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The histology of tendon attachments to bone in man

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INTRODUCTION

It is commonly reported in anatomy texts that some tendon attachments leave well-defined, smooth areas on dried bones, that resemble articular surfaces (Warwick & Williams, 1973). We have failed to find any convincing explanation for this similarity, as few authors have compared the features of different tendon attachments in man or correlated microscopic with naked eye appearances.

Much of the literature on the histology of tendon attachments is in German and unknown to many English anatomists. The works of Dolgo-Saburoff (1929) and Schneider (1956) are particularly valuable as they established a useful model for the histology of tendons attached to epiphyses. At such attachment sites there are four zones: (1) tendon, (2) fibrocartilage, (3) calcified fibrocartilage, (4) bone. Some authors, the most influential of whom was Schaffer (1930), referred to tendon 'fibrocartilage' as one of four varieties of chondroid tissue, for they did not view it as true cartilage. Beresford (1981) regards the zone of calcified fibrocartilage as Type II chondroid bone ('grone' II) and equivalent to the metaplastic bone of Haines & Mohiuddin (1968).

Biermann (1975) and Knese & Biermann (1958) distinguished between three types of muscle attachments: (1) Those attached by tendons to cartilaginous apophyses, e.g. the attachment of iliopsoas to the lesser trochanter. An apophysis (Greek *apo* = from, and *physis* = growth; a term which is now largely obsolete) can be any marked bony process and thus a 'cartilaginous' apophysis is presumably one where a cartilaginous outgrowth has preceded the bony one. Apophyseal tendons include the epiphyseal tendons of Schneider (1956). (2) Two types of diaphyseal attachments: (*a*) those with fleshy attachments to the periosteum (*die flachenhaften Ansätze*), e.g. the fleshy origin of infraspinatus, and (*b*) those with circumscribed tendinous attachments to bony crests, ridges and prominences (*die zirkumskriften Ansätze*), e.g. the insertion of deltoid. Although cartilage may be present at circumscribed diaphyseal attachments, it is not as prominent as in apophyseal tendons.

Many of the tendons that leave smooth markings on bones are epiphyseal (e.g. those of the rotator cuff, the common flexor and extensor origins, popliteus and the two heads of gastrocnemius). We have therefore investigated the hypothesis that it is the presence of fibrocartilage at the attachment of these tendons that determines the smoothness of their markings on dried bones. The opportunity is also taken to comment on the functional significance of fibrocartilage in the tendon of supraspinatus.

MATERIALS AND METHODS

Specimens were taken from dissecting room cadavers of both sexes (ages 47–90) that did not show obvious signs of arthritis in the joints or bones concerned. All the cadavers had been embalmed with adducted limbs. One to five samples of each of the tendons listed in Table 1 were taken, together with a small fragment of the bone to which they were attached. In addition, two samples each were taken from formalin-fixed, cleaned and dried bones, of the head and capitulum of the humerus and the sites of the tendon attachments listed in Table 1. In all cases, we ensured that the appearance of the attachment sites corresponded with the classic descriptions in the standard anatomy texts.

The formalin-fixed specimens were further treated with 10% neutral buffered formalin, decalcified in 5% nitric acid, dehydrated with graded alcohols, cleared in methyl salicylate or Inhibisol and embedded in 56 °C paraffin wax. Serial sections were cut on an MSE sledge microtome, at 8 μm, along the long axis of the tendon, and at right angles to the bone. Six sections were mounted every 1 mm throughout each specimen and stained with Ehrlich's haematoxylin and eosin, Masson's trichrome and azan.

Thin, ground sections of a few samples of dried bones were stained by the von Kossa method for calcium salts.

RESULTS

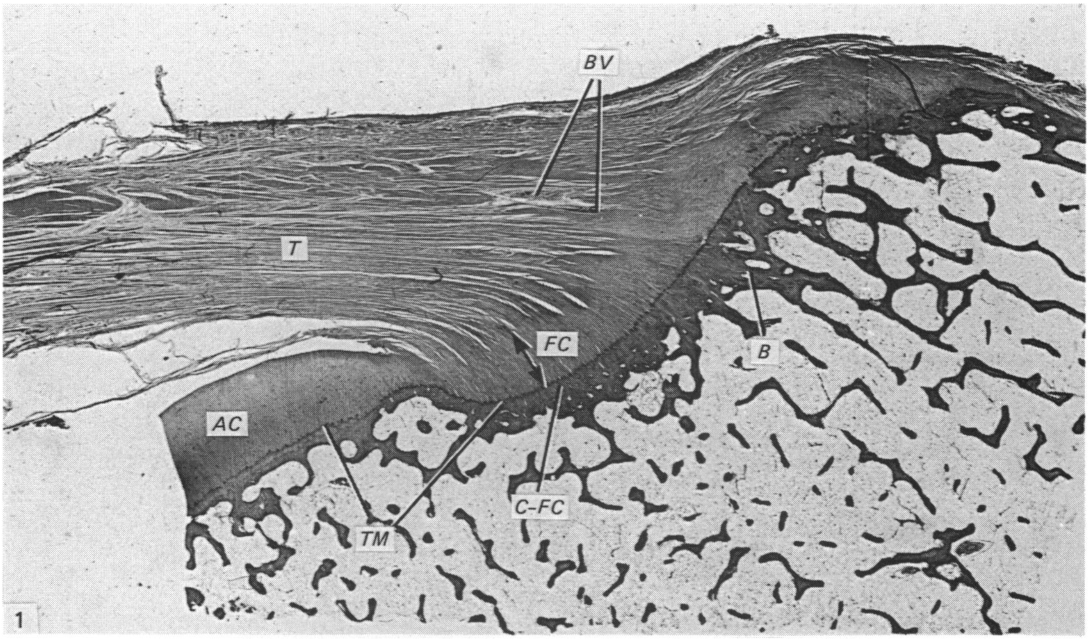
General features

Tendons with a prominent plug of fibrocartilage at their bony attachment sites share certain histological features (Fig. 1). There are four zones as listed in the Introduction. In the zone of uncalcified fibrocartilage, chondrocytes and cartilage matrix lie between bundles of collagen fibres that enter it from the tendon zone. Although no serial sections of injected specimens were prepared, it is our impression that the zone of uncalcified fibrocartilage is avascular (Fig. 1). Between the calcified and non-calcified fibrocartilage are one or more prominent basophilic lines (*Grenzlinie*, tidemark, cement line or blue line) that mark the outer limit of calcification. On occasions the lines are irregular, but they generally provide a much smoother contour than that at the osteochondral junction (Fig. 2).

Chondrocytes are most numerous on the muscle side of the tidemark and are often arranged in short rows. Bundles of collagen fibres are recognisable up to the osteochondral junction (Fig. 2). When fibrocartilage is present at a tendon attachment site, a periosteum is lacking.

Fig. 1. The insertion of supraspinatus shows certain features that it shares with other tendons that have a prominent plug of fibrocartilage at the attachment site. There are four zones – tendon (*T*), uncalcified fibrocartilage (*FC*), calcified fibrocartilage (*C–FC*) and bone (*B*). Blood vessels (*BV*) are absent from the fibrocartilage zones. The tidemark (*TM*) between the calcified and uncalcified zones of articular cartilage (*AC*) is continuous with that at the insertion of the tendon. Haematoxylin and eosin. × 9.

Fig. 2. Between the zones of uncalcified (*FC*) and calcified (*C–FC*) fibrocartilage there are prominent blue lines (tidemarks) (*TM*). Rows of chondrocytes are more numerous in the uncalcified fibrocartilage (arrows). The collagen fibres meet the tidemark approximately at right angles and are recognisable up to the irregular osteochondral junction (*J*). *B*, Bone. Supraspinatus. Haematoxylin and eosin. Green filter. × 200.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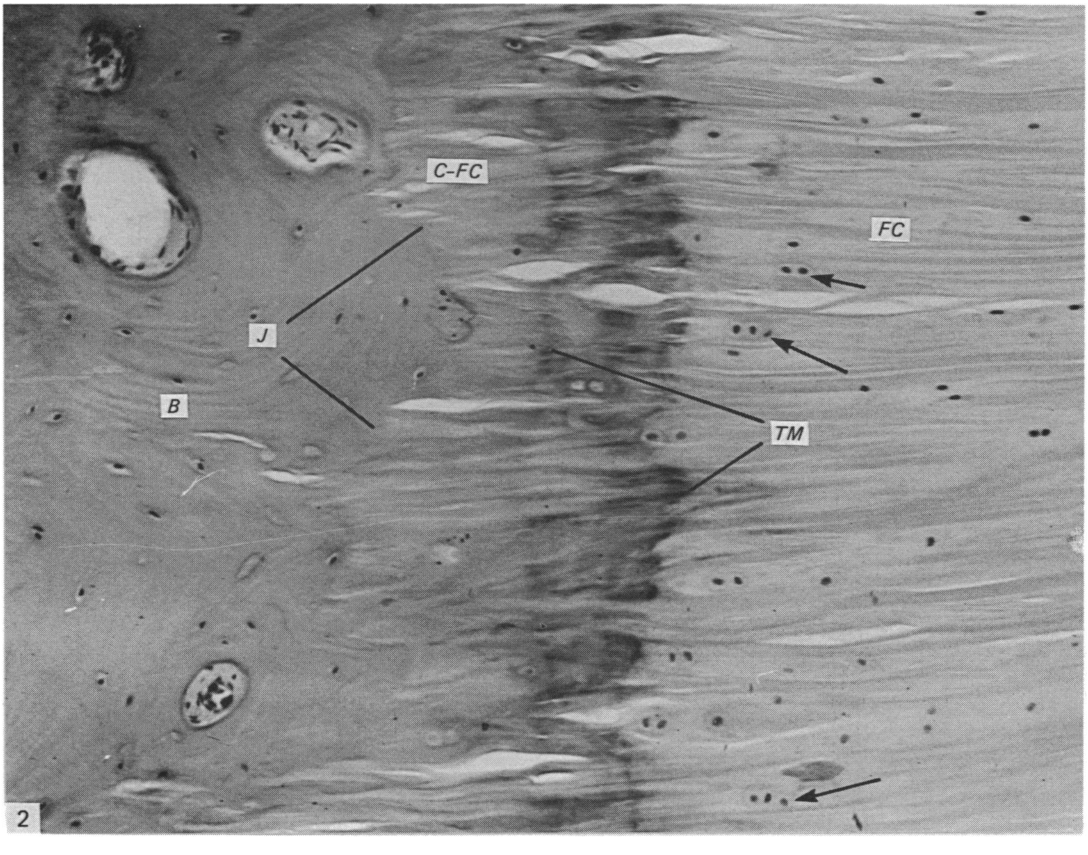
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Table 1. *A survey of the histology of human tendons and their attachment sites on human bones*

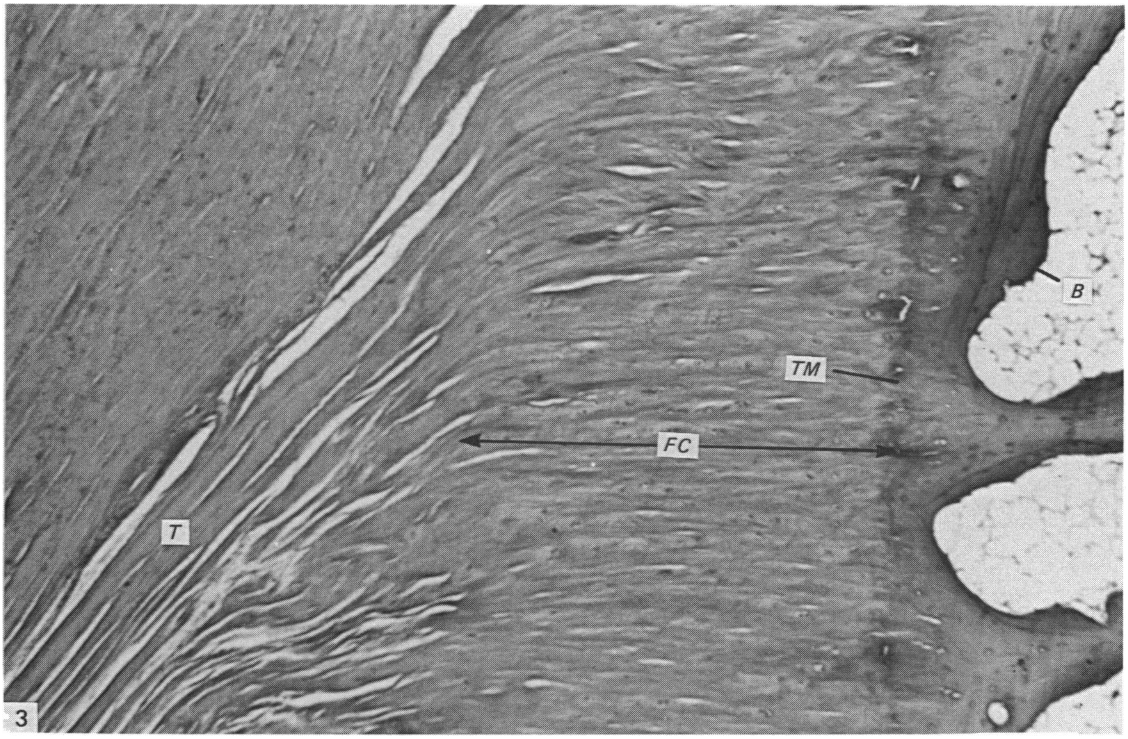
Specimen	Origin (O) or insertion (I)	Calcified and non-calcified fibro-cartilage (+/−)	Calcified cartilage remaining after maceration
Long bones – epiphyseal and metaphyseal attachments			
Supraspinatus	I	+	+
Infraspinatus	I	+	+
Teres minor	I	+	+
Subscapularis	I	+	+
Biceps brachii	I	+	+
Triceps	I	+	+
Brachialis	I	+	+
Brachioradialis	I	+	
Common flexor	O	+	+
Common extensor	O	+	
Abductor pollicis brevis	I	+	
Popliteus	O	+	+
Iliopsoas	I	+	+
Semimembranosus	I	+	+
Adductor magnus (hamstring portion)	I	−	
Gastrocnemius (lateral head)	O	+	
Gastrocnemius (medial head)	O	+	
Anconeus	O		+
Long bones – diaphyseal attachments			
Deltoid	I	−	
Pronator teres	I	−	
Triceps (lateral head)	O		−
Teres major	I		−
Pectoralis major	I		−
Latissimus dorsi	I		−
Other bones			
Extensor carpi radialis longus	I	+	
Pectoralis minor	I	−	
Long head of biceps	O	+	
Long head of triceps	O	+	
Flexor carpi ulnaris	I	+	

Survey of tendon histology

Table 1 shows that tendons attached to the ends of long bones generally have plugs of fibrocartilage at their attachment sites. However, the amount of fibrocartilage can vary both between tendons and from one part of a tendon to another. At the insertion of supraspinatus, the zone of uncalcified fibrocartilage is thinner laterally. In the tendons of teres minor and subscapularis, there is more fibrocartilage superiorly than inferiorly, and in brachialis and abductor pollicis brevis there is more proximally than distally. Thus, the fibrocartilage is most obvious in that portion of a tendon nearest

Fig. 3. At the insertion of supraspinatus, the collagen fibres of the tendon (*T*) (in bodies fixed with adducted limbs) largely bend above the level of the uncalcified, fibrocartilage plug (*FC*) and only slightly within it. *B*, Bone; *TM*, tidemark. Haematoxylin and eosin. Green filter. × 60.

Fig. 4. The insertion of deltoid. The collagen fibres (*C*) run almost parallel to the bone surface (*B*). *TM*, Tidemark. Haematoxylin and eosin. Green filter. × 200.



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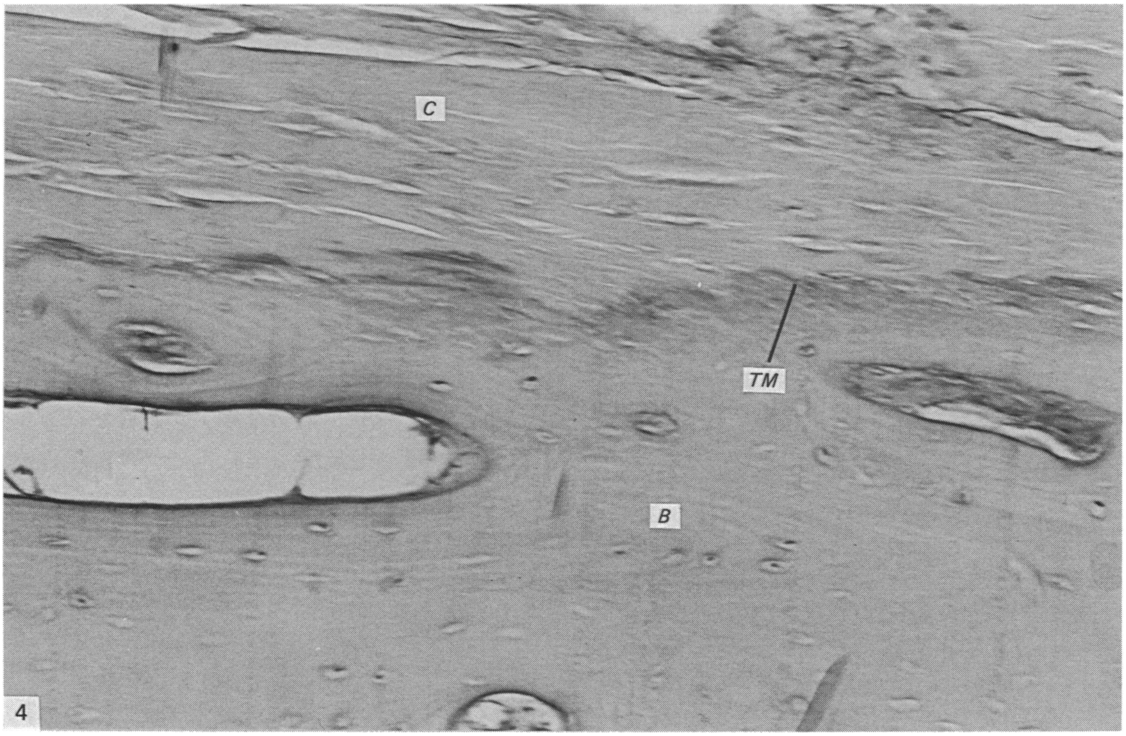

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the joint it crosses. In the tendons of popliteus and the common flexor origin (which are attached to pits), there is more fibrocartilage in the centre of the pit than peripherally.

In thick plugs of fibrocartilage, the collagen fibres often meet the tidemark approximately at right angles. This is particularly well shown in the tendon of supraspinatus, where there is an abrupt change in angle just before the tendon becomes fibrocartilaginous and only a gradual change within the tissue (Fig. 3). In supraspinatus, some tendon fibres are cut transversely in a sectional plane that cuts the majority of fibres longitudinally (see Fig. 9 of Codman, 1934). Whether such fibres belong to supraspinatus or to another rotator cuff muscle is unclear to us, though Codman (1934) thinks they belong to infraspinatus.

Where fibres enter hard tissues directly, either as parts of a tendon that has fibrocartilage elsewhere, or in those that are largely devoid of any cartilage (as is the case with pronator teres and deltoid, the tendons of which contain only small amounts of fibrocartilage – see Table 1), the collagen fibres approach the bone at acute angles (Fig. 4). Despite the virtual absence of fibrocartilage from such tendons, a tidemark still denotes the outer limit of calcification.

In tendons whose attachments are particularly close to an articular surface (such as the tendons of the rotator cuff), the zones of fibrocartilage are continuous with the periphery of the articular cartilage. On the humeral head, the articular cartilage is fibrocartilaginous at its periphery and its tidemark is continuous with that in the tendons of the rotator cuff (Fig. 1).

Dried bones

In eleven tendons with fibrocartilage at their attachment sites, the underlying zone of calcified fibrocartilage remains attached to the bone after maceration of the soft tissues (Table 1). This persistent zone is clearly demonstrated by azan staining – it is predominantly blue and the subchondral bone red (Fig. 5). However, the calcified fibrocartilage is also visible in haematoxylin and eosin sections (Fig. 6). In specimens of ground bone, the zone stains positively for calcium salts with the von Kossa reaction. Without exception, the tendons disrupt at a tidemark, for this is the most superficial feature of the dried specimens (Fig. 6).

In addition, the insertion sites of deltoid and pronator teres were examined on dried bones. The corresponding tendons contain little or no fibrocartilage (Table 1) and calcified fibrocartilage is absent from the bony samples.

As dried bones proved a reliable guide for identifying tendons with prominent zones of fibrocartilage, a number of other attachment sites were examined – it is far simpler to cut sections of dried bones than to cut tendon-bone specimens from the dissecting room. Tendons that attach to diaphyses and produce rough markings on

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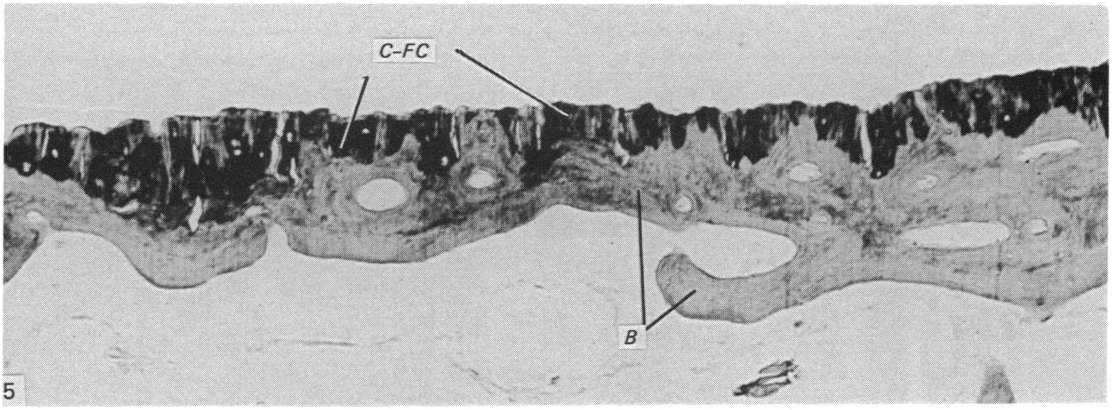
Fig. 5. Calcified fibrocartilage (*C–FC*) remains as a part of the hard skeleton on the humeral facet for supraspinatus after maceration of the soft tissues. *B*, Underlying bone. Azan. Red filter. × 60.

Fig. 6. The facet for the tendon of subscapularis separates at the tidemark (*TM*) after maceration leaving the zone of calcified fibrocartilage (*C–FC*) as a part of the hard skeleton. The irregular osteochondral junction is indicated by a broken line and the deeper bone (*B*) is slightly darker staining. The fuzzy material superficial to the tidemark is where the albumen coating the slide has been stained. Haematoxylin and eosin. Green filter. × 110.

Fig. 7. Calcified cartilage (*CC*) remains on the humeral head after maceration. *B*, underlying bone. Azan. Red filter. × 60.



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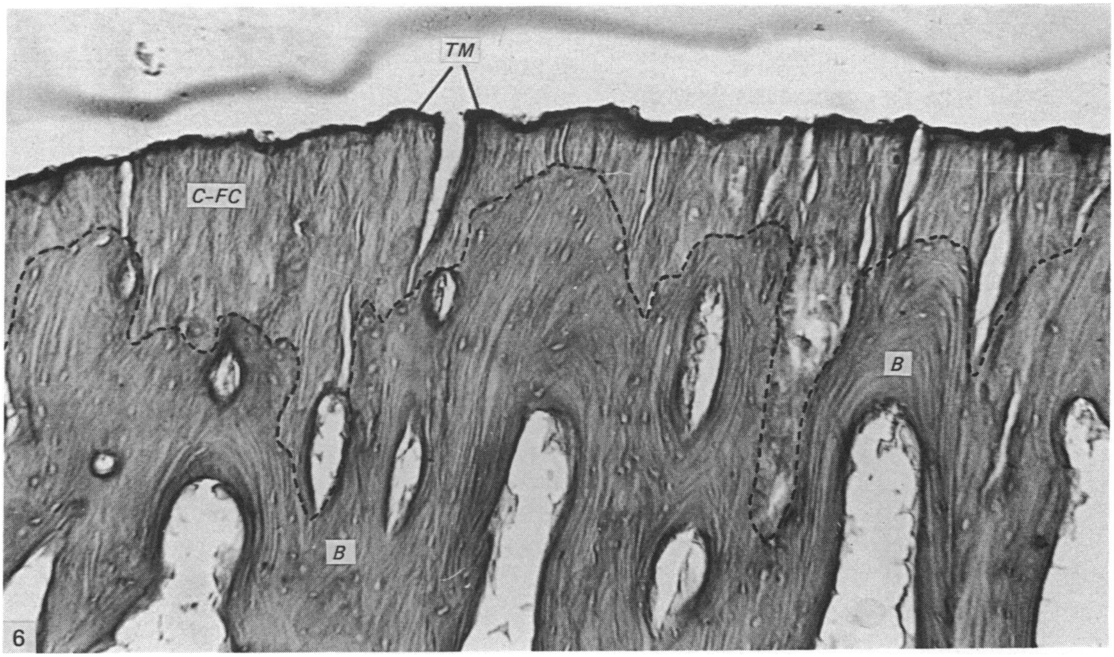

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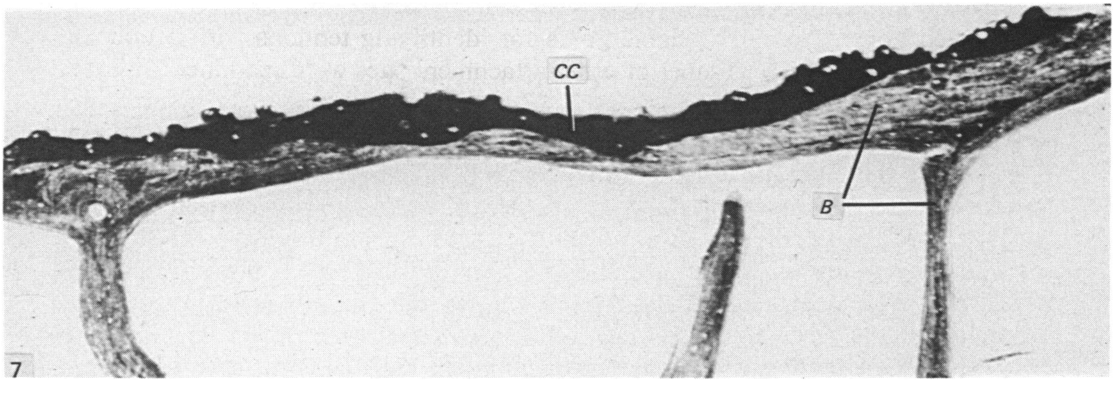

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long bones were chosen in particular. These samples included the attachment sites of the origin of the lateral head of triceps and the insertions of teres major, pectoralis major and latissimus dorsi (Table 1). No calcified fibrocartilage was found in any of these specimens. However, in the smooth and pit-like facet on the humerus corresponding to the site of origin of anconeus, calcified fibrocartilage was obvious (Table 1).

In the portions of the humeral head and the articular surface of the capitulum taken from dried bones, calcified cartilage remained after maceration (Fig. 7) and the articular cartilage separated at the tidemark.

DISCUSSION

The soft tissue specimens came from a number of dissecting room cadavers. No particular selection was used, other than avoiding damaged or pathological specimens. Thus, our findings can be reasonably interpreted as applying to normal, mature adults and elderly individuals, but we have no information obtained from young persons.

The observations reported here support the contention of Schneider (1956) that tendons attached to epiphyses have fibrocartilage at their attachment sites. Schneider (1956) has suggested that since the outer surface of an epiphysis remains cartilaginous for much longer during growth than does the diaphysis, epiphyseal tendons retain traces of their previous insertion into cartilage as a fibrocartilaginous disc. It is interesting therefore that we found a thick disc of fibrocartilage in the epiphyseal part of the insertion of teres minor but little on the part that inserts on the neighbouring metaphysis. On the other hand the presence of small amounts of fibrocartilage in the insertions of deltoid and pronator teres indicates that this tissue can develop secondarily at circumscribed diaphyseal attachments. Knese & Biermann (1958) suggested that chondrification can extend into a tendon by transformation of tendon cells into chondroblasts. There seems no reason why this should not happen at epiphyseal as well as diaphyseal attachments.

The sites of tendon attachment where we have observed substantial fibrocartilage have a characteristic appearance on dried bones. The surface of the bone is smooth although not necessarily flat, it is free of vascular foramina and the colour and texture are more like those of an articular surface than the areas of bone covered by periosteum.

In our opinion, those epiphyseal tendons that leave smooth markings on normal bones do so because (*a*) the prominent zone of fibrocartilage at their attachment sites is associated with a junction between hard and soft tissues (the 'tidemark') that is less jagged than the underlying osteochondral junction, (*b*) calcified and noncalcified tissues separate at a tidemark, whether or not there is fibrocartilage near the surface. It is not possible to say whether the tissues separate *through* the tidemark or immediately above it, or whether some lines are lost where there are multiple tidemarks. The regularity of the tidemark gives the smooth appearance of the marking on the dried bone. Similarly, the uncalcified area of articular cartilage separates from the deeper calcified cartilage at the tidemark, to leave the surface smooth. Haines & Mohiuddin (1968), also observed that the calcified cartilage persists in the dried skeleton "...as a hard layer which smoothes out the rough surface of the lamellar bone...". The presence of calcified cartilage at both sites explains the similar appearance of articular surfaces and certain tendon facets (Warwick & Williams, 1973; Romanes, 1981).

Boyde & Jones (1982), who were interested in the properties of the tidemark beneath articular cartilage, succeeded in exposing it for scanning electron microscopy by removing the uncalcified tissue with, for example, sodium hypochlorite and sodium hydroxide. Under these conditions the tidemark on the adult femoral head seemed very rough. Interestingly, they could find no means of separating the calcified cartilage from bone. Horizontal splits between the uncalcified and calcified layers of articular cartilage on the patella were commonly found by Meachim & Bentley (1978) at necropsy.

We would support the observation of Haines & Mohiuddin (1968) that 'metaplastic bone' remains attached to bones during maceration and is a very different tissue from the calcified cartilage of epiphyseal plates. Indeed, others have suggested this before (see Beresford, 1981 for a review), though the ideas have never filtered through to anatomy texts. We prefer to avoid any implications of metaplasia and favour the terms 'calcified cartilage' or 'Type II chondroid bone' instead. As Beresford (1981) points out, there is a whole spectrum of tissues between cartilage and bone, but no agreed terminology for them. He regards the term 'chondroid bone' as the least unsatisfactory term.

From our observations and the works referred to above, it is possible to amplify the standard textbook descriptions (Warwick & Williams, 1973; Breathnach, 1965; Romanes, 1981) of the normal markings left by tendon and muscle attachments to dried bones as follows: Fleshy attachments produce smooth, featureless surfaces, indistinguishable from areas of bone covered by periosteum alone, but attachments of tendons, aponeuroses and fibrous septa produce distinct markings (e.g. tubercles, ridges, pits or fossae). If there is little fibrocartilage at the attachment site, the markings are rough; if there is a lot, they are smooth but clearly demarcated from adjacent non-articular areas.

At the lateral edge of the humeral facet for supraspinatus, there is a ridge that corresponds to the region where the fibrocartilage disc has disappeared and the tendon fibres are attached to bone directly. It follows that if a part of an epiphyseal attachment can lose its fibrocartilage, there must be a reason why some of this tissue persists in the adult. If the fibrocartilage has any functional significance it will probably be mechanical. Schneider (1956) has suggested that a flexible pad of fibrocartilage and an underlying zone of calcified fibrocartilage acts as a 'two layered defence system' that protects the bone against excessive shearing stress, and the tendon against excessive pressure or tension. It has also been suggested (Knese & Biermann, 1958) that the relative elasticity of tendon, fibrocartilage and bone is important and that the fibrocartilage acts as a *Dehnungsbremse* or 'stretching brake'. Knese & Biermann (1958) argued that a stretched tendon tends to narrow, but that the change is resisted by the cartilage matrix, so that the tendon does not stretch at its interface with the bone.

We do not wish to generalise about the significance of tendon fibrocartilage, for the structural variation between the attachment sites of epiphyseal tendons suggests that each tendon is best treated as a special case. Indeed Schneider (1956) even argued that the structure of the attachment zone varies in a given tendon according to the occupation of the person. He mentioned, for example, differences in the insertion zone of biceps brachii in a window cleaner (who uses his forearm in a pronated position) and a farm hand (who milks cows with his supinated forearm). Our comments therefore are restricted to the tendon of supraspinatus, with which we are most familiar.

Tendons that attach to the shafts of long bones are roughly parallel to the bone. When the bone moves, they stay close to it, and maintain the same acute angle to the shaft. On the other hand, the angle between the humerus and the tendon of supraspinatus that crosses the shoulder joint and immediately inserts on the humerus, changes substantially during movement. The belly of the muscle remains parallel to the spine of the scapula. The tendon must therefore bend to reach its insertion, but the angle through which it bends changes during arm movement. The tendon fibres in our specimens (from cadavers fixed with adducted limbs) bent largely above the level of the fibrocartilage so that the collagen fibres met the tidemark at right angles. The fibrocartilage ensures that the tendon does not bend where soft and hard tissues meet. Thus, we view the fibrocartilage of supraspinatus as protecting the tendon rather than the bone at the insertion zone. The bone it *does* protect is that of the humeral head, away from the insertion zone. An examination of an articulated skeleton shows that the fibrocartilage pad ensures that the tendon reaches its facet without pressing on the head of the humerus. It is not surprising to read of the observation of Codman (1934) that the tendon can rub on the head of the humerus during shoulder dislocations. The size of the fibrocartilage pad is now inappropriate to prevent rubbing. One may think of the fibrocartilaginous disc as having some of the functions of a sesamoid cartilage at the end of a tendon.

When the angle between tendon and bone alters, so potentially does the area at which the tendon meets the bone. It is a matter of simple geometry (Appendix 1) to show that for an angle change of 60° (in a single plane and for a perfectly round tendon), the area doubles. This change in area is far greater than any envisaged by Knese & Biermann (1958) as a result of a tendon narrowing when it is pulled. Furthermore, the changes are independent of tension or indeed any other force. In our view, the cartilage matrix binds the collagen fibres of supraspinatus together and ensures that they always reach the tidemark at angles approaching a right angle. Thus, the tendon fibres are not splayed out or compressed at a hard tissue interface. In a multiaxial joint such as the shoulder joint, the fibrocartilage pad must resist a tendency to widen or narrow at all points on its periphery, but in a uniaxial joint, the tendency to narrow or widen would only be along the axis of the joint. Perhaps, some criss-crossing of fibres within the fibrocartilage plug (suggested by Codman's (1934), and our own, finding of transversely sectioned tendon fibres in a plane where most fibres are cut longitudinally) helps to bind the plug together.

SUMMARY

Based on a parallel study of a wide range of human tendons from embalmed dissecting room subjects and from a study of dried bones, an explanation is offered for the well known similarity in gross appearance between the markings left by certain tendons (e.g. those of the rotator cuff) and by articular surfaces on dried bones. Epiphyseal tendons leave markings on bones that look like those left by articular surfaces. These tendons have a prominent zone of fibrocartilage at their attachment site and the deepest part of this is calcified, just as the deepest part of articular hyaline cartilage is calcified. After maceration of the soft tissues, the calcified (fibro) cartilage is left attached to the bone at articular surfaces and at the sites of tendon attachment. In all cases, the tissues separate at the basophilic tide-

mark between the calcified and uncalcified regions. This tidemark is smooth where there is much overlying uncalcified (fibro) cartilage and it is the smoothness that gives the typical appearance of the dried bone. Blood vessels do not generally traverse the tendon fibrocartilage plugs. Hence the areas are devoid of vascular foramina.

The functional significance of tendon fibrocartilage is discussed with particular reference to supraspinatus. It is suggested that the uncalcified fibrocartilage ensures that the tendon fibres do not bend, splay out or become compressed at a hard tissue interface, and are thereby offered some protection from wear and tear. It is also suggested that the fibrocartilage plug of supraspinatus prevents the tendon from rubbing on the head of the humerus.

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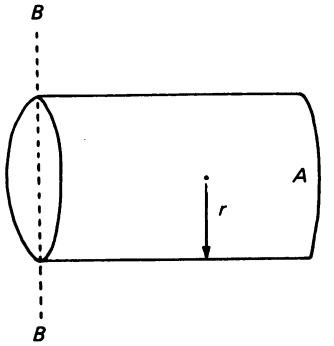
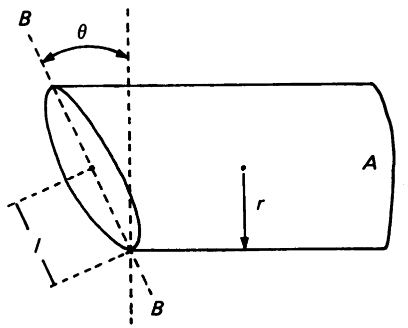
APPENDIX

Consider a tendon *A*, circular in cross section, and meeting a bone at a plane *B*–*B*, at a varying angle θ.





The radius of the short axis of the ellipse is always *r*, and the radius of the long axis is $l = \frac{r}{\cos\theta}$.

Area of ellipse $= \pi r l$,

$$= \frac{\pi r^2}{\cos\theta}.$$

πr^2 is constant, so the area with which the tendon meets the bone is proportional to $\frac{1}{\cos\theta}$.

A graph of θ against $\frac{1}{\cos\theta}$ shows that:

when $\theta = 0°$, $\frac{1}{\cos\theta} = 1$,

when $\theta = 30°$, $\frac{1}{\cos\theta} = 1{\cdot}15$,

when $\theta = 60°$, $\frac{1}{\cos\theta} = 2$,

when $\theta = 90°$, $\frac{1}{\cos\theta}$ is infinitely large.