these distal wing tendons can be regarded as being applied at the angles of a diamond of tendons, formed by the two lateral bands. The central tendon is applied at the proximal end, and the terminal tendon is the distal end. Any tension applied to the diamond by the wing tendons can be resolved into longitudinal forces which will be applied at the terminal tendon, and horizontal components, which will act in opposite directions to each other, and tend to widen and shorten the diamond. This will relax the median band and transmit some of the force applied by the long extensor tendon around the side of the diamond to act at the distal attachment.

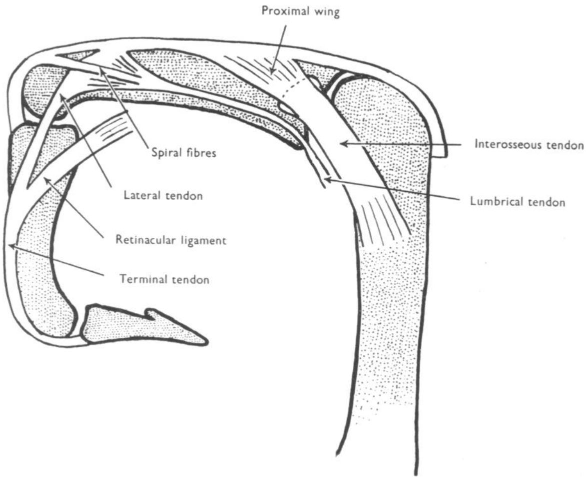


Fig. 8. A diagram of the expansion in flexion. This shows the lateral movement of the lateral tendons in flexion. It is impossible for them to extend the distal phalanx in this position. The tension of the distal wing in this position is applied by the spiral fibres to the base of the middle phalanx, and the distal phalanx is extended by the retinacular ligament.

Thus the lumbrical can be regarded as altering the shape of the expansion and sharing the pull of the long extensor between the two attachments, and thus extending both joints at the same time.

The movements of the lumbrical muscles, and the alterations in length (Fig. 9)

To simplify discussion of the movements of the fingers, four positions have been defined. These are:

(1) Full extension.
(2) Flexion at the metacarpo-phalangeal joint, with extension at the interphalangeal joints.
(3) Extension at the metacarpo-phalangeal joint, with flexion at the interphalangeal joints.
(4) Full flexion.

A diagram can be constructed showing the comparative lengths of the lumbrical muscle in the varying positions. This is done by considering the movements of the profundus tendon, from which it takes origin, and of the extensor expansion to which it is attached. The excursions of the tendons are taken from Bunnell (1948) and those of the extensor expansion by direct measurement.

The proximal movement of the profundus tendon in flexion of the metacarpo-phalangeal joint from 1 to 2 is about 15 mm. In the movement

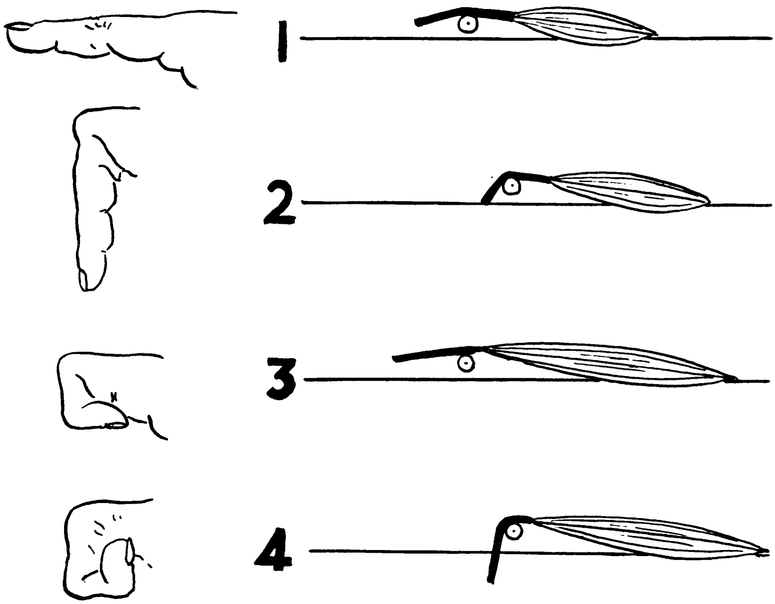


Fig. 9. Diagram of the lengths of the lumbrical, showing that in positions 1 and 2 it is contracted and that in positions 3 and 4 it is relaxed. Also, that apart from the movement 3 to 2, it does not alter in length during metacarpo-phalangeal flexion. 3 to 2 is the only movement in which metacarpo-phalangeal flexion takes place at the same time as interphalangeal extension.

1 to 3, flexion of the interphalangeal joints, the proximal excursion of the tendon is 25 mm. In the movement 1 to 4, flexion of all the joints together, the excursion is 40 mm. Thus we have a row of points, representing the attachment of the lumbrical to the profundus tendon, moving progressively proximally in the four positions.

In considering the distal attachment of the lumbrical, there are two types of movement.

Firstly, in flexion of the metacarpo-phalangeal joint there is proximal movement of the lumbrical pulley by about 15 mm. Secondly, on flexion of the interphalangeal joints there is distal movement of the lumbrical tendon through the lumbrical pulley of about 10 mm.

It can now be seen that there are two main lengths of the lumbrical.

In 1 and 2 the muscle is contracted, in action, and about 5 cm. long. In 3 and 4 it is relaxed, inactive, and about 8.5 cm. long.

It was shown by Backhouse and Catton (1954) that there are action currents in the lumbrical only in the presence of interphalangeal extension, irrespective of the position of the metacarpo-phalangeal joints.

It is in order to extend or to hold the interphalangeal joints extended, in both extension and flexion of the metacarpo-phalangeal joints, with the same length and power of contraction, that the lumbrical must be able to act from a different position, and this it is able to do by having a moving origin from the flexor profundus tendon.

Thus the prime action of the lumbrical, and also of the distal interosseous, is interphalangeal extension. This it does partly directly, but more effectively indirectly, by the servo-mechanism by which it alters the point of application of the long extensor.

When the interphalangeal joints are extended, they can also act as flexors of the metacarpo-phalangeal joints, and Backhouse and Catton have demonstrated added action currents in the muscles during this movement.

Also the lumbricals can be regarded as extensible nerve endings, to correlate the tensions between the long flexors and the long extensors, and they are well provided with nerve endings for this purpose (Rabischong, 1961).

The proximal components, the proximal wing tendons, proximal interossei, mostly dorsal interossei

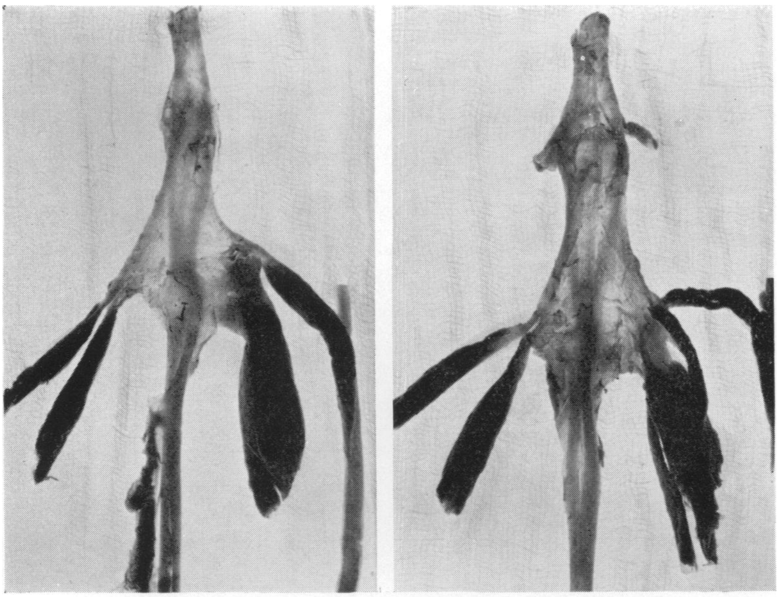
It is well known that the insertions of these muscles are variable. They have been closely studied by Salsbury (1937), and Eyler and Markee (1954). Boileau Grant (1958) describes them as having a bifid attachment, and this is how I have found them.

There is a flat tendon from the muscle, extending distally and dorsally to join the extensor expansion as the transverse fibres. Beneath this there lies a short tendon attached to the base of the proximal phalanx, on the phalangeal tubercle.

As a result of this the muscle can act at one or other of these attachments or slung between the two according to the position of the fingers.

In full extension, when both the interphalangeal and the metacarpo-phalangeal joints are extended, the transverse bands are carried proximally by the extensor tendon, and become relatively relaxed. The tension of the muscle is then applied to the phalangeal attachments on the phalangeal tubercles. The action in this position is ad- or ab-duction.

If the interphalangeal joints are now flexed, the expansion is carried distally, and the muscles will be capable of producing interphalangeal extension.



(a) (b)

Fig. 10. (*a*) Index finger. Here the basic tendon pattern is clearly seen, with the diamond of tendons and the four wings. Note in addition a short extensor of the index. (*b*) Middle finger. The basic pattern is again clear. The retinacular ligament is well shown. The lumbrical is here joined by a belly from an interosseous. A second belly serves the proximal wing, and there is a further belly which has a phalangeal attachment.

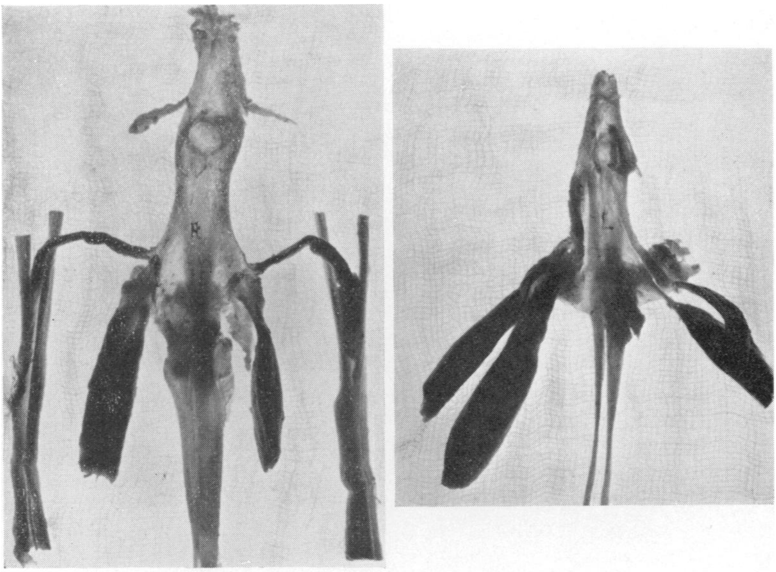
The point of action of the muscles in the position of metacarpo-phalangeal extension may be slung behind the axis of the metacarpo-phalangeal joint, and the result of activity of the muscles may be hyper-extension.

When the metacarpo-phalangeal joints are flexed the force of the interossei will be applied as a sling round the dorsum of the proximal phalanx, and will produce powerful flexion of these joints. If in addition the interphalangeal joints are also flexed, this sling will be carried farther distally and produce an even greater moment round the axis of the joint.

The pattern of intrinsic muscles

This pattern of four motors for each finger requires at least 16 muscle bellies to be complete, whereas the classical description gives only 13, made up as follows:

4 Lumbricals,
3 Palmar interossei,
4 Dorsal interossei,
2 bellies of abductor digiti minimi.



(*a*) (*b*)

Fig. 11. (*a*) Ring finger. The flexor profundus tendon has been split to allow mounting. There is a lumbrical serving the distal wing on either side of this finger. (*b*) Little finger. The extensor digiti minimi goes directly to the ulnar lateral band. The separation between the two radial wings is particularly clear. The two ulnar wings are supplied by the abductor digiti minimi.

The following four figures were prepared by dissecting the extensor expansions of a left hand, and the muscles serving them, spreading them out, and photographing them by transmitted light in order to show up the tendon structure. The diamond of tendons is clearly shown, though not so well in the little finger.

The retinacular ligaments are shown particularly clearly in the middle and ring fingers.

Joining each expansion there are at least four muscle bellies, with a proximal and distal wing on each side. In most cases the separation between the two wings can be clearly seen. There was very little sharp dissection used in the preparation of these specimens, and the lines between the wings are natural and not artefacts. Dissection was necessary in the case of each proximal wing to separate the firm phalangeal attachment.

In detail the following points should be noted:

The index finger (Fig. 10a)

There was a fairly well marked proximal wing from the first dorsal interosseous, with the transverse fibres going to the extensor tendon. The dark mass attached to the extensor tendon proximally is a muscle belly, a short extensor of the index.

The middle finger (Fig. 10b)

There is a separate belly coming off the interosseous muscle, on the radial side, which reinforces the lumbrical muscle actuating the distal wing. There is a second separate belly from this muscle, which passes beneath the wing, and probably is applied solely to the bone.

On the other side of the finger, which in the classical pattern has no palmar interosseous, there are clearly two bellies, providing proximal and distal wing motors.

The ring finger (Fig. 11a)

The profundus tendon to this finger has been split in half, so that the specimen could be spread out. The fourth lumbrical serves the distal wing on the ulnar side of this finger.

The little finger (Fig. 11b)

There is no lumbrical. The distal wing on the radial side is served by an interosseous belly. These two wings are particularly clearly separated. The extensor digiti minimi proprius goes directly to the ulnar lateral band. The two ulnar wings are supplied by separate bellies of the abductor digiti minimi.

In these figures the basic plan of the expansion with its diamond of tendons and the component wings is illustrated, and also the muscles that supply them.

However, it is also clear that it is subject to wide variations, as several variations are present here.

Actions of the proximal interossei

These may be summarized simply as follows:

At the interphalangeal joints they cause extension.

At the metacarpo-phalangeal joints:

In extension, they adduct and abduct;
In hyperextension they may hyperextend, and
In flexion they flex.

By a combination of the movements of adduction, abduction and flexion, they produce rotatory movements which are necessary to oppose the fingers to the thumb in the precision grip (Napier, 1956; Backhouse, 1960).

The shifting insertions enable the muscles to fulfil these varying functions, allow economy of muscle bulk, and increase the efficiency of the hand.

ACKNOWLEDGEMENTS

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ROHAN WILLIAMS MEMORIAL FUND

The Council of the Faculty of Radiologists has decided to launch an appeal to set up a memorial to its late President, Dr. Rohan Williams, M.D., F.R.C.P., F.R.C.S., F.R.C.O.G., F.F.R., F.C.R.A., who died in office on 17th March 1963.

Rohan Williams made great contributions to many fields of medicine as well as radiology, and it is hoped that this appeal will meet with a wide and generous response. The Council has in mind the establishment of an academic prize, lectureship, or possibly a travelling scholarship in his memory. Donations should be sent to the Honorary Treasurer of the Faculty of Radiologists, at the Royal College of Surgeons of England, Lincoln's Inn Fields, London, W.C.2, and cheques made payable to "The Faculty of Radiologists".