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Short Report

Variations in the quantity of uncalcified fibrocartilage at the insertions of the extrinsic calf muscles in the foot

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ABSTRACT

It has been suggested that fibrocartilage at entheses (tendon–bone junctions) prevents collagen fibres bending at the hard tissue interface. We have investigated this function by exploring the relationship between the presence or amount of fibrocartilage at the attachments of the major extrinsic muscles in the foot, and the extent to which these tendons bend near their entheses during movement. The tendons were taken from each of 5 formalin-fixed dissecting room cadavers and prepared for routine histology, and sections were collected systematically throughout the blocks. Tendons that attached to the tarsus and metatarsus had fibrocartilaginous entheses, but those attached to the phalanges had fibrous entheses. In all tarsal and metatarsal tendons, the fibrocartilage was significantly thicker ($P < 0.05$) in the deepest part of the enthesis. Here the greatest amount of fibrocartilage was in the Achilles tendon (mean thickness ± S.E.M.: 1560 ± 161 μm). There were moderate amounts at the medial cuneiform attachment of tibialis anterior (533 ± 82 μm), peroneus brevis (472 ± 64 μm) and tibialis posterior (454 ± 26 μm), small quantities at the first metatarsal attachment of tibialis anterior (104 ± 14 μm) and peroneus longus (21 ± 8 μm), but only traces at the attachments of the flexor and extensor tendons of the phalanges. The differences can be related to variations in the freedom of movement of the tendons near their attachments. This depends on the extent to which the tendons are bound by retinacula and the range of movement of the joint nearest the enthesis. The results suggest that more 'mobile' tendons have more fibrocartilage. This is in line with the view that enthesis fibrocartilage has a mechanical role in preventing tendon fibres from fraying at bone attachments.

Key words: Tendon; insertion site; enthesis; collagen.

INTRODUCTION

Two types of tendon attachments to bone (entheses) are recognised histologically—fibrocartilaginous and fibrous (Woo et al. 1988; Benjamin & Ralphs, 1995). In fibrocartilaginous entheses, there is a transitional zone of fibrocartilage between the tendon and the bone which is lacking from purely fibrous attachments. Fibrocartilaginous entheses are more common and are most typical of tendons attaching to epiphyses (Benjamin et al. 1986). The function of the fibrocartilage is unclear, but it has been proposed that it prevents tendon fibres bending at the hard tissue interface and thus reduces wear and tear (see Benjamin & Ralphs, 1995, for review). If the fibrocartilage has such a mechanical role, more fibrocartilage might be expected at those entheses where the tendon bends more at its attachment when the muscle contracts. This is so in tendons at the elbow and knee (Evans et al. 1990; Benjamin et al. 1992) where the more 'mobile' tendons are the ones with more fibrocartilage. The purpose of the present study was to investigate further this relation between mobility of a tendon and the quantity of fibrocartilage, by comparing the attachments of the tendons of the extrinsic (calf) muscles in the foot. The mobility of these tendons near their entheses depends on the extent to which they are held by retinacula (which reflects their distance from the ankle joint) and whether tendon movement near the enthesis is uniplanar (phalangeal

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tendons) or triplanar (tarsal and metatarsal tendons; Root et al. 1977).

MATERIALS AND METHODS

The attachments (including tendon and a portion of bone) of the following tendons were taken from each of 5 formalin-fixed dissecting room cadavers (3 males aged 47, 62 and 90 y, and 2 females aged 77 and 79 y) with no gross pathology of the foot. *Tarsal and metatarsal tendons*: Achilles tendon, tibialis anterior to the medial cuneiform, tibialis anterior to the 1st metatarsal, tibialis posterior to the tuberosity of the navicular, peroneus longus to the 1st metatarsal and peroneus brevis. *Phalangeal tendons*: flexor digitorum longus of digit 2, extensor digitorum longus of digit 2, flexor hallucis longus and extensor hallucis.

All the cadaveric specimens were further fixed in 10% neutral buffered formol saline for 7 d, decalcified with 2% nitric acid, dehydrated with graded alcohols and cleared in inhibisol. They were embedded in 58 °C paraffin wax and sections were cut at 8 µm thickness on a Leitz rotary microtome. All the blocks were cut along the long axis of the tendon and at right angles to the bone. In order to ensure systematic random sampling of the blocks, the thickness of each block was measured and 8 sections were collected at each of 10 sampling points spaced at equal intervals throughout the block. This allowed the same number of sections to be collected from tendons of different sizes. Two sections from each sampling point were stained with haematoxylin and eosin, Azan, Masson's trichome, and Alcian blue/direct red.

The sectioned attachment zones were divided into 3 areas of equal size (Fig. 1). These were designated zone X, the deepest part (nearest the 'insertional angle' between the tendon and the bone, as defined in Fig. 1), zone Y, the intermediate part, and zone Z, the superficial part (furthest from the insertional angle). Five measuring points were equally spaced in each of these areas and all measurements were made on a Gillert and Sibert projection microscope at a magnification of × 100. At each point, the thickness of the uncalcified fibrocartilage was recorded by measuring the distance between the tidemark and the furthest recognisable fibrocartilage cell within the tendon. For the purposes of this investigation, a fibrocartilage cell was considered to be a round/oval cell lying in a lacuna and close to cells of similar type. This definition has been applied to our previous work (e.g. Benjamin et al. 1991). Statistical comparisons between the tendons were made using ANOVA and Tukey's pairwise comparisons. These tests are appropriate for the multiple comparisons that were necessary between each tendon and the others.

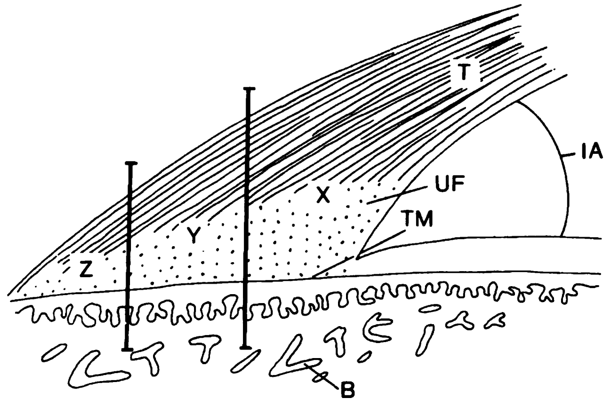
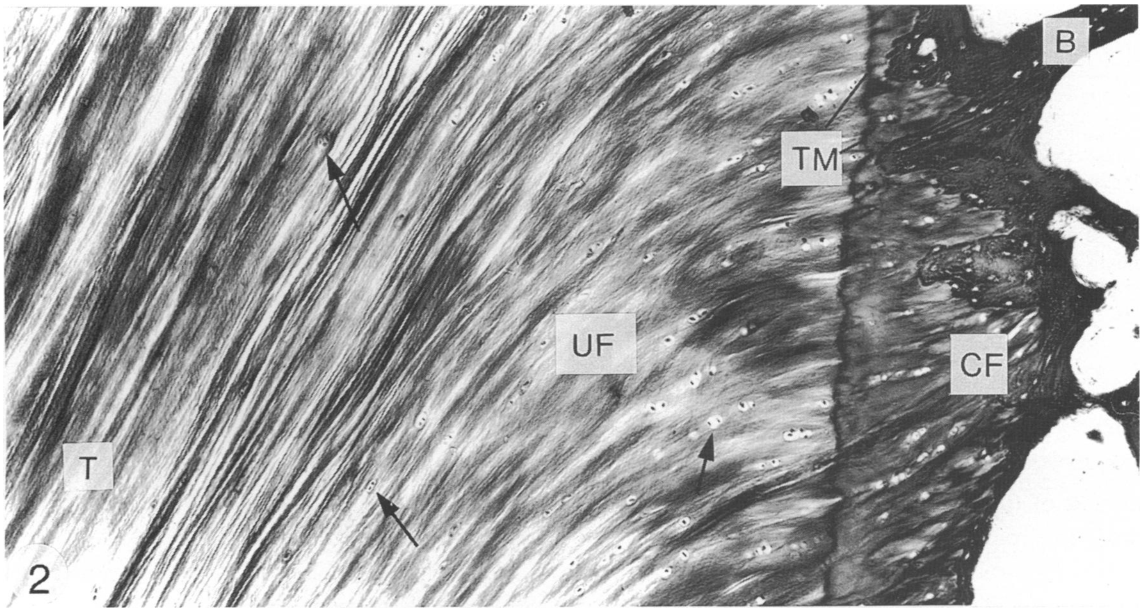


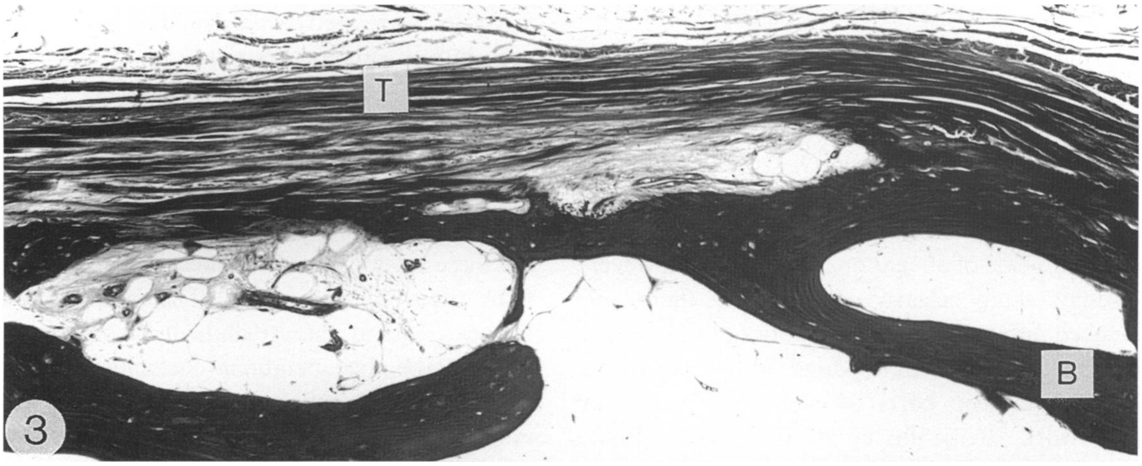
Fig. 1. Protocol for dividing the enthesis into deep (X), intermediate (Y) and superficial (Z) thirds. The thickness of the zone of uncalcified fibrocartilage (UF) was measured from the tidemark (TM) to the furthest recognisable fibrocartilage cell within the tendon (T). B, bone; IA, insertional angle.

RESULTS

The histological variations between the entheses were considerable. The extremes were represented by the Achilles tendon, and extensor hallucis and extensor digitorum longus (Figs 2–4). The Achilles tendon had a fibrocartilaginous enthesis in which attachment occurred via a characteristic sequence of 4 tissues—dense regular connective tissue, uncalcified fibrocartilage, calcified fibrocartilage and bone. In contrast, extensor hallucis/digitorum longus had largely fibrous entheses, except for the occasional isolated fibrocartilage cell.

The thickness of the zones of uncalcified fibrocartilage in the different tendons are summarised in the Table. Tendons that attached to the tarsus and metatarsus had fibrocartilaginous entheses, but those that attached to the phalanges were largely fibrous. The greatest quantity of fibrocartilage was always in the deepest part of an attachment (zone X). In all fibrocartilaginous entheses, there was a gradual diminution throughout the middle and superficial thirds (zones Y and Z) of the attachment zone and always significantly more fibrocartilage in zone X than in zone Z ($P < 0.05$). In the deep part of the enthesis (zone X), there was a significantly thicker zone of fibrocartilage in the Achilles tendon than in any other tendon in the foot ($P < 0.05$). There was also a significantly thicker zone of fibrocartilage ($P < 0.05$) at the medial cuneiform attachment of tibialis anterior, and in peroneus brevis and tibialis posterior, than in peroneus longus, the 1st metatarsal





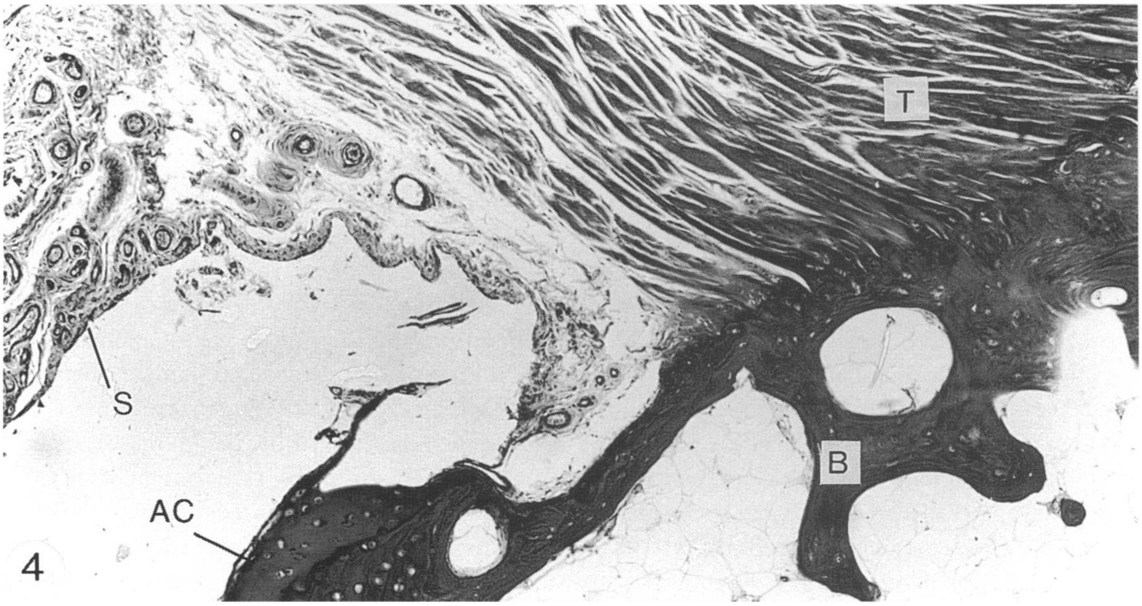


Fig. 2. A characteristic sequence of 4 tissues: T, tendon; UF, uncalcified fibrocartilage; CF, calcified fibrocartilage; B, bone, at the fibrocartilaginous enthesis of the Achilles tendon. TM, tidemark; arrows, fibrocartilage cells. × 70, Masson's trichrome.

Fig. 3. The fibrous enthesis of extensor hallucis longus. Note the absence of fibrocartilage cells. B, bone; T, tendon. × 70, Masson's trichrome.

Fig. 4. The fibrous attachment of extensor digitorum longus to the terminal phalanx of digit 2 immediately distal to the articular cartilage (AC) of the distal interphalangeal joint. B, bone; S, synovial fold; T, tendon. × 70, Masson's trichrome.

Table. *Thickness of fibrocartilage in the deep (X), intermediate (Y) and superficial (Z) parts of each tendon enthesis (mean values [μm] ± S.E.M.). The significance of differences between each tendon and the rest is indicated in brackets*

	X	($P < 0.05$)	Y	($P < 0.05$)	Z	($P < 0.05$)
1. Achilles tendon	1560±161	(2–10)	865±99	(2–10)	348±106	(6–10)
2. Tibialis anterior (medial cuneiform)	533±82	(1, 5–10)	354±16	(1, 5–10)	329±34	(6–10)
3. Peroneus brevis	472±64	(1, 5–10)	267±39	(1, 5–10)	117±33	(6–10)
4. Tibialis posterior	454±26	(1, 5–10)	276±20	(1, 5–10)	233±67	(6–10)
5. Tibialis anterior (1st metatarsal)	104±14	(1–4)	89±25	(1–4)	71±26	(none)
6. Peroneus longus	21±8	(1–4)	13±6	(1–4)	4±2	(1–4)
7. Flexor hallucis longus	0	(1–4)	0	(1–4)	0	(1–4)
8. Extensor hallucis longus	0	(1–4)	0	(1–4)	0	(1–4)
9. Flexor digitorum longus	0	(1–4)	0	(1–4)	0	(1–4)
10. Extensor digitorum longus	0	(1–4)	0	(1–4)	0	(1–4)

attachment of tibialis anterior or any of the tendons attaching to the phalanges.

DISCUSSION

Fibrocartilage at entheses is derived from cartilage of the embryonic bone rudiment and represents that which is left behind after endochondral ossification has occurred (Ralphs et al. 1992). Developmentally, therefore, there is no reason why such fibrocartilage should not be found in all regions of an enthesis and at the attachments of all tendons in the foot. However, the present study clearly shows that there are pronounced differences in the quantities of uncalcified fibrocartilage in different tendons and between the superficial and deep parts of each enthesis. As in previous work (Benjamin et al. 1986, 1991, 1992; Evans et al. 1990, 1991), we have used dissecting room cadavers and have no information relating to young persons. However, the relative differences between one tendon and another are likely to exist at all ages.

The differences between the thickness of fibrocartilage in the different tendons relate well to differences in the extent to which each tendon is free to move near its enthesis. The most mobile tendon (Achilles) has the greatest thickness of fibrocartilage. It attaches directly to the calcaneus without passing beneath any retinaculum, has the greatest change in insertional angle (as defined in Fig. 1) during foot movements and moves in all 3 planes. Other tendons that move in more than one plane (e.g. the tendons of insertion of biceps brachii and supraspinatus; Benjamin et al. 1986, 1992) also have large quantities of fibrocartilage. The least mobile tendons (all those attached to the phalanges) have largely fibrous attachments. Such tendons act on uniplanar hinge joints between the phalanges where there is relatively little movement during gait (Root et al. 1977). It also reflects the distance of the phalangeal tendons from the ankle joint and thus the succession of fibrous tissues needed to bind them down.

The tendons of peroneus brevis, tibialis posterior and tibialis anterior (medial cuneiform attachment) are also associated with triplanar movements, but such movements are restricted by retinacula around the ankle. The presence of retinacula inevitably means that there is a less pronounced change in insertional angle near the enthesis accompanying foot movements —most of the change of direction of the tendon occurs at the retinaculum itself and not at the insertion site. All these tendons have significantly less fibrocartilage than the Achilles tendon. The small amounts of fibrocartilage at the attachment of peroneus longus and at the 1st metatarsal attachment of tibialis anterior could reflect the greater restriction on mobility placed on these tendons than on the other tarsal or metatarsal tendons examined. Peroneus longus is held by 2 retinacula and passes through a fibrous tunnel on the plantar surface of the foot. Mobility near the metatarsal enthesis of tibialis anterior is restricted by the more proximal attachment of the tendon to the medial cuneiform, i.e. the proximal attachment anchors the distal one. The distributional differences between fibrocartilage in the deep and superficial third of an enthesis probably relate to the compression exerted on the deep fibres by those forming the rest of the attachment.

It must also be considered that the differences in the quantity of fibrocartilage in the different tendons examined in this study could reflect differences in tendon size or shape rather than mobility. Fibrocartilage was more characteristic of large rounded tendons than smaller flat ones. The greatest thickness of fibrocartilage was in the largest tendon (Achilles). However, the correlation between the size or shape of a tendon and the quantity of enthesis fibrocartilage is not good in tendons elsewhere in the body. At the elbow, there is substantially more fibrocartilage at the insertion of biceps brachii than triceps or brachialis, even though biceps is the smallest tendon (Benjamin et al. 1992). There is also significantly more fibrocartilage at the enthesis of triceps than brachialis despite the flattened shape of the former. Finally, there are pronounced differences between the two ends of the patellar tendon that relate clearly to differences in mobility but cannot be correlated with differences in tendon size or shape (Evans et al. 1990).

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