THE INSERTIONS OF THE FLEXORES POLLICIS LONGUS ET DIGITORUM PROFUNDUS

By J. L. WILKINSON
Department of Anatomy, Manchester University

The progressive development of the faculties of manual palpation and prehension was a most significant factor in human evolution. The volar aspect of the digits of the hand is therefore of considerable interest, yet there are features of its topographic anatomy which have passed unnoticed.

Dissection of a hundred fingers and a hundred thumbs from adult human cadavers has revealed fundamental differences, probably of morphological significance, between the distal insertions of the flexor pollicis longus and flexor digitorum profundus tendons. These have been compared and correlated with relevant findings in forty human little toes and a wide series of animal dissections. The synovial flexor sheaths of fourteen adult human fingers and thumbs have been injected and ninety terminal phalanges have been examined.

DIFFERENCES BETWEEN THE INSERTIONS OF THE TWO TENDONS

In man each flexor digitorum profundus tendon is, to quote Albinus (1749) '...in a manner split longitudinally and appears as if formed of two conjoined together'. Each tendon possesses a distinct longitudinal ventral median furrow and a shallower dorsal one. The volar groove can usually be distinguished opposite the metacarpophalangeal joint. Though only narrow here, it becomes much more evident distal to the bifurcation of the flexor digitorum sublimis, and is deepest opposite the middle phalanx, where it sometimes almost divides the tendon into two halves.

This mid-line division was noted by Winslow (1733), Boyer (1815), Bichat (1819), Cloquet (1822), Meckel (1825) and Poirier & Charpy (1901), but is not described in standard English anatomical works.

The superficial tendon fibres of a flexor digitorum profundus tendon, when traced distally from the level of the bifurcation of the corresponding sublimis tendon, gradually diverge from this mid-line furrow towards the tendon margins. Opposite the terminal interphalangeal joint the volar fibres diverge more acutely to insertions on each side of the ventral surface of the base of the distal phalanx, so exposing the deeper fibres which are attached more distally and centrally on the volar aspect of the shaft of this bone (Pl. 1, fig. 1).

In the thumb the flexor pollicis longus tendon also possesses a ventral groove from which fibres diverge. The superficial fibres of this tendon at the level of the terminal joint pass distally to insertions on the shaft of the terminal phalanx. The deepest fibres form *two discrete lateral tendon fasciculi* which diverge to be inserted on each side of the volar surface of the base of this bone (Pl. 1, fig. 2). Sometimes, one of these fasciculi receives an accession of a few fibres from the margin of the tendon (Pl. 1, fig. 3). Transverse 100μ sections of a flexor pollicis longus tendon emphasize the discrete nature and predominantly deep origin of the lateral fasciculi (Pl. 1, fig. 4).

The flexor pollicis longus tendon of *Macacus rhesus* shows similar lateral fasciculi but these are ill-defined or absent in several other primates examined and are lacking in the lower animals which have been dissected.

A ligamentous band extends on each side between the lateral aspects of the base of the phalanx and the proximally projecting tips of the tuberositas unguicularis and protects the vessels and nerves which pass dorsally from the pulp to the nail bed. A few of the laterally inserted fibres of the long flexor tendon both in the finger and the thumb are continued into this ligament (Pl. 1, figs. 1–3). Some of the centrally inserted fibres in the thumb, and to a lesser extent in the fingers, are sometimes relayed from the shaft to the base of the tuberositas unguicularis (Pl. 1, fig. 3).

Briefly stated, when traced distally from the level of the terminal joint, the most *superficial* tendon fibres in the finger pass to lateral insertions, and in the thumb they go to more central and distal insertions. The *deep* tendon fibres in the finger have central distal insertions, and in the thumb they possess lateral basal insertions.

THE TERMINAL PHALANGES

There are differences between the bony roughenings for tendon insertions in the thumb and the fingers; these roughenings are coloured black in Pl. 1, figs. 5 and 7.

In the thumb the main central insertion and the two lateral fasciculi are sometimes associated with separate bony tuberosities (Pl. 1, fig. 5*a*), but more commonly the latter are united by two slender ridges (Pl. 1, fig. 5*b*), often undermined by a small vessel. Radiographs of twenty-five living subjects showed that during flexion of the terminal phalanx, the mid-line volar sesamoid (present in 72 %) comes into apposition with the base of the phalanx, in the concavity of this U-shaped insertion (Pl. 1, fig. 6).

In the terminal phalanges of fingers the roughening for flexor tendon attachment is limited proximally by a transverse bony ridge (Pl. 1, fig. 7).

The insertions of these flexor tendons is primarily diaphysial, extending more than half way from the articular margin to the base of the tuberositas unguicularis. In the adult, and also in the 3½ months' foetus, the flexor tendons of the terminal phalanges reach much more distally than the corresponding extensor tendons, as is well demonstrated by sagittal sections (Wilkinson, 1951).

THE DIGITAL SYNOVIAL FLEXOR SHEATHS

Papers on the digital synovial sheaths by Fourcroy (1785), Chemin (1896), Whittaker (1907), Lucien (1910) and Retterer (1896, 1918*a*) and the anatomical atlases of Spalteholz (1901), Toldt (1944), Grant (1947) and Sobotta (1948) fail to record certain differences which exist between the distal termination of the polliceal flexor sheath and that in other digits. Poirier (1901) reported that the visceral layer of the sheath is reflected from the tendon distally in a 'preputial' manner, forming a 'simple annular cul-de-sac', a view commonly held.

There are technical difficulties in filling the cavities of these sheaths. These may be overcome in the following manner. A digit is amputated at the metacarpo-phalangeal joint and the synovial sheath opened. The digit is then flexed so that the cut end of the flexor tendon extrudes from the sheath. The tendon is divided flush with the amputated stump, so that when the digit is again extended, the tendon retreats into its canal, and a small pocket is formed in the proximal portion of the sheath. A glass cannula is inserted into this pocket and sealed in position with gelatine. The digit is then placed within a large test-tube, which has been half-filled with warm gelatine. More gelatine is added until the digit and the lower half of the cannula are immersed. When the gelatine sets it forms a perfect seal between the synovial sheath and the cannula and also maintains the latter in position. A small quantity of 10 % colloidal silver iodide is dropped into the cannula, after which the test-tube with its contents is centrifuged at 900 r.p.m. for 15 min. The colloidal particles having now been forced to the distal tip of the synovial sheath, supernatant fluid in the cannula is replaced with silver iodide and the centrifuging continued for half an hour. This process is repeated until fluoroscopic screening indicates that the sheath is filled. Though a somewhat elaborate procedure, this is the only method, of many tried, which portrays the details of the distal portion of the cavity of the synovial sheath.

The synovial sheath of the flexor pollicis longus

The terminal part of the lumen of this sheath has a small cul-de-sac on either side which possesses a slight dorsal inclination (Pl. 2, fig. 8). Dissection of the injected sheath indicates that these lateral diverticula lie on the volar surface of the lateral fasciculi of the flexor pollicis tendon. They are demarcated by fusion of the visceral and parietal synovial layers along the sulci which separate the central and lateral parts of the tendon at its insertion. When the median furrow in the ventral surface of the tendon is well marked, the parietal layer is carried into it prematurely, and by blending with the visceral layer creates a central cleft in the distal tip of the sheath.

The synovial sheath of the flexor digitorum profundus

The distal portion of the cavity of this sheath is more rounded than in the thumb (Pl. 2, fig. 9). There is no mid-line cleft in the tip of the sheath, nor are lateral diverticula present in its terminal extremity. Where the visceral synovial membrane is reflected from the tendons of the *flexor digitorum sublimis* as the latter pass to their insertions, two small diverticula are seen, comparable in shape and dorsal inclination to those noted in the thumb.

Thus a careful examination of the synovial sheaths in the thumb and the fingers emphasizes the discrete nature of the lateral tendon fasciculi of the flexor pollicis longus.

A SUGGESTED EXPLANATION OF THESE DIFFERENCES

Why are there such striking differences in the mode of insertion of these two long flexor tendons? To answer this question attention is directed to the lateral tendon fasciculi of the flexor pollicis longus. These probably represent rudiments of a flexor perforatus tendon. The evidence for this view will be discussed under four headings: (1) the morphology of the terminal phalanx; (2) flexor tendons in the toes; (3) digital flexor tendons in lower animals; (4) polliceal 'perforatus' tendons in man.

(1) *The morphology of the terminal phalanx*

The pollex possesses three bones distal to the carpus; all other manual digits have four. The problem implicit in this statement underlies a controversy two thousand years old. It is unnecessary to recount every opinion expressed about the nature of the first metacarpal bone as these have been well summarized by Welcker (1884), Krause (1896), Wakeley (1924) and Jones (1949).

The first metacarpal has been held to represent a phalanx, but there is now fairly general agreement that this is not so. It is of historical interest to note that Galen (A.D. 131–200) and Vesalius (1555) maintained that the four ulnar metacarpal bones articulate proximally by synarthroses and distally by diarthroses, whereas the first 'metacarpal' possesses both *proximal* and distal diarthroses and is thus to be considered a phalanx. The foundation for this theory, therefore, rests on what is now patently a fallacy. The basal position of the epiphysis does not always distinguish the first from other metacarpals in animals or even in man. Moreover, the relative mobility of the first metacarpal bone does not affect its homology with the first metatarsal, though the two bones are equally mobile in the anthropoid ape.

The general process of phalangeal reduction has been studied in foetal cetacea by Kükenthal (1888), who stressed that the sequence of reduction comprises a fusion of terminal with subterminal phalanges. It is therefore interesting to recall Gräfenberg's assertion (1905), that the diaphysial ossification of human terminal phalanges takes place from two centres which soon fuse, thus recapitulating an ancient phylogenetic reduction. Gräfenberg also showed that the terminal phalanx of the thumb is longer than the other terminal phalanges at all stages of development.

There are many records of human tri-phalangeal thumbs (Windle, 1891; Salzer, 1897; Pfitzner, 1898; Joachimsthal, 1898, 1900; Rieder, 1900; Jurčić, 1906; Geelvink, 1913; Kristjansen, 1926; Lapidus & Guidotti, 1943). In these cases the terminal phalanx is usually shortened, and an accessory element (middle phalanx) is present between this and the basal phalanx. This suggests that the terminal polliceal phalanx represents two fused phalanges, an inference, however, which is open to some criticism, for even the palaeozoic stegocephali had only two polliceal phalanges (Windle, 1891).

It has been shown that the lateral fasciculi of the flexor pollicis longus are inserted into the base of the terminal phalanx. It would be very interesting to know whether these tendon bundles are attached to the small middle phalanx in the abnormal three-membered thumb of man. The accounts of tri-phalangeal thumbs deal only with external and radiological appearances and no account of a dissection of this abnormality has been discovered.

Having studied the process of marginal phalangeal reduction by bony fusion between the middle and terminal phalanges of the little toe, Pfitzner (1900) concluded that the ungual phalanx of the thumb is similarly a compound structure derived from two phalanges. Jones (1949) stated 'I know no fact derived from any study of normal or abnormal anatomy or from paleontology that contradicts this finding'.

(2) *Flexor tendons in the toes*

The arrangement of the tendon fibres of the flexor digitorum longus at its distal insertion in the second, third and fourth toes closely resembles that seen in its manual counterpart, the flexor digitorum profundus. In the case of the marginal digits, however, there are certain differences.

The great toe

The importance of the human great toe in bipedal locomotion is reflected in the commonest pedal digital formula. The size of the flexor hallucis longus tendon in man necessitates extensive distal attachments, and these appear to have undergone some modification. The uniformity of tendon fibre arrangement found in the insertion of the corresponding polliceal flexor tendon is lacking in the hallux, and comparable discrete lateral tendon fasciculi are rarely distinguishable. The changes of structure in this toe in response to alteration of function will be dealt with in a further communication.

The little toe

Skeletal changes in this toe have been shown by Pfitzner (1890, 1896) and others to shed light on the nature of the osseous structure of the thumb. This writer recorded (1896) fusion of the middle and terminal phalanges in 37 % of 838 little toes, and stated (1890) that in toes with two phalanges the perforatus tendon was *always* rudimentary or absent. In the present series of forty little toes fusion of the middle and terminal phalanges is present in 25 %, and in half of the latter the reduction of the middle phalanx co-exists with a reduction of its associated short flexor tendon as a separate entity. In each of four of these toes the perforans tendon was found to provide a fasciculus, histologically proved to be of a tendinous nature, to a fused middle phalanx (Pl. 2, fig. 10). In one toe with phalangeal fusion the perforans and perforatus tendons unite immediately prior to their insertions (Pl. 2, fig. 11). In only one toe with three phalanges is there an extensive fusion of tendons, the perforans tendon providing two fasciculi to a separate middle phalanx (Pl. 2, fig. 12).

If the inter-related normal perforans and perforatus tendons of the little toe are compared with the insertion of the flexor pollicis longus (Pl. 2, fig. 13), a marked resemblance is noted, the perforatus in the little toe corresponding to the lateral tendon fasciculi in the thumb.

Since the base of the terminal polliceal phalanx probably contains elements of a fused middle phalanx, these observations on little toes suggest that the *polliceal lateral fasciculi represent rudiments of flexor perforatus tendons.*

(3) *Digital flexor tendons in lower animals*

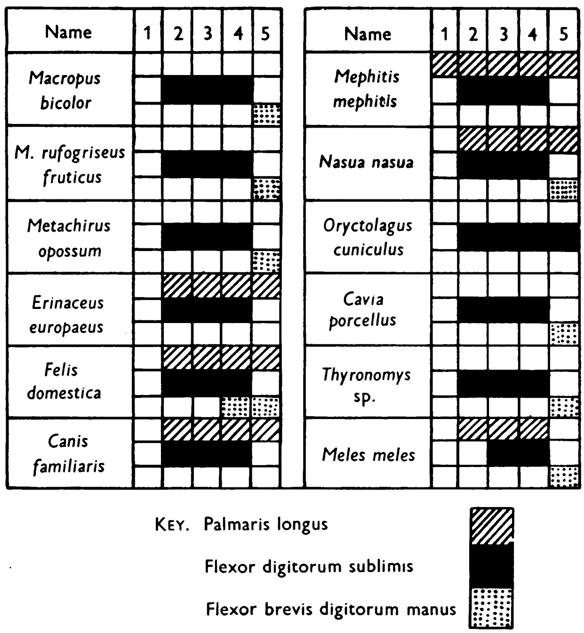
In Amphibia and Reptilia, short muscles of palmar origin provide digital tendons which are often perforated by the flexor tendon of the terminal phalanx. In digits with more than three phalanges, more than one pair of perforatus tendons are sometimes present. No example has been found of true polliceal perforatus tendons.

In Mammalia below the order Primates it is necessary to distinguish between the flexor tendons in the digits and their proximal muscular connexions. From one to three different muscles may be attached to a *digital* perforatus tendon. The muscular attachments of these tendons in twelve animals are shown diagrammatically in Table 1.

(i) *The flexor digitorum sublimis.* This muscle may arise from the ulnar-sided epicondyle of the humerus (e.g. *Felis domestica, Mephitis*), or it may take origin from the musculo-tendinous stratum which provides flexor tendons to the terminal phalanges (e.g. *Canis familiaris* and the marsupials).

(ii) *The palmaris longus.* The most superficial flexor muscle of the antebrachium is, to a variable degree, divided into discrete digital tendons in the manus. The distinctness of these tendons strongly suggests an important function in digital flexion and they are sometimes misnamed accordingly. Thus in *Canis familiaris* the large muscle referred to as the 'flexor digitorum sublimis' by Bradley (1912) is in fact the palmaris longus, and the small deep muscles ('palmaris accessorius'—Sisson, 1910) which join its tendons are strictly comparable to the flexor digitorum sublimis in marsupials. Thus Huxley (1871) and Windle & Parsons (1897) were incorrect in assuming that the palmaris longus is absent in this animal.

Table 1. *Muscles inserted into digital perforatus tendons*



(iii) *Flexor brevis digitorum manus.* A short muscle, usually of palmar origin, is sometimes inserted into digital perforatus tendons. In *Felis domestica* this muscle arises from the lower portion of the palmaris longus tendon. As Haines (1950) also noted, the perforatus tendons of the fourth digit of this animal receives contributions from three sources (See Table 1).

The tendon ring

Integration of these various contractile elements is brought about by their attachment to a fibrous or fibrocartilaginous ring which encircles each profundus tendon at the level of the metacarpo-phalangeal joint. The digital perforatus tendons extend distally from this ring, and palmar tendons of diverse muscular origin are attached to it proximally. Though Windle & Parsons (1897) referred to the widespread presence of tendon rings in insectivores, rodents and carnivores, accounts of such rings are often lacking in the descriptions of these orders by other writers. In *Canis familiaris* the tendon rings are particularly well developed and constitute the fibrocartilaginous tunnel described by Douglas (1763) and Retterer (1918*b*). Parsons (1898) noted the occasional presence of this ring in man.

Palmar tendons of a flexor perforatus complex are often not in line with the digit they supply. Tendon rings ensure apposition and alignment of digital perforatus and perforans tendons and also protect them at the level of the metacarpo-phalangeal joint. These rings are not present in the marsupials examined, in which only a single superficial flexor tendon passes to each digit.

Table 2. *Polliceal 'sublimis' tendons*

Author	Animal	Muscle supplying the tendons	Digital insertion
Humphry (1869)	*Manis*	Flexor dig. sublimis	1st phalanx
Humphry (1872)	*Uromastix spinipes*	Flexor dig. sublimis	1st phalanx
Mivart (1881)	*Felis domestica*	Flexor dig. sublimis	Ulnar side of pollex
Dobson (1882)	*Erinaceus algirus*	Palmaris longus	?
	E. jerdoni	Flexor dig. sublimis	?
Shepherd (1883)	*Ursus americanus*	Flexor dig. sublimis	2nd phalanx
Bardeleben (1894)	*Hyrax brucei*	Flexor brevis superficialis	?
	Paradoxurus	Flexor dig. sublimis	2nd phalanx
Windle & Parsons (1897)	*Procyon lotor*	Flexor dig. sublimis	?
	Nasua	Flexor dig. sublimis	?
	Ursus americanus	Flexor dig. sublimis	?
	Felis catus	Flexor dig. sublimis	?
Frazer (1907)	*F. domestica*	Flexor dig. sublimis	Ulnar side of pollex
Howell (1932)	*Dipodomys*	Flexor dig. sublimis	?

Polliceal 'perforatus' tendons

There are many descriptions of 'sublimis' tendons in the pollex of lower animals (see Table 2). Superficial flexor tendons and an associated ring are well developed in the pollex of *Mephitis mephitis* (Pl. 2, figs. 14, 15), but in this case, as in the minimus of *Mephitis* and *Erinaceus europaeus*, and the index of *Meles meles*, only the palmaris longus, through easily defined thickenings in the palmar aponeurosis, supplies the contractile element to the tendon ring. In the pollex of *Mephitis* the perforatus tendons are inserted into the palmar ligament of the distal joint, the tendon on the ulnar side being slightly larger than that on the radial aspect.

A single, very weakly developed polliceal 'perforatus' tendon is sometimes found to be blended with the ulnar part of the fibrous flexor sheath in *Felis domestica*. A tendon ring, present in the other digits of this animal, has apparently fused with the fibrous flexor sheath in the pollex, and a slip from palmaris longus passes to this sheath.

Thus perforatus tendons, confined to a digital extent, and attached proximally only to the palmaris longus through a tendon ring, are sometimes present in the digits of quadrupeds, and are occasionally found in the pollex. This probably explains the observation of Parsons (1898) on the mammalian flexor digitorum sublimis—'After that to the pollex, the minimus tendon is the one most frequently wanting, but on several occasions when this has happened, I have found, on splitting up the theca, the perforated loop of the tendon surrounding the flexor perforans, and having its usual insertion, although there was no tendon in the hand and fore-arm to this digit.'

Particular developments of the pre-axial digit took place amongst the early primates, but specialized locomotion by brachiation stayed this advance amongst the larger members of this order.

Three chimpanzees (*Anthropithecus troglodytes*) have been examined. The flexor pollicis longus tendon is rudimentary in all, taking origin either from the flexor retinaculum or from the flexor profundus tendon to the index. In one specimen, dissected shortly after death, two accessory polliceal tendons were found blending with the metacarpo-phalangeal joint capsule proximally and proceeding to distal insertions deep to, and on either side of, the functionless long flexor tendon (Pl. 3, fig. 16). The tendon on the radial side is relatively poorly developed and is partly fused with the fibrous flexor sheath; that on the ulnar side is quite discrete and lies within the sheath. Immediately prior to their distal insertion fibres decussate between these two tendons, dorsal to the flexor pollicis longus. In the other two specimens only the ulnar-sided accessory tendon can be clearly distinguished, but their state of preservation is not as good as that of the first animal. No other record has been found of these rudiments.

In these primates the abductor et flexor pollicis brevis and the adductor pollicis obliquus send small *extra-vaginal* tendons to the ungual phalanx, not to be confused with the *intra-vaginal* tendons described here. An extension from the abductor was reported by Hepburn (1892) and Fick (1925), from the flexor pollicis brevis by Vrolik (1841) and Humphry (1867), and from the adductor by Gratiolet & Alix (1866) and Sutton (1883).

Accessory intra-vaginal tendons, inserted deep to, and on either side of, the vestigial long flexor tendon were found in the thumbs of a gorilla (*Gorilla gorilla*) and an orang (*Simia satyrus*). In the former the adductor pollicis has gained a partial attachment to the ulnar-sided tendon. In the orang the flexor pollicis longus tendon is embedded proximally in the flexor pollicis brevis muscle, and the adductor pollicis and flexor pollicis brevis are attached to the accessory intra-vaginal tendons.

An intra-vaginal extension to the terminal phalanx in the orang was stated to come from the adductor by Broca (1869), from the inner head of the flexor pollicis brevis by Langer (1879) and Bischoff (1880), from the outer head of the latter muscle by Fick (1895) and from the adductor obliquus by Primrose (1900). These distal prolongations have often been regarded as representing the flexor pollicis longus tendon, e.g. by Langer (1879), but Straus (1942) has shown that the slip which Langer described can co-exist with other rudiments of the long flexor tendon.

Those tendons which are accessory to the flexor pollicis longus and lie within the fibrous flexor sheath in these primates are probably remnants of polliceal perforatus tendons. These accessory tendons do not pass into the antebrachium, but a similarly restricted proximal extent is commonly found in the perforatus tendons of quadrupeds and it is also a characteristic of homologous human rudiments, to be described below. The *ulnar*-sided perforatus tendon in the thumb is the largest and most discrete in the human foetus, in quadrupeds and in the anthropoid apes examined. The latter are not truly 'perforatus' tendons in that they do not extend on to the volar aspect of the long flexor tendon. This feature is, however, a characteristic of the polliceal perforatus tendons of *Mephitis*, and also of the human foetus; moreover the flexor perforatus tendons of the little toe occasionally fail to extend on to the ventral surface of the long flexor tendon.

The position of insertion of these accessory intra-vaginal tendons and their distal relationship to the flexor pollicis longus is *paralleled in man by the lateral tendon fasciculi.*

(4) *The polliceal 'perforatus' tendons in man*

A. *The human foetus*

Frazer (1907) described the existence of a band of cells in the 3 months' foetus arising from the flexor digitorum sublimis above the wrist which came into contact with the *ulnar* side of the flexor pollicis tendon below the wrist, inclined on to the dorsal aspect of this tendon in the thumb and was attached to *both sides* of the terminal phalanx adjacent to the insertion of the long flexor tendon. He maintained that it could not be traced microscopically in the last few months of foetal life, but stated that '...after birth the band can sometimes be distinguished in my opinion by naked eye'. Gräfenberg (1905) suggested that '...in early ontogenesis...it is not impossible that from the superficial common finger flexor, elements are radiating in the direction of the tendon to the first digit'. The only other reports of a human superficial polliceal flexor concern the flexor accessorius ad pollicem of Ganzer (e.g. Fürst, 1900); but this connexion between the superficial and deep flexor layers is the remnant of the condylo-radial head of the primitive *deep* flexor (Windle, 1889), and is not directly relevant to the problem.

In this investigation, serial sections of the manus and lower forearm of four foetuses (C.R. lengths: 35, 57, 70 and 80 mm.) have been examined. Definitive tendons are not present in the 35 mm. foetus. In all the other specimens there is an accessory tendon on the *ulnar* side of the flexor pollicis tendon. It is particularly marked in the 80 mm. foetus (Pl. 3, fig. 17). This arrangement differs from the account given by Frazer in three ways:

(1) The small tendon fuses with the palmar portion of the capsule of the distal joint and one cannot distinguish between the constituent cells of this tendon and the joint capsule distal to this attachment.

(2) The accessory tendon does not exist proximal to the head of the first metacarpal bone.

(3) At this level a weakly developed ring of cells extends from the ulnar-sided tendon and encircles the flexor pollicis longus tendon.

B. *The human adult*

In an examination of forty-two adult thumbs, remnants of a flexor perforatus were found in twelve, i.e. bilaterally in six cadavers. This gives the rather surprising proportion of 28·6 % of the total.

Pl. 3, fig. 18, is a photograph of the right hand of one of these specimens. There is no difficulty in identifying the perforatus tendons, not any danger of confusing them with the general fascia in this region. They are intra-vaginal, and are discrete and glistening except at their most proximal and distal extremities. Proximally they fuse with the parietal synovial membrane on either side of the long tendon opposite the metacarpo-phalangeal joint: sometimes they are also loosely attached to the flexor pollicis longus tendon. They unite more distally, deep to the latter, and are inserted as a single slender tendon into the *ulnar* part of the volar aspect of the palmar ligament of the distal joint.

These rudimentary perforatus tendons cannot be traced proximal to the head of the first metacarpal bone and they have no connexion with the flexor digitorum sublimis. This restricted extent is in harmony with observations on the human foetus and on lower mammals.

It is possible that Frazer chanced upon a very transient stage in the development of these perforatus tendons, not present in the foetal specimens investigated here. It is interesting to note that he described these tendons as having distal insertions which we now recognize as identical in position with the accessory polliceal tendons in apes and with the lateral fasciculi of the flexor pollicis longus tendon in the human adult.

SUMMARY AND CONCLUSIONS

1. Lateral fasciculi arise from the deep surface of the flexor pollicis longus tendon and are inserted into the volar surface of the base of the terminal phalanx on each side of the main portion of the long flexor tendon. The discrete nature of the fasciculi is demonstrated by histological section of the tendon, and by a study of their osseous, vascular and synovial relationships.

2. There are strong reasons for believing that the terminal phalanx of the pollex represents a fusion of two phalanges.

3. Reduction of the middle phalanx in little toes showing phalangeal fusion is associated with reduction of the associated flexor perforatus tendon. Under these conditions the flexor perforans tendon commonly provides a tendon or tendons to the base of the conjoined phalanx.

4. Digital perforatus tendons in quadrupeds are often attached to a mobile tendon ring at the level of the metacarpo-phalangeal joint. The tendons which are inserted proximally into this ring come from diverse sources. Sometimes, particularly in marginal digits, the perforatus tendons have no attachment to the flexor digitorum sublimis, the palmaris longus providing the only contractile element to their associated tendon ring. Polliceal perforatus tendons of this nature are occasionally present and extend distally to the terminal joint capsule. The tendon on the ulnar side is commonly larger than that on the radial side.

5. In human foetuses of 3 to $3\frac{1}{2}$ months a polliceal perforatus tendon lies on the ulnar side of the flexor pollicis longus tendon. It extends from the level of the metacarpo-phalangeal joint, where there are traces of a tendon ring, to the capsule of the distal joint. This structure has also been identified in 28·6 % of adult specimens.

6. Vestigial polliceal perforatus tendons are present in some anthropoid apes. They extend from the level of the head of the first metacarpal bone; the ulnar-sided tendon is the larger, more discrete, and more constant than that on the radial side. They decussate with one another dorsal to the flexor pollicis tendon and are inserted into the terminal phalanx in positions occupied in man by lateral tendon fasciculi.

The function of tendon rings clarifies the unusual disposition of human polliceal perforatus rudiments. In the absence of any direct evidence of a palmar tendon from the flexor digitorum sublimis to the pollex, it is suggested that the palmaris longus was probably attached to the tendon ring of this digit in man's forerunners: this is the arrangement of similarly isolated perforatus tendons in quadrupeds. A strong ligamentous band from the palmar aponeurosis in man to the level of the polliceal metacarpo-phalangeal joint would necessarily become attenuated by the development of an independent mobility of this digit. Thus the digital portions of the perforatus tendons would become truly isolated, functionless and eventually vestigial. The proximal parts of the perforatus tendons in the human thumb have undergone this regression. The flexor pollicis longus having utilized the insertions of these tendons to extend its own lower attachments, the distal portions of the polliceal perforatus tendons have become incorporated into the structure of the long flexor tendon as lateral fasciculi.

I should like to thank Prof. G. A. G. Mitchell for his encouragement and criticism in the preparation of this paper.

The animal material examined was generously made available by Prof. F. Wood Jones; Prof. H. A. Harris; Dr E. L. Patterson; Dr W. C. Osman Hill, Prosector of the Zoological Society of London and Dr G. Iles, Curator of the Belle Vue Zoological Gardens.

I am indebted to Miss Marjorie Beck the medical artist, and to the Technical Staff of Manchester University Anatomy Department: to Mr C. K. Pearson for histological work, to Mr P. Howarth for the photography and Mr F. L. Newell for the radiography.

The Medical Research Council has defrayed expenses involved in this study.

REFERENCES

ALBINUS, B. S. (1749). *Tables of the Skeleton and Muscles of the Human Body*, 20th table. (Translation.) London: Knapton.

BARDELEBEN, K. VON (1894). On the bones and muscles of the mammalian hand and foot. *Proc. zool. Soc. Lond.* pp. 345–376.

BICHAT, DE X. (1819). *Traité d'Anatomie descriptive*, 2, 238. Paris: Brosson, Gabon.

BISCHOFF, L. W. (1880). Beiträge zur Anatomie des Gorilla. *Abh. bayer Akad. Wiss.* 13, Abt. 3, 1–48.

BOYER, M. LE BARON (1815). *Traité Complet d'Anatomie*, 4th ed., 2, 299. Paris: Migneret.

BRADLEY, O. C. (1912). *A Guide to the Dissection of the Dog*, p. 135. London: Longmans, Green and Co.

BROCA, P. (1869). L'Ordre des Primates. *Bull. Soc. Anthrop. Paris*, 2nd series, 4, 228–401.

CHEMIN (1896). La synoviale tendineuse. *Bibliogr. anat.* 4, 132–144.

CLOQUET, J. (1822). *Manuel d'Anatomie du Corps Humaine*, p. 195. Paris: Crochard.

DOBSON, G. E. (1882). *A monograph on the Insectivora*, Part 1, pp. 50, 51. London: John van Voorst.

DOUGLAS, J. (1763). *Myographiae Comparatae*, p. 130. London and Edinburgh: Donaldson.

FICK, R. (1895). Vergleichend anatomische Studien an einem erwachsenen Orang-Utan. *Arch. Anat. Physiol., Lpz.*, pp. 1–100.

FICK, R. (1925). Beobachtungen an den Muskeln einiger Schimpansen. *Z. ges. Anat.* 1. *Z. Anat. EntwGesch.* 76, 117–141.

FOURCROY (1785). Mémoire pour servir à l'histoire anatomique des tendons, dans lequel on s'occupe spécialement de leurs capsules muqueuses. *Hist. de l'acad. des Sciences*, 98, 392. Paris.

FRAZER, J. E. (1907). Anmerkung über den Bau und die Entwicklung der Sehne des Flexor longus pollicis. *Arch. Anat. Physiol., Lpz.*, pp. 225–226.

FÜRST, C. M. (1900). Ein Fall von verkürzten und zweigliedrigen Fingern, begleitet von Brustmuskeldefecten und anderen Missbildungen. *Z. Morph. Anthr.* **2**, 56–76.

GALEN (A.D. 131–200). Opera Omnia (1609). *De ossibus*. Tom. 11, Cap. XIX, Class 1 and 2.

GEELVINK, P. (1913). Ueber hyperphalangie. *Arch. Psychiat. Nervenkr.* **52**, 1015–1029.

GRÄFENBERG, E. (1905). Die Entwicklung der Knochen, Muskeln und Nerven der Hand und der für die Bewegungen der Hand bestimmten Muskeln des Unterarms. *Arb. anat. Inst., Wiesbaden*, Heft 90, Bd. 30, Abt. I, 1–150.

GRANT, J. B. (1947). *An Atlas of Anatomy*. 2nd ed. London: Baillière, Tindall and Cox.

GRATIOLET, L. P. & ALIX, P. H. E. (1866). Recherches sur l'anatomie du Troglodytes Aubryi. *Nouv. Arch. Mus. Hist. nat. Paris*, **2**, 1–264.

HAINES, R. W. (1950). The flexor muscles of the forearm and hand in lizards and mammals. *J. Anat., Lond.*, **84**, 13–29.

HEPBURN, D. (1892). The comparative anatomy of the muscles and nerves of the superior and inferior extremities of the anthropoid apes. *J. Anat., Lond.*, **26**, 149–186.

HOWELL, A. B. (1932). The saltatory rodent Dipodomys. *Proc. Amer. Acad. Arts Sci.* **67**, no. 10, 377–536.

HUMPHRY, G. M. (1867). On some points in the anatomy of the chimpanzee. *J. Anat., Lond.*, **1**, 254–268.

HUMPHRY, G. M. (1869). The myology of the limbs of the unau, the aï, the two-toed anteater and the pangolin. *J. Anat., Lond.*, **4**, 17–78.

HUMPHRY, G. M. (1872). *Observations in Myology*, p. 64. Cambridge and London: Macmillan.

HUXLEY, T. H. (1871). *A Manual of the Anatomy of Vertebrated Animals*, p. 335. London: Churchill.

JOACHIMSTHAL (1898). Ueber Brachydactylie und Hyperphalangie. *Virchow's Arch.* **151**, 429–438.

JOACHIMSTHAL (1900). Verdoppelung des linken Zeigefingers und Driegliederung des rechten Daumens. *Berl. klin. Wschr.* **37**, 835–838.

JONES, F. WOOD (1949). *The Principles of Anatomy as seen in the Hand*, 2nd ed. reprint, p. 50. London: Baillière, Tindall and Cox.

JURČIĆ, F. (1906). Ein Fall von Hyperphalangie beider Daumen. *Arch. klin. Chir.* **80**, 562–566.

KRAUSE, W. (1896). Entwickelung der Extremitätenknochen. Bardeleben's *Lehrbuch der Anatomie des Menschen*, Bd. 1, Abt. 3, 77–84. Jena: Fischer.

KRISTJANSEN, A. (1926). Om Hyperphalangia pollicis. *Hospitalstidende*, **69**, 109–119.

KÜKENTHAL, W. (1888). Über die Hand der Cetaceen. *Anat. Anz.* **3**, 638–646.

LANGER, C. (1879). Die Musculatur der Extremitäten des Orang als Grundlage einer vergleichend-myologischen Untersuchung. *S.B. Akad. Wiss. Wien*, Abt. 3, **79**, 177–222.

LAPIDUS, W. P. & GUIDOTTI, F. P. (1943). Tri-phalangeal thumb. *Surg. Gynec. Obstet.* **77**, 178–186.

LUCIEN (1910). Les gaines synoviales carpiennes des fléchisseurs des doigts chez l'homme. *Bibliogr. anat.* **20**, 70–79.

MECKEL, J. F. (1825). *Manuel d'Anatomie*, **2**, 176. Paris: Baillière.

MIVART, ST G. (1881). *The Cat*, p. 150. London: John Murray.

PARSONS, F. G. (1898). The muscles of mammals with special reference to human myology. *J. Anat., Lond.*, **32**, 721–752.

PFITZNER, W. (1890). Die kleine Zehe. *Arch. Anat. Physiol. Lpz.* (*Anat. Abt.*), 12–41.

PFITZNER, W. (1896). Beiträge zur Kenntniss des Menschlichen Extremitätenskelets. *Morphol. Arb. Jena*, **6**, 245–527.

PFITZNER, W. (1898). Ueber Brachyphalangie und Verwandtes. *Vehr. anat. Ges. Jena*, **12**, 19–23.

PFITZNER, W. (1900). Beiträge zur Kenntniss des menschlichen Extremitätenskelets. *Z. Morph. Anthr.* **2**, 365–678.

POIRIER, P. & CHARPY, A. (1901). *Traité d'Anatomie Humaine*, 2nd ed., vol. **2**, Pt. 1, 118–120, 183. Paris: Masson et Cie.

PRIMROSE, A. (1900). The anatomy of the orang outang. *Univ. Toronto Stud. anat.* no. 1.

RETTERER, E. (1896). Sur le développement morphologique et histologique des bourses muqueuses et des cavités péri-tendineuses. *J. Anat., Paris*, **32**, 256–300.

RETTERER, E. (1918*a*). Des gaines digitales péritendineuses de l'homme. *C.R. Soc. Biol., Paris*, **81**, 464–467.

RETTERER, E. (1918*b*). Connexions des tendons du perforé et du perforant du chien, et leur structure fibro-cartilagineuse. *C.R. Soc. Biol., Paris*, **81**, 521–524.

RIEDER, H. (1900). Eine Familie mit dreigliedrigen Daumen. *Z. Morph. Anthr.* **2**, 177–197.

SALZER, H. (1897). Zwei Fälle von dreigliedrigem Daumen. *Anat. Anz.* **14**, 124–131.

SHEPHERD, F. J. (1883). Short notes on the myology of the American Black Bear (*Ursus americanus*). *J. Anat., Lond.*, **18**, 103–117.

SISSON, S. (1910). *A Text-Book of Veterinary Anatomy*, p. 323. Philadelphia and London: Saunders.

SOBOTTA, J. (1948). *Atlas der Deskriptiven Anatomie des Menschen.* Berlin-München: Urban and Schwarzenberg.

SPALTEHOLZ, W. (1901). *Hand Atlas of Human Anatomy.* Leipzig: Hirzel.

STRAUS, W. L. (1942). Rudimentary digits in Primates. *Quart. Rev. Biol.* **17**, no. 3, 228–243.

SUTTON, J. B. (1883). On some points in the anatomy of the Chimpanzee (*Anthropithecus troglodytes*). *J. Anat., Lond.*, **18**, 66–85.

TOLDT, C. (1944). *An Atlas of Human Anatomy.* New York: Macmillan.

VESALIUS, A. (1555). *De Humani Corporis Fabrica.* Lib. 1. De pedis ossibus. De ossibus digitorum manus. Basle: Oporinum.

VROLIK, W. (1841). *Recherches d'anatomie comparée sur le chimpansé*, p. 20. Amsterdam: Müller.

WAKELEY, C. P. G. (1924). Bilateral epiphysis at the basal end of the second metacarpal. *J. Anat., Lond.*, **58**, 340–345.

WELCKER, H. (1884). *Die Morphologische Bedeutung des ersten Daumengliedes.* Separatabdruck aus dem Preisvertheilungsprogramm der Universität, Halle.

WHITTAKER, C. R. (1907). The arrangement of the synovial membrane in the palmar digital sheaths. *J. Anat., Lond.*, **41**, 155–158.

WILKINSON, J. L. (1951). The anatomy of an oblique proximal septum of the pulp space. *Brit. J. Surg.* **38**, 454–459.

WINDLE, B. C. A. (1889). The flexors of the digits of the hand. *J. Anat., Lond.*, **24**, 72–84.

WINDLE, B. C. A. (1891). The occurrence of an additional phalanx in the human pollex. *J. Anat., Lond.*, **26**, 100–116.

WINDLE, B. C. A. & PARSONS, F. G. (1897). On the myology of terrestrial carnivora. *Proc. zool. Soc. Lond.* pp. 370–409.

WINSLOW, J. B. (1733). *An Anatomical Exposition of the Structure of the Human Body.* English translation by G. Douglas. Vol. I, Sect. 3, p. 43. London: G. Bettesworth and C. Hitch.

EXPLANATION OF PLATES

PLATE 1

Fig. 1. The distal insertions of a flexor digitorum profundus tendon. × 1·6.

Fig. 2. The distal insertions of a flexor pollicis longus tendon. *f*, lateral fasciculi. × 1·3.

Fig. 3. The distal insertions of a flexor pollicis longus tendon. *f*, lateral fasciculi. × 1·7.

Fig. 4. Transverse 100 μ sections of the distal 1·5 cm. of a flexor pollicis longus tendon. *f*, lateral fasciculi. Approximate levels of sections: (*a*) head of subterminal phalanx; (*b*) terminal articulation; (*c*) base of distal phalanx. Haematoxylin and eosin. × 5·6.

Fig. 5. Terminal polliceal phalanges. The roughening associated with the insertion of the long flexor tendon has been marked with indian ink in (*a*) and (*b*). The bristles in (*b*) and the arrows in (*c*) indicate the positions of vascular foramina. × 1·1.

Fig. 6. Lateral radiograph of a thumb, flexed at the terminal joint. × 1·1.

Fig. 7. Terminal phalanges of fingers. The roughening for the insertion of the flexor digitorum profundus has been marked with indian ink in (*b*). Note the proximally projecting tips of the tuberositas unguicularis. In (*a*) there is also a spike (*s*) which represents the proximal attachment of the ligament which extends between the base of the phalanx and the tuberositas unguicularis. × 1·2.

PLATE 2

Fig. 8. Radiographs of the distal portion of the lumen of the injected synovial sheath of a flexor pollicis longus tendon. *d*, lateral diverticula of sheath; *m*, mid-line cleft. × 1·3.

Fig. 9. Radiographs of the injected synovial sheath of the flexor tendons of an index finger. *d*, small diverticula where the flexor digitorum sublimis tendons leave the sheath.

Fig. 10. A right little toe with fused phalanges. A groove (*g*) marks the site of fusion of the middle and terminal phalanges. The long flexor tendon provides a fasciculus (*f*) to the base of the conjoined phalanx. × 1·3.

Fig. 11. Distal fusion of flexor tendons in a little toe: phalangeal fusion. *pu*, perforatus tendons. *pa*, perforans tendon. × 1·2.

Fig. 12. Right little toe. The long flexor tendon supplies two fasciculi (*f*) to the middle phalanx. No phalangeal fusion.

Fig. 13. A comparison between the insertion of a flexor pollicis longus tendon (*a*, × 1·5) and the flexor tendons of a little toe (*b*, × 2). Note the similarity in disposition of the lateral tendon fasciculi (*f*) in the thumb and the perforatus tendons (*pu*) in the toe.

Fig. 14. A magnified view of the volar aspect of the left pollex and index of *Mephitis mephitis*. The deep flexor tendons have been cut and retracted distally. *Ppu*, polliceal perforatus tendons; *Ipu*, perforatus tendons of the index; *C*, volar surface of the distal joint capsule. *Pl*, palmaris longus tendons; *Fds*, flexor digitorum sublimis tendon; *Pr*, long flexor tendons of the terminal phalanges. × 5·4.

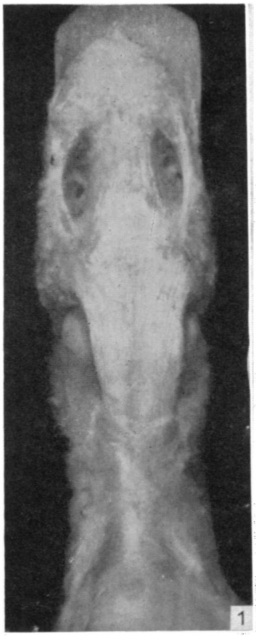
Fig. 15. Diagrams of the tendon rings in the index and pollex of *Mephitis*. Abbreviations as in fig. 14.

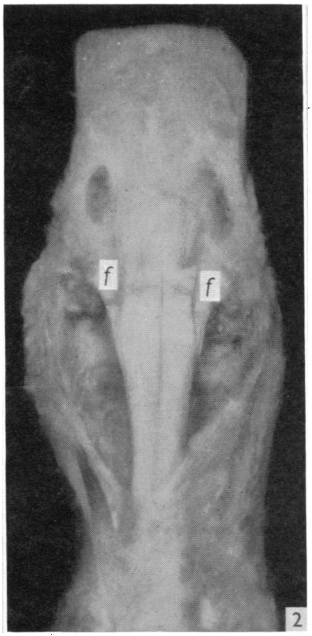
PLATE 3

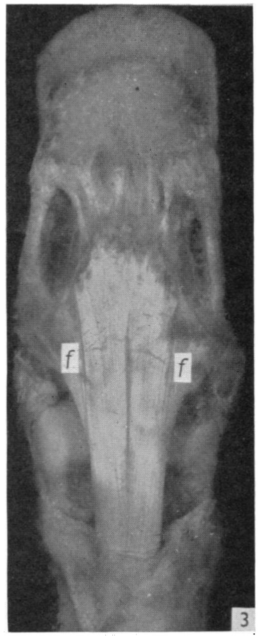
Fig. 16. A dissection of the right pollex and thenar eminence of *Anthropithecus trogolodytes*. *Fpl*, flexor pollicis longus tendon. *Acc*, large ulnar and small radial-sided accessory tendons to the terminal phalanx. *Eaf*, distal extension of the abductor et flexor pollicis brevis. *Eo*, distal extension of the adductor obliquus. × 0·8.

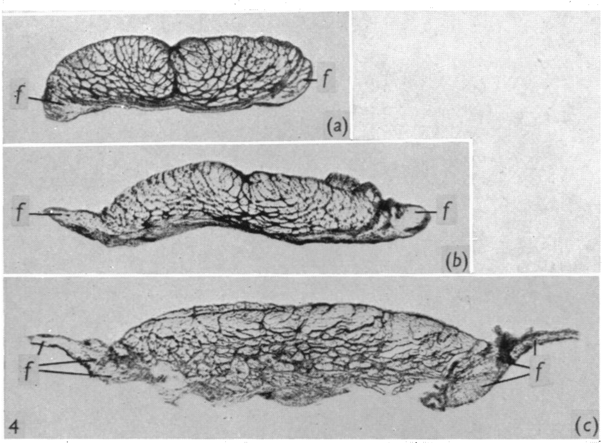
Fig. 17. Transverse 10 μ sections of the right flexor pollicis longus tendon of an 80 mm. human foetus. *Acc*, ulnar-sided accessory tendon. *R*, ring of cells. *P*, proximal phalanx. *M*, first metacarpal. × 46.

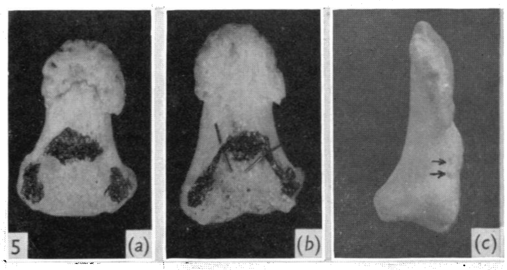
Fig. 18. A rudimentary perforatus tendon (*Pu*) in the right pollex of an adult male cadaver. *Sy*, parietal layer of the synovial flexor sheath.

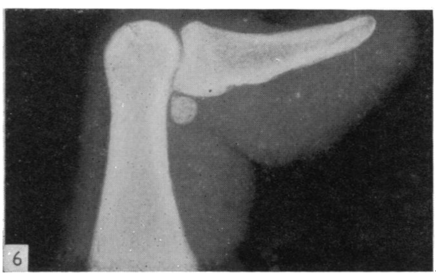


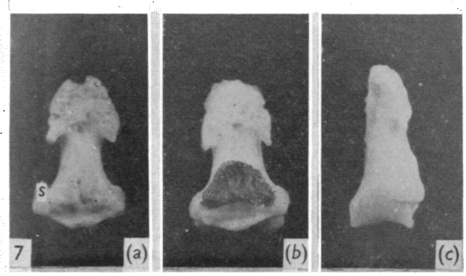




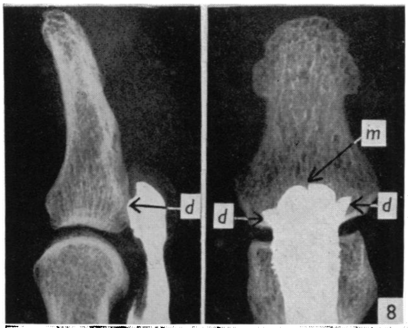


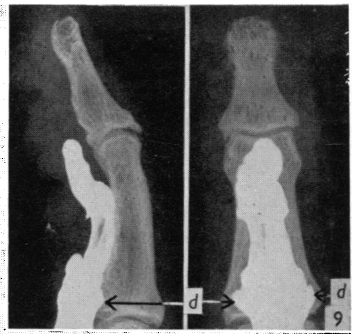


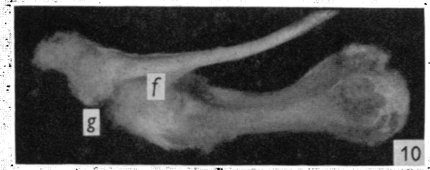


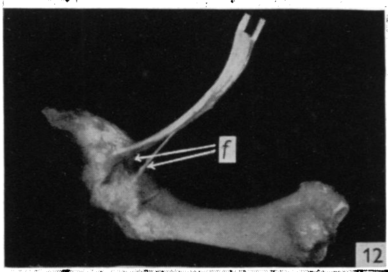


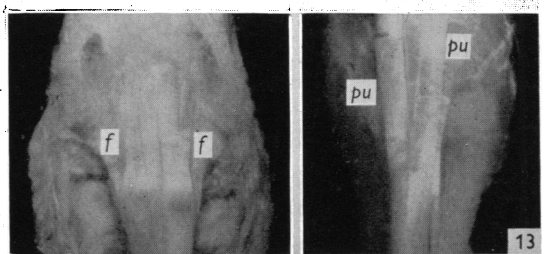
WILKINSON—THE INSERTIONS OF THE FLEXORES POLLICIS LONGUS ET DIGITORUM PROFUNDUS

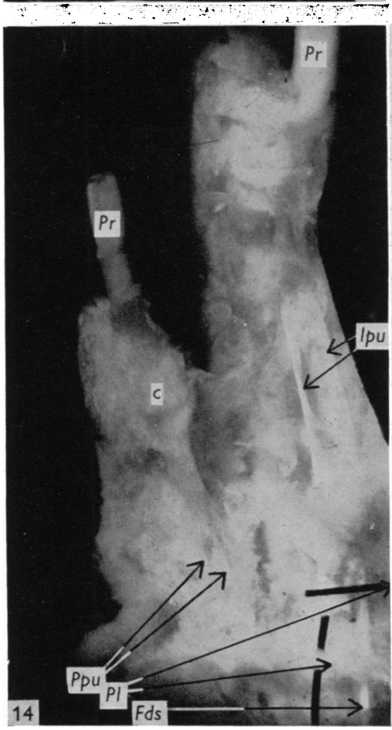


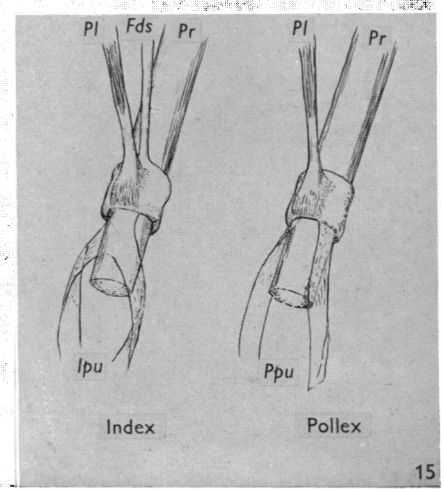




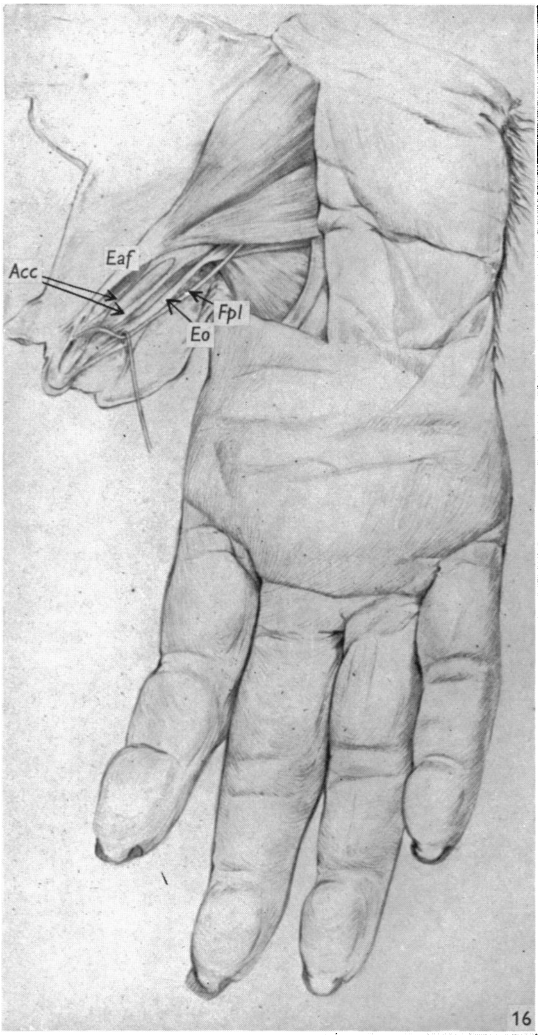


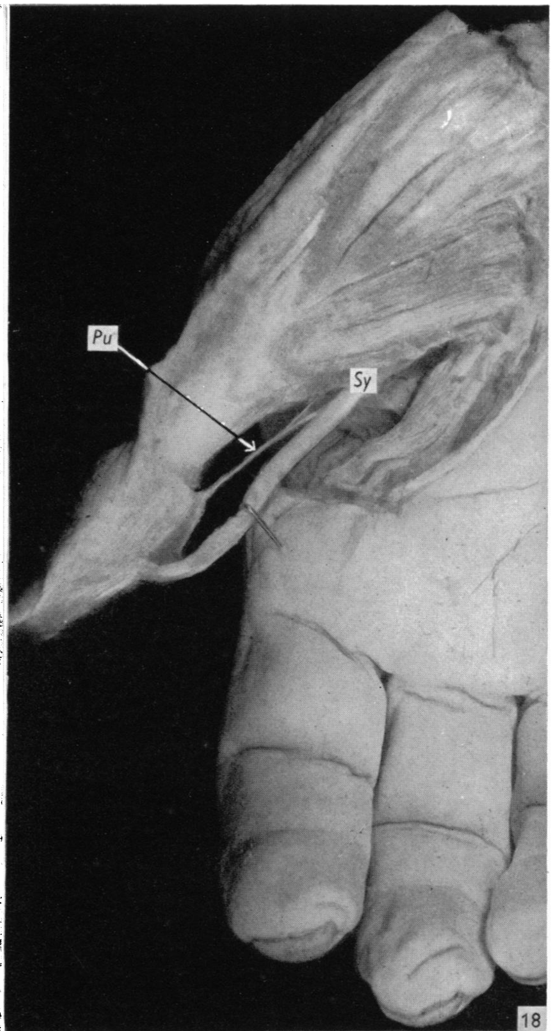


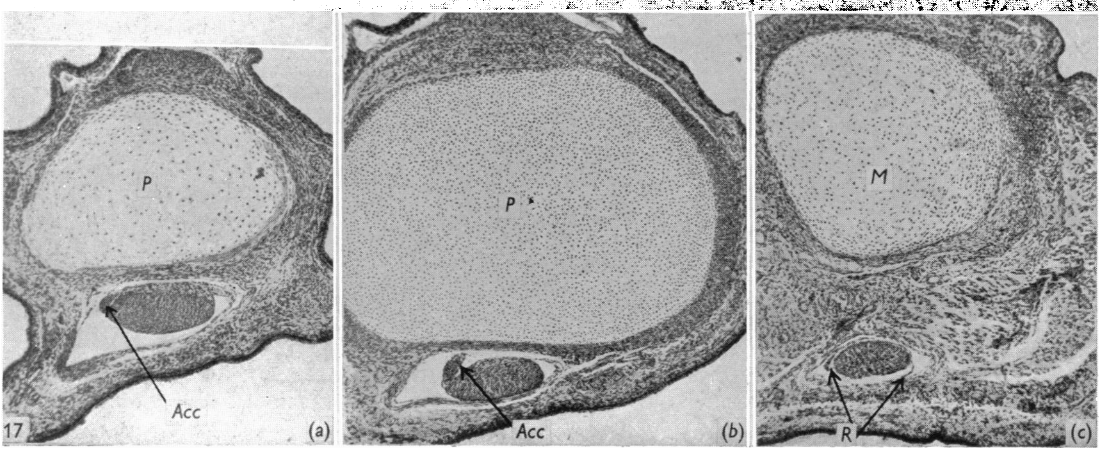




WILKINSON—THE INSERTIONS OF THE FLEXORES POLLICIS LONGUS ET DIGITORUM PROFUNDUS







WILKINSON—THE INSERTIONS OF THE FLEXORES POLLICIS LONGUS ET DIGITORUM PROFUNDUS