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The tibialis posterior tendon in the primate foot

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INTRODUCTION

A striking difference between the feet of man and of other primates is held to be the differing manner of termination of the tibialis posterior tendon. The current phylogenetic interpretation is that provided by Keith (1894, 1929), who maintained that this tendon, like its serial homologue in the forelimb (m. flexor carpi radialis), inserted primitively into the bases of the second, third and fourth metatarsals and that it reached this insertion in primates by passing deep to a ligament spanning the interval between the calcaneal sustentaculum tali and the navicular tuberosity. The human condition was said to have resulted from fusion of this sustentaculo-navicular ligament (part of the primate internal Y-shaped ligament) to the underlying tendon, conferring on m. tibialis posterior a secondary navicular insertion, which Keith (1929) held to be important in the evolution of the longitudinal arch of the foot. It is apparent that a calcaneal attachment must also result from such a mechanism of transfer.

There are, however, difficulties inherent in this view: in those representatives of different mammalian orders in which a relatively unspecialized pedal structure is retained, the tibialis posterior tendon inserts solely into the navicular tuberosity (or into its rodent homologue, the so-called tibial navicular bone). If Keith's view of the primitive insertion is to be accepted, arrangements in all these orders must be convergent to that in man (Lewis, 1962). But in none, however, does the tendon attach also to the sustentaculum tali, and in all the homologue of the primate Y-shaped ligament lies quite freely on the surface of the tendon. At least, therefore, the mechanism of transfer of insertion of the tendon would have to be other than that postulated by Keith. It seems more plausible that the primitive insertion of the tendon is to the navicular tuberosity (or to its separate rodent homologue), and there is considerable evidence suggesting that these bony parts are, in fact, the mammalian representatives of the primitive tetrapod tibiale (Lewis, 1964). If such be, then, the primitive insertion, the primate attachments of the tibialis posterior tendon and their functional significance call for reassessment.

MATERIALS AND METHODS

As an example of a generalized mammalian foot, that of the rat was first studied, and tendon arrangements therein were confirmed in other rodents and in certain unspecialized marsupials. Against an established basic pattern of mammalian pedal structure, the feet of the following primate species were dissected: ring-tailed lemur (*Lemur catta*), brown lemur (*L. fulvus*), Moholi bush-baby (*Galago moholi*), red-handed tamarin monkey (*Mystax midas*), Humboldt's saki (*Pithecia monachus*), weeper capuchin monkey (*Cebus nigrivittatus*), common squirrel monkey (*Saimiri*

sciurea), white-nosed monkey (*Cercopithecus nictitans*), olive colobus monkey (*Procolobus verus*), black and white colobus monkey (*Colobus polykomos*), gibbon (*Hylobates lar*), and chimpanzee (*Pan satyrus*).

Observations were also made upon the termination of the tibialis posterior tendon of *Homo* during the routine dissection of fifty adult feet in this Department.

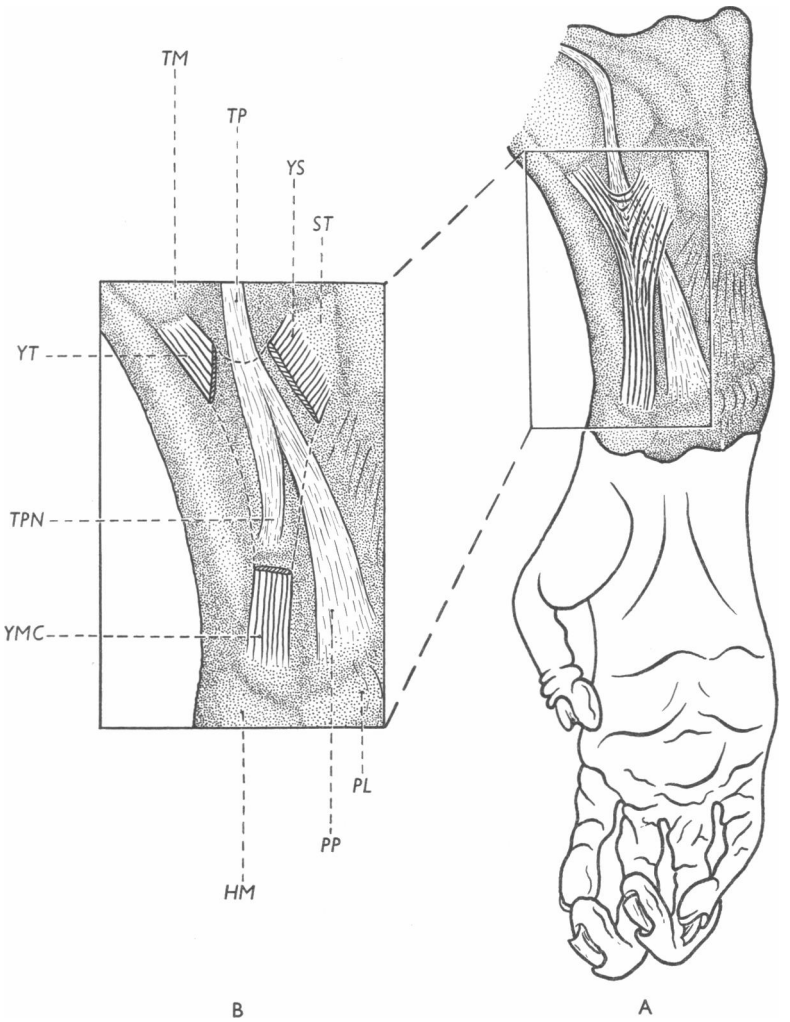

Fig. 1. (A) A diagrammatic representation of the sole of the right foot of *Procolobus verus* illustrating the tibialis posterior tendon and the overlying Y-shaped ligament. (B) An enlarged area of the foot, with part of the Y-shaped ligament removed (broken line) to expose the underlying tibialis posterior tendon. ***HM***, First metatarsal; ***PL***, position of peroneus longus tendon; ***PP***, plantar prolongation of tibialis posterior tendon; ***ST***, sustentaculum tali of calcaneus; ***TM***, tibial malleolus; ***TP***, tibialis posterior tendon; ***TPN***, navicular insertion of tibialis posterior tendon; ***YMC***, attachment of Y-shaped ligament to medial cuneiform; ***YS***, attachment of Y-shaped ligament to calcaneal sustentaculum tali; ***YT***, attachment of Y-shaped ligament to tibial malleolus.

OBSERVATIONS

Mus norvegicus albinus (Fig. 2A)

As in other rodents the navicular is represented by two bony elements—the tibial and fibular navicular bones. The tibialis posterior tendon inserts entirely into the tibial navicular (tibiale). Prior to its insertion the synovial-covered tendon lies deep to a ligament passing from the tibial malleolus to the medial cuneiform bone. This ligament is no mere indefinite fascial thickening but is a very tough, discrete structure which, after entering the sole from its tibial attachment, skirts the lateral part of the tibiale to attach to the medial cuneiform. Its lateral convexity in the sole is in contact with the sustentaculum tali, but without obvious attachment to it.

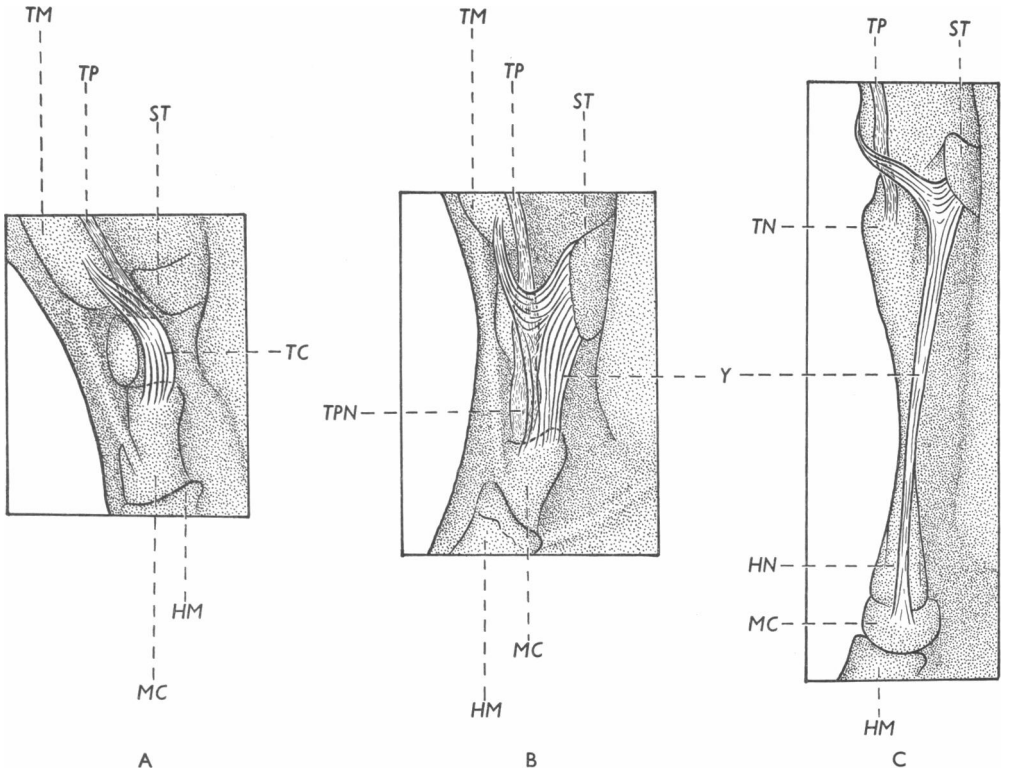

Fig. 2. The arrangements in the sole of the right foot of: A, *Mus norvegicus albinus*; B, *Lemur catta*; C, *Galago moholi*. In each case the region of the foot illustrated corresponds to that shown in Fig. 1 B. *HM*, First metatarsal; *HN*, head of navicular; *MC*, medial cuneiform; *ST*, sustentaculum tali of calcaneus; *TC*, ligament between tibial malleolus and medial cuneiform; *TM*, tibial malleolus; *TN*, tubercle of navicular; *TP*, tibialis posterior tendon; *TPN*, navicular insertion of tibialis posterior; *Y*, Y-shaped ligament.

An essentially similar arrangement is seen in many other rodents and in the more unspecialized of marsupial feet (e.g. *Trichosurus vulpecula* and *Didelphys marsupialis*); in the marsupials the navicular is a single bone with the tibialis posterior tendon inserting into its tuberosity.

Lemur catta (Fig. 2B)

The tibialis posterior tendon inserts entirely into the navicular tuberosity. Its terminal part lies in a synovial-lined tunnel deep to a tough ligament, the typical internal Y-shaped ligament of the primate foot. This ligament, with attachments to tibial malleolus, sustentaculum tali and medial cuneiform, is clearly derived from that noted above in the generalized mammalian foot. By acquiring a secondary attachment between its convexity and the adjacent sustentaculum tali, the simpler structure is converted into a Y-shaped form. It should be stressed that its distal attachment is to the medial cuneiform and not to the navicular, as stated by Keith.

Lemur fulvus

Arrangements in this species are essentially similar to the preceding.

Galago moholi (Fig. 2C)

Tibialis posterior inserts solely into the navicular, in this case to the tuberosity at the proximal end of this greatly elongated bone. There is the usual Y-shaped ligament, but its attachment to the medial cuneiform has been carried far distally by the elongation of the navicular; this lengthened stem of the ligament may be readily mistaken for a tendon. These arrangements bear clear witness to Keith's error in assigning the distal attachment of the ligament to the navicular.

Mystax midas

Arrangements herein are very similar to those in *Lemur catta*. The tibialis posterior tendon is inserted entirely into the navicular tuberosity, and lies, invested by synovial membrane, deep to a typical Y-shaped ligament showing the usual attachments.

Pithecia monachus (Fig. 3A)

Arrangements are similar to those in the preceding species.

Cebus nigrivittatus (Fig. 3B)

Some advance is here noted on the simple arrangement exhibited in the preceding species. The synovial-covered tibialis posterior tendon, lying deep to a typical Y-shaped ligament, inserts mainly into the navicular tuberosity, but its most lateral part blends with the ligamentous investment of the plantar aspect of the tarsus, thus giving rise to an incipient prolongation of the tendon into the central plantar region.

Saimiri sciurea

This species presents a tendon arrangement similar to that of *Cebus nigrivittatus*.

Cercopithecus nictitans (Fig. 3C)

The trend seen as incipient in the preceding two species is here further developed. Deep to the usual Y-shaped ligament, the synovial-covered tibialis posterior tendon inserts partly into the navicular tuberosity; approximately the lateral half of the tendon is, however, prolonged into the central region of the sole where it is finally

attached to the lateral and intermediate cuneiform bones, to the cuboid, to the sheath of the peroneus longus tendon and to the bases of the second, third and fourth metatarsals.

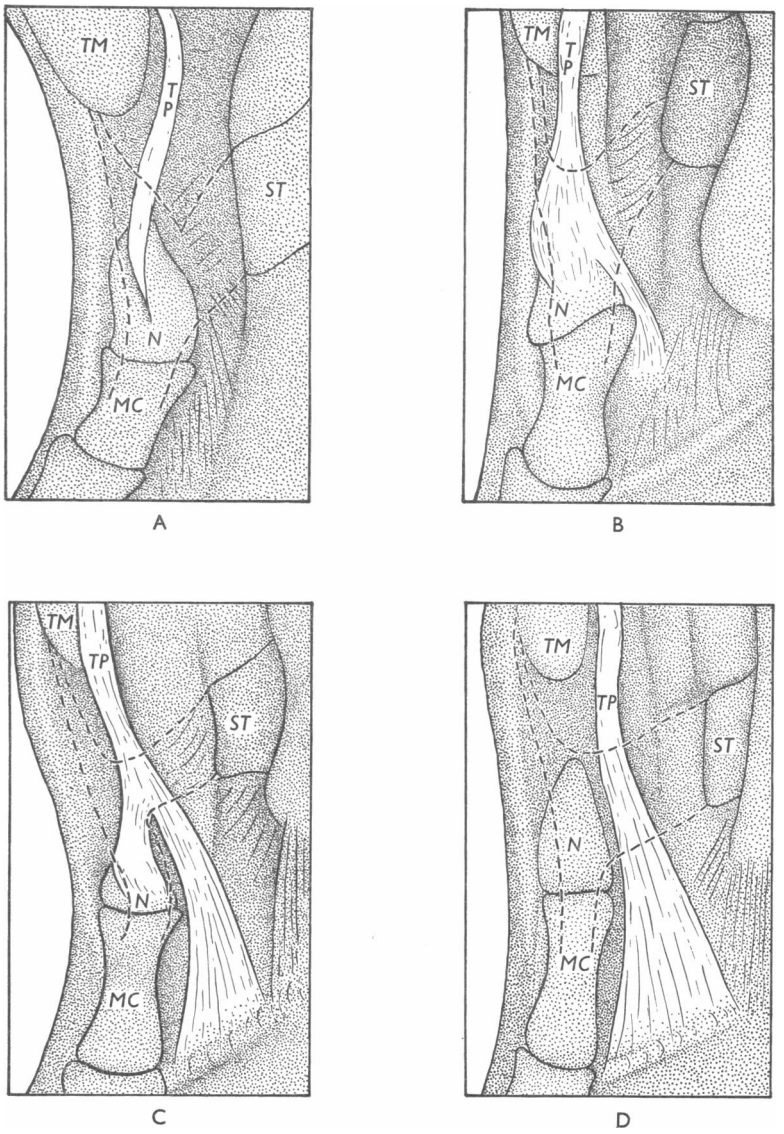

Fig. 3. The arrangements in the sole of the right foot of: A, *Pithecia monachus*; B, *Cebus nigrivittatus*; C, *Cercopithecus nictitans*; D, *Colobus polykomos*. In each case the region of the foot illustrated corresponds to that shown in Fig. 1 B. In each case the position of the overlying Y-shaped ligament, which has been removed, is indicated by the broken line. *MC*, Medial cuneiform; *N*, navicular; *TM*, tibial malleolus; *TP*, tibialis posterior tendon; *ST*, sustentaculum tali of calcaneus.

Procolobus verus (Fig. 1)

Arrangements are essentially similar to those in *Cercopithecus.*

Colobus polykomos (Fig. 3D)

The trend observed in the preceding four species here reaches its culmination. The tibialis posterior tendon is without navicular attachment and is entirely prolonged into the sole, deep to a typical Y-shaped ligament, to obtain an insertion similar to that of the lateral portion of the tendon in *Cercopithecus nictitans.*

Hylobates lar

The arrangements are not unlike those in *Cercopithecus nictitans.* The tibialis posterior tendon attaches partly to the navicular tuberosity but has a lateral portion prolonged into the central region of the sole as far as the bases of the second, third and fourth metatarsals and the sheath of the peroneus longus tendon. The terminal part of the tendon, as usual, is under cover of a Y-shaped ligament; in this species, however, there is a commencing adherence, as yet only partial, between the tendon and the overlying ligament.

Pan satyrus

The arrangements seen here are clearly derivative from a pattern such as that seen in *Hylobates lar.* The tibialis posterior tendon has a considerable primary navicular attachment which is somewhat prolonged forward to the medial cuneiform presumably by the tendon here merging with the ligamentous connexions of the two bones. A lateral part of the tendon is prolonged into the central region of the sole as far as the bases of the second, third and fourth metatarsal bones. The Y-shaped ligament no longer exists as a separate entity; its upper limb from the tibial malleolus is lacking or is incorporated in the anterior fasciculus of the deltoid ligament of the ankle joint, but remains of its lower part, bridging the interval between sustentaculum tali and medial cuneiform, can be clearly recognized as merged with the surface of the tibialis posterior tendon thus giving that tendon a secondary insertion into the sustentaculum tali and the medial cuneiform.

Homo (Fig. 4)

With one additional modification the arrangements are not unlike those in *Pan.* The tibialis posterior tendon has a considerable attachment to the navicular tuberosity (prolonged forward to the medial cuneiform) and also a lateral continuation into the sole. Superficial to this latter prolongation, and thereby merged with the tendon, is a thick tendinous bundle, clearly derivative from the lower sustentaculo-cuneiform part of the Y-shaped ligament, which confers upon the tendon its tough secondary insertion to the sustentaculum tali and a large part of its insertion to the medial cuneiform bone. As in *Pan* the upper band of the Y-shaped ligament is no longer separately identifiable. That prolongation of the tendon entering the sole has attachments which differ from those in *Pan* and which are not in accord with the standard descriptions of most British text-books. A considerable part of it has

become a tendon of origin for the m. flexor hallucis brevis. This tendon is drawn laterally by another attachment to the cuboid and lateral cuneiform bones and their associated ligaments, thus giving the muscle a Y-shaped tendinous origin. Other

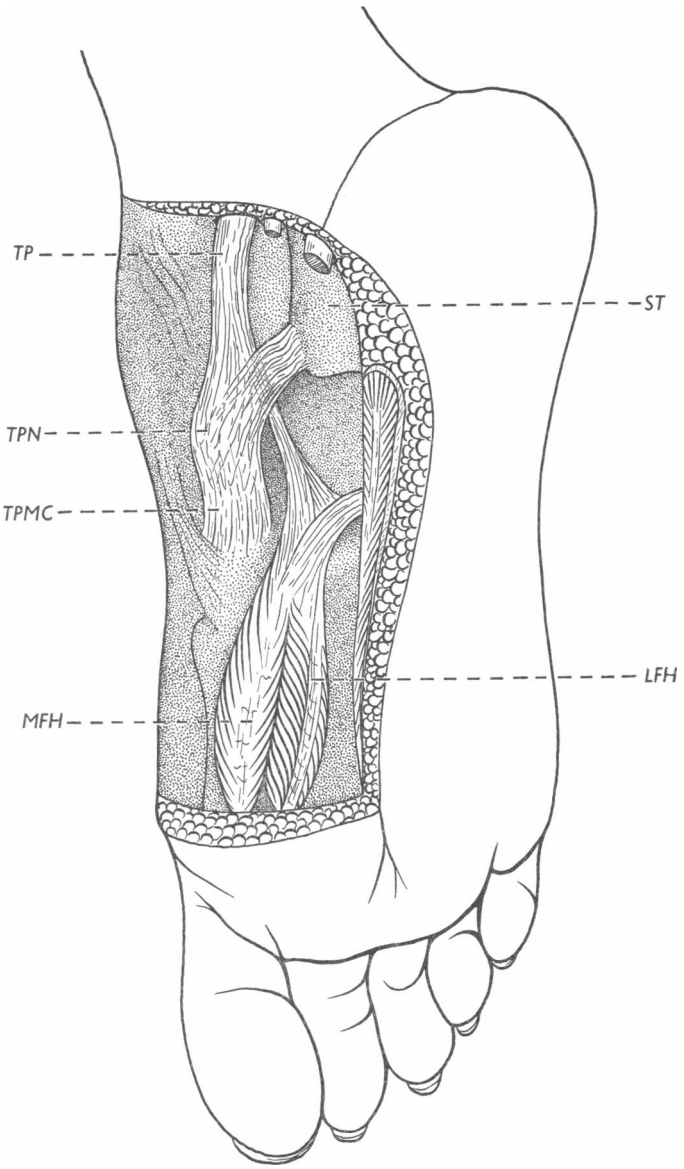

Fig. 4. A diagrammatic representation of the arrangements in the human foot. Note the attachment of the tibialis posterior tendon to the sustentaculum tali and the origin of m. flexor hallucis brevis by a Y-shaped tendon whose medial limb is in continuity with the tibialis posterior tendon. ***LFH***, Lateral head of m. flexor hallucis brevis; ***MFH***, medial head of m. flexor hallucis brevis; ***ST***, sustentaculum tali of calcaneus; ***TP***, tibialis posterior tendon; ***TPN***, navicular insertion of tibialis posterior; ***TPMC***, medial cuneiform insertion of tibialis posterior.

tendinous bundles derived from the lateral portion of the tibialis posterior tendon usually run in the depths of the interval between, on the one hand, the slip in continuity with m. flexor hallucis brevis and, on the other, the navicular and medial cuneiform bones; these bundles insert into the intermediate cuneiform and the bases of the second, third and fourth metatarsals. With minor variations this arrangement is almost constant, being found in forty-six of the fifty feet examined. The taut, tendinous band in continuity with m. flexor hallucis brevis has no attachment to the related bones and ligaments, other than that attachment drawing it laterally. Free movement here is facilitated by a large bursa which is usually interposed between the commencement of the muscular part of flexor hallucis brevis and the underlying structures—medial cuneiform, the first tarso-metatarsal joint and the terminal part of the sheath of the peroneus longus tendon. Another bursa may be found more proximally.

[In most recent British text-books m. flexor hallucis brevis is incorrectly described and illustrated, as merely running obliquely across the sole from a fibular-sided origin from the cuboid, lateral and (perhaps) intermediate cuneiform bones and their ligamentous investments, including here the tendinous attachments of tibialis posterior to these bones. French anatomists, however (e.g. Poirier & Charpy, 1901; Le Double, 1897), have stressed the constant continuity between a part of the tibialis posterior tendon and m. flexor hallucis brevis. Wood (1868) and more recently Kaplan (1955) noted this continuity, but held it to be an anomalous condition; indeed Kaplan thought it was present only in subjects with hallux valgus and that it was a variation predisposing to this condition. The 10th edition of *Quain's Anatomy* (Thane, 1892) described and figured conditions correctly. However, in the 11th edition (Bryce, 1923) both the description and illustration were altered, and the continuity between the tibialis posterior tendon and m. flexor hallucis brevis was omitted. It seems likely that recent British text-book descriptions derive, directly or indirectly, from this later inaccurate version.]

DISCUSSION

It is apparent that the Y-shaped ligament of primates has not appeared as an evolutionary novelty within this order, but is a simple modification of a ligament commonly found in mammals, running from the tibial malleolus to the medial cuneiform. Since its distal attachment is to the medial cuneiform, and not to the navicular, as described by Keith, it cannot be implicated in any mechanism accounting for a shift of the tibialis posterior insertion to the navicular. Keith (1929) incorrectly illustrated the Y-shaped ligament, for the structure he depicted includes in reality two quite separate and distinct primate pedal entities, viz. the true Y-shaped ligament and another ligament, of quite different derivation (Lewis, 1964), which bridges the tibialis anterior insertion between its attachments to the navicular and first metatarsal. In some primates this latter ligament includes an ossicle (prehallux) within its substance.

There can be little doubt that the primitive insertion of tibialis posterior is to the mammalian homologue of the tibiale, represented in most mammals by the navicular tuberosity and in rodents by the tibial navicular bone. Some modification of this

disposition may occur when the foot is narrowed consequent upon digital reduction. For example, in the dog the slender tibialis posterior tendon terminates by merging with the medial ligaments of the tarsus; in ungulates there is a muscle belly in the leg but its tendon fails to reach the sole and merges in the leg with the m. flexor fibularis tendon; in the Macropodidae the whole muscle is lacking. It seems that accounts err which favour an insertion of the tibialis posterior tendon otherwise than into the mammalian homologue of the tibiale in unspecialized mammalian feet—an error due perhaps to a failure to recognize the quite separate identity of the overlying ligament.

In the Prosimii, including the Tupaioidea (Le Gros Clark, 1926), the tibialis posterior retains its primitive navicular insertion. This is also usually the case in New World monkeys, though here some incipient continuity may be established with the ligaments of the tarsus, producing a slight prolongation of the tendon into the central region of the sole (e.g. *Cebus*).

This trend is more advanced in Old World monkeys: the tibialis posterior tendon, where it lies deep to the Y-shaped ligament, attains a dual insertion, attaching to the navicular tuberosity and through a lateral prolongation into the sole to the bases of the second, third and fourth metatarsals. This trend has its maximal expression in *Colobus polykomos* where the navicular insertion is absent. The prolongation of the tendon into the sole presumably enhances the grasping action of the foot by pulling the digital portion against the hallucial portion.

In the Pongidae there is adherence between the Y-shaped ligament and the underlying tendon. This fusion is minimal in *Hylobates* but in *Pan* the sustentaculocuneiform part of the ligament has lost its separate identity by merging with the tibialis posterior tendon, thus carrying that tendon's insertion forward on to the medial cuneiform.

The additional direct continuity which is established in man between the tibialis posterior tendon and m. flexor hallucis brevis may be seen as a uniquely human modification associated with the evolution of an arched, weight-bearing foot. It clearly provides a mechanism for enhancing the contraction of the short hallucial flexor and for projecting the pull of m. tibialis posterior forwards to the metatarsophalangeal joint of the great toe, which is precisely where the pull of an arch-raising muscle is most required; as Hicks (1953) has shown, arch-raising is brought about by flexion of the first ray of the foot accompanied by inversion. The continuity of the two muscles must also be effective in contributing to that elevation of the medial propulsive part of the longitudinal arch of the foot which occurs during extension of the great toe (as in walking) and which adds to the spring of the step. Such continuity then provides an active mechanism for this effect, additional to the passive windlass-like action of the plantar aponeurosis about the first metatarsophalangeal joint, which has been demonstrated by Hicks (1951, 1954).

SUMMARY

1. It is shown that the primate internal Y-shaped ligament, lying superficial to the tibialis posterior tendon, is attached to tibial malleolus, calcaneal sustentaculum tali and medial cuneiform, and is a minor modification of a rather similar structure found in other mammals.

2. It is suggested that the primitive tibialis posterior insertion is into the navicular tuberosity, mammalian homologue of the tibiale.

3. A primitive navicular insertion of m. tibialis posterior occurs in Prosimii and some New World monkeys, but in some species of the latter the tendon presents an incipient lateral prolongation into the sole.

4. In Old World monkeys this lateral plantar prolongation, reaching as far as the bases of the second, third and fourth metatarsal bones, is elaborated and may entirely replace the navicular insertion.

5. In the Pongidae the Y-shaped ligament adheres to the tibialis posterior tendon. This is maximal in *Pan* where the lower limb of the ligament (the only persistent part) is fully coalesced with the tendon, conferring on it additional attachments to sustentaculum tali and medial cuneiform.

6. Arrangements in *Homo* resemble those in *Pan* with the addition of direct continuity between a slip of the tibialis posterior tendon and the m. flexor hallucis brevis.

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