J. Anat. (1980), **131**, 1, pp. 179–195
With 8 figures
Printed in Great Britain

Migration of tendinous insertions. I. Cause and mechanism*

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(*Accepted* 12 *December* 1979)

INTRODUCTION

If a bone is inspected at different ages, one sees that the insertions of muscles and ligaments on the diaphysis occupy the same relative positions with respect to the extremities of the bone. This observation can only be explained by the migration of the insertions on the diaphysis, for it is known that there is no interstitial growth of the diaphysis, which grows in length only by means of its epiphyseal plates. If the increase in distance between these plates were not compensated for by the migration of the insertions towards the nearest epiphysis, they would eventually come to be attached nearer the middle of the bone.

Insertions can be divided into three types: (1) apophyseal, (2) periosteal, (3) tendinous. The two first are not directly involved in the problem of migration. The insertions of the first type attach to an apophysis whose displacement is caused by activity of its growth plate; the insertion is simply dragged along by the apophysis (e.g. the insertion of the iliopsoas muscle on the lesser trochanter). The second type inserts by means of the periosteum on a large extent of the bone surface. These insertions are subject to the same laws of growth as the periosteum, which grows interstitially, regularly throughout its length (Warwick & Willes, 1934; Hert, 1960*a*). They can easily be separated from the bone together with the periosteum. The third type – tendinous insertions – is represented by insertions of ligaments and muscles by means of a well defined tendon whose fibres are directly continuous with the bony fibres. The peripheral part of the tendon is continuous with the fibrous layer of the periosteum. There is no typical periosteal membrane at the contact site. This study deals only with this third type of insertion, and the fact that a tendon anchored in the bone can migrate over the surface of the bone in spite of the obvious solidity of its fixation.

Such migration has been observed before and various explanations have been put forward as to its cause and local mechanisms. According to Lacroix (1949) the cause of the migration is the stretching of the periosteum which drags the insertions. He also invoked the role of muscular traction. His hypothesis, although plausible, has not been confirmed experimentally. Grant & Hawes (1977) and Grant, Buschang & Drolet (1978) suggested that the migration is controlled by the growth of the bone rather than by the muscle itself, without discussing the possible involvement of periosteum.

Although little work has been devoted to explaining the cause of the migration, the local mechanism permitting the movement of a tendon while still retaining

* Part of this work was presented at the Fourth European Anatomical Congress, Basle (Dörfl 1977).

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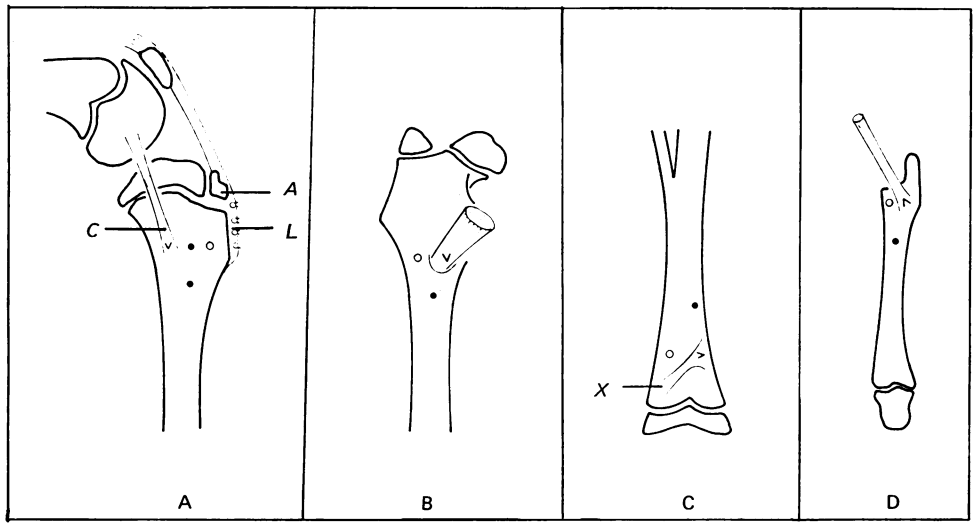


Fig. 1. Drawings of the positions of the different metallic markers in the four insertions studied. (A) Proximal extremity of tibia with insertion of medial collateral ligament (*C*) and patellar ligament (*L*). *A*, apophysis. (B) Proximal extremity of femur with insertion of quadratus femoris. (C) Distal extremity of tibia with anterior annular ligament (*X*). (D) First metatarsal with insertion of tibialis anterior. o, periosteal markers; •, bony markers; v, 8, markers in tendon or ligament.

its attachment to the bone has received more attention. Weidenreich (1930), Petersen (1930) and Vis (1957) proposed that the tendon was directly incorporated in the bone, which thus had a special structure – 'Einstrahlungsknochen'. According to Warwick & Willes (1934), the fibres fixing the tendon to the bone lengthen and are subsequently included in the periosteal bone. Videman (1970), using marker techniques (^{35}S-sulphate, ^{3}H-thymidine, tetracycline), described rapid growth in the zone of insertion; he concluded that the newly formed tendon is incorporated directly in the bone. Hoyte & Enlow (1966) showed that tendons are often attached to a resorptive surface; they explained the mechanism of migration by a decalcification of the bone at the site of insertion during which the continuity of the fibres is not broken. In the context of a study of a related problem Kraw & Enlow (1976) and Enlow (1975) studied the continuous attachment of a tooth to the alveolar walls during its migration. Fibres liberated from the bone at the resorptive surface of the alveolus are converted into periodontal fibres and, conversely, periodontal fibres become enclosed at the depository surface of the alveolus. These two processes are accompanied by the lengthening or shortening of fibres taking place in an intermediate plexus of precollagenous fibres in the periodontium.

The present study attempts to explain by experimental work in the rabbit the cause of migration and the way in which it is dependent on the growth of periosteum and bone and on muscular tension. Various insertions were chosen for study. Some are subject to muscular tension and migrate rapidly (patellar ligament), slowly (quadratus femoris) or not at all (tibialis anterior). Others are not subject to muscular tension (medial collateral ligament of the knee, anterior annular ligament of the tibia) but migrate nevertheless. The local mechanism of migration was studied in each case to determine whether it was similar in different insertions or whether several mechanisms existed.

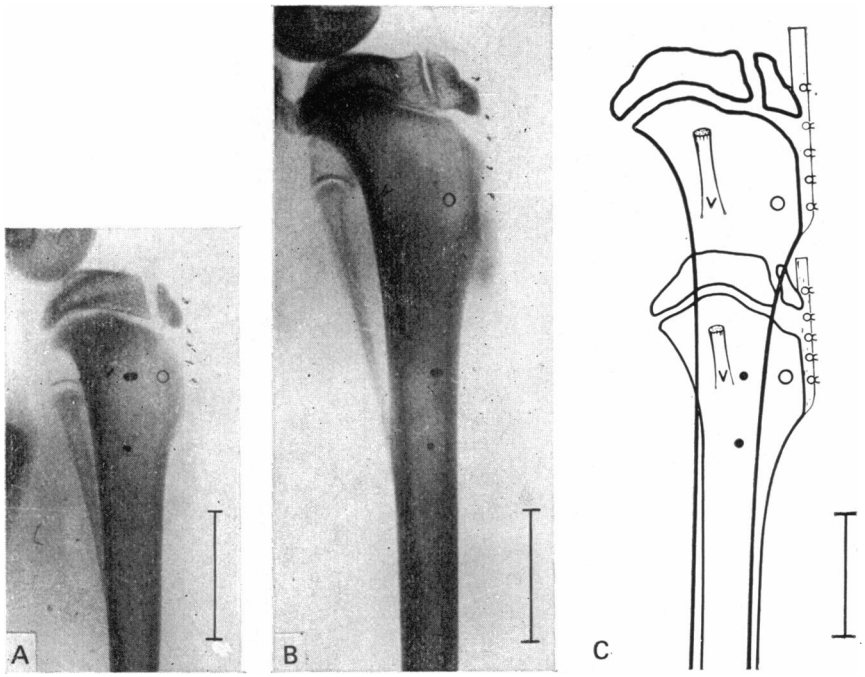


Fig. 2. (A) Radiograph of proximal extremity of tibia of 60 days old rabbit immediately after operation. (B) Same 92 days later. (C) Superimposition of A and B using bony markers as guides. Scale bars = 1 cm. Symbols as in Fig. 1.

MATERIALS AND METHODS

Fifty four rabbits aged from 30 to 127 days were used. The insertions studied were (Fig. 1): (A) the patellar ligament on the tibia, together with the medial collateral ligament of the knee; (B) the quadratus femoris on the femur; (C) the proximal and distal insertions of the anterior annular ligament of the tibia; (D) the tibialis anterior on the base of the first metatarsal.

Three methods were used: (1) marking by metal wire; (2) marking by tetracycline hydrochloride; (3) histological examination. Operations were performed unilaterally, the other side serving as a control.

(1) Metal markers were used to follow, by radiography, the migration of the insertions and the periosteum on the bony diaphysis during its growth. In rabbits anaesthetized with Nembutal (30 mg/kg, I.V.) the insertions of tendons and ligaments and the neighbouring periosteum were marked with stainless steel wire (diameter 60 μm) or silver wire (diameter 70 μm) (Fig. 1). The same places were also marked on the surface with India ink. Only the animals (32) in which the wire marks coincided with India ink marks at the end of the experiments, lasting from 42 to 130 days, were assessed. Non-coincidence was most frequently found in the periosteal markers which became incorporated in the bone if not placed precisely in the fibrous layer. For this reason the marker was usually glued to the periosteal surface with Histoacryl blue (B. Braun Melsungen AG). One or two sturdy markers in the diaphysis permitted the exact superimposition of radiographs taken every seven days during the experiment.

(2) Milch, Rall & Tobie (1958) showed that tetracyclines are incorporated into

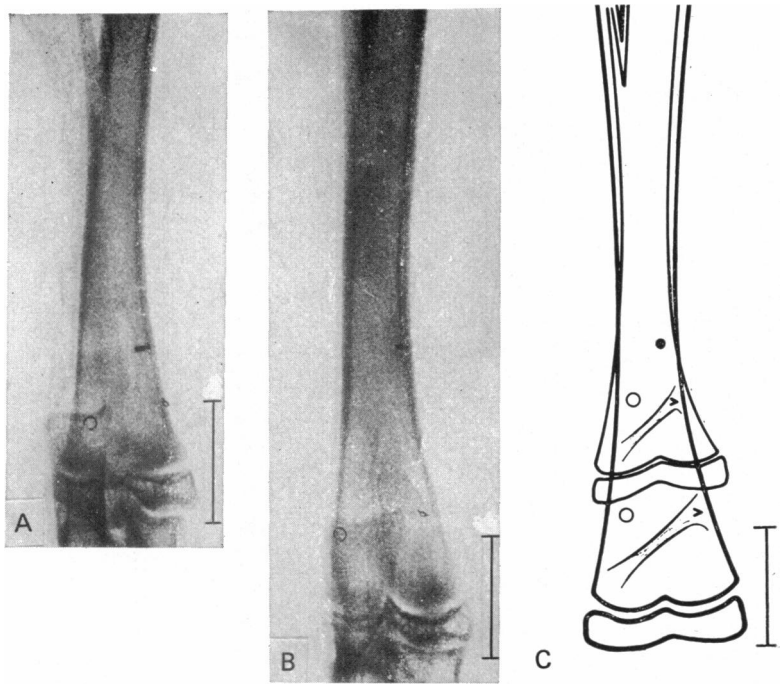


Fig. 3. (A) Radiograph of distal extremity of tibia of 40 days old rabbit after marking of diaphysis, periosteum and anterior annular ligament. (B) Same 50 days later. (C) Superimposition of A and B using bony markers as guides. Scale bars = 1 cm. Symbols as in Fig. 1.

bone at the time of the deposition of calcium salts. They can be detected in sections by their yellow fluorescence in ultraviolet light. This technique was used here as an indicator of osteogenesis at insertion sites. Tetracycline hydrochloride (Achromycin, Lederle) was administered (40 mg/kg, I.V.) to 12 rabbits aged from 30 to 127 days. They were killed by an overdose of Nembutal 2 to 60 days after the injection. The bones were studied, in part, by transmitted light in ground-bone sections of 40 to 60 μm (Frost, 1958; Juster, Laval-Jeantet & Oligo, 1965); but in most cases the bones were simply cut by saw and the surfaces polished, permitting convenient examination by incident light. The bone is not fragile, and by progressive abrasion the whole of the region of interest can be studied. Specimens were studied by ultraviolet illumination (HBO 50 W, exciter filter UG 1, barrier filter Wratten 2 B).

(3) Ten rabbits aged from 30 to 127 days were used for histological examination. The bones with the insertions were fixed by immersion in 10 % formalin, decalcified in 5 % nitric acid and embedded in paraffin. Sections, 10 to 12 μm thick, were stained by the method of Mallory or with haematoxylin and eosin. To differentiate between precollagenous and collagenous fibres, the method of Herovici (1963) was used after fixation in a mixture of 100 % formalin, glacial acetic acid and absolute ethanol (10:5:85).

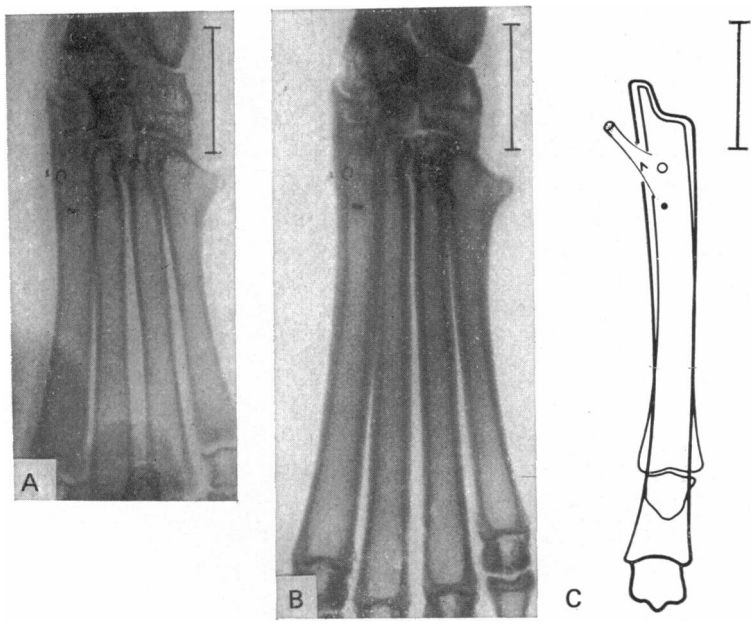


Fig. 4. (A) Radiograph of metatarsus of 60 days old rabbit. Insertion of tibialis anterior, periosteum and first metatarsal are marked. (B) Same 50 days later. (C) Superimposition of A and B. The markers in the insertion and periosteum have remained at the same distance from the bony marker. Scale bars = 1 cm. Symbols as in Fig. 1.

RESULTS

(1) *Metal markers*

The displacement of metal markers was followed by radiography every seven days. At the end of the experiments the bones and the insertions were dissected free and compared with control bones of the opposite, non-operated, side. No macroscopical differences were observed between the two sides.

(A) *Insertion of the patellar ligament*

The patellar ligament was marked in 10 rabbits aged from 45 to 60 days (Fig. 1A; Table 1). Figure 2 illustrates an experiment on a rabbit aged 60 days. The markers placed in the medial collateral ligament, the periosteum and the distal marker in the patellar ligament are at the same level, at the beginning of the experiment, as the upper bony marker. After 92 days the first three markers had climbed 14 mm relative to the bony marker. The five markers in the patellar tendon occupied a segment of 10 mm at the beginning of the experiment, and 14 mm after 92 days. They had separated from each other by equal distances, indicating a regular interstitial growth of the tendon. Superimposition of stages A and B (Fig. 2C) shows that not only the insertions but also the tibial tuberosity migrate proximally. Although the migration of the tendon, the ligament and the periosteum is real, the migration of the tuberosity is only apparent, for it is resorbed at its distal extremity as it is formed at its proximal border (see 2A).

(B) *Insertion of quadratus femoris* (Fig. 1B)

In 6 rabbits aged 35 days and killed 90 days later, a marker was placed in the tendon of the quadratus femoris and another fixed to the periosteum with Histoacryl at the same level. A bony marker was placed in the diaphysis 5 mm below the insertion of the quadratus. In view of the difficulty of obtaining a standard orientation of the upper extremity of the femur during radiography this was not done, and the initial situation of the markers was simply compared with the final position. In all cases the periosteal and tendon markers had moved away from the bony marker by the same distance (varying from 4 to 5 mm) proximally (Table 1). As the contribution of the proximal epiphyseal plate to the longitudinal growth of the femoral diaphysis is only 30 % (Hert, 1960*b*), the displacement of the markers is small.

(C) *Insertion of the anterior annular ligament* (Fig. 1C; Table 1)

In 8 rabbits aged from 30 to 40 days a marker was placed in the superior insertion of the ligament, another was glued to the periosteum at the same level, and a third was introduced proximal to the first two in the tibial diaphysis. In the example illustrated in Figure 3 the animal was marked at 40 days of age and killed at 90 days. The marker in the ligament and that in the periosteum migrated distally from the bony marker by the same distance, 10 mm, during the 50 days of the experiment.

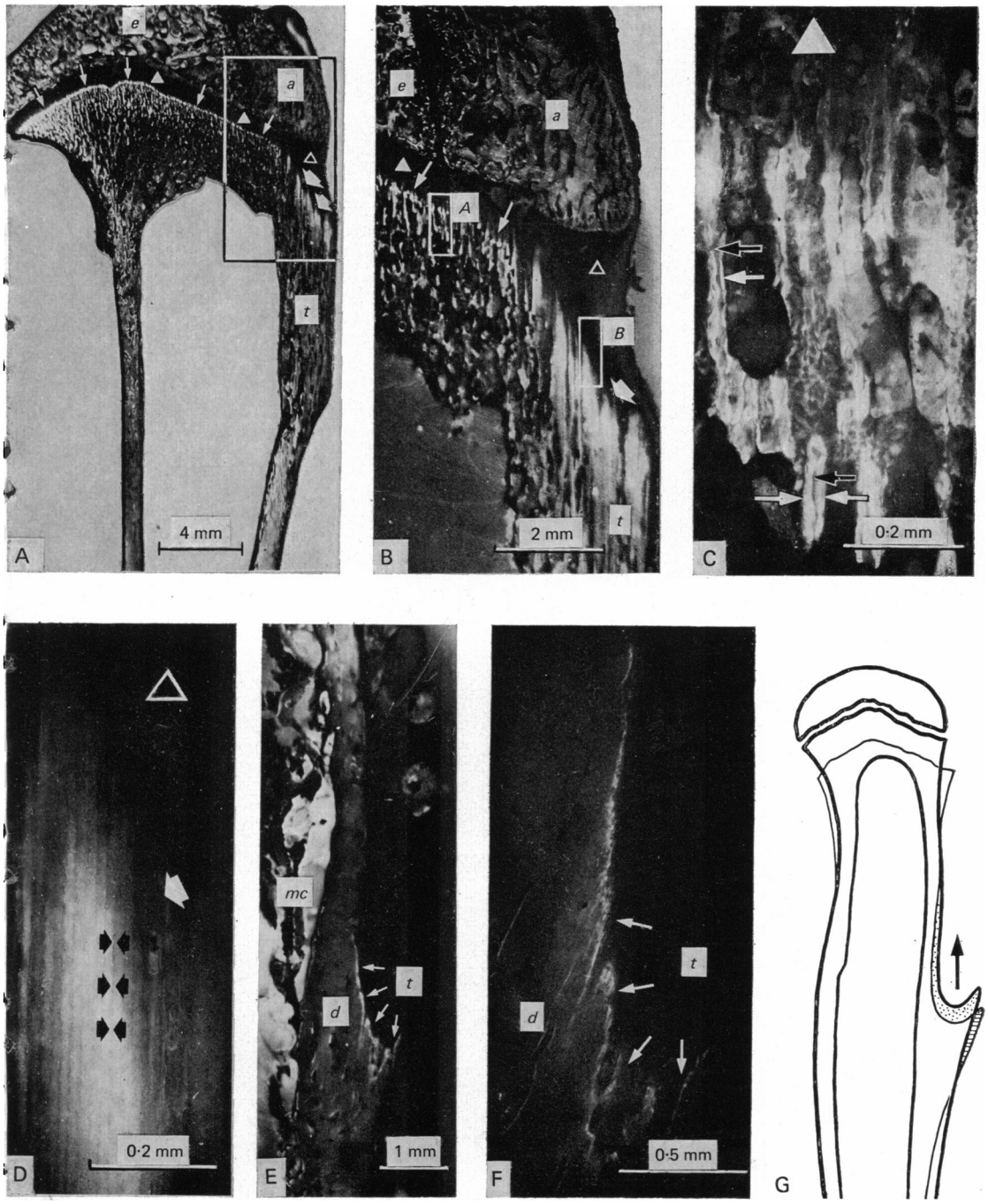
(D) *Insertion of tibialis anterior* (Fig. 1D; Table 1)

Eight rabbits aged 45 to 60 days were marked. Figure 4 illustrates the experiment on a rabbit operated at 60 days and killed 50 days later. A marker was placed in the tendon of tibialis anterior, a second glued to the neighbouring periosteum and a third inserted in the diaphysis, 3 mm distal to the others. During the experiment the tendinous and periosteal markers remained at the same distance from the bony marker, while the first metatarsal elongated by 9 mm.

(2) *Tetracycline marking*

The following observations were made on animals aged from 30 to 60 days killed 70 hours after tetracycline injection.

Fig. 5. Seventy hours after tetracycline injection. Incident light. (A) Sagittal section of proximal extremity of tibia of 45 days old rabbit. The medullary cavity is excised. *a*, apophysis; *e*, epiphysis; *t*, tibial tuberosity; open triangle, deep part of patellar tendon; filled triangles, epiphyseal plate; small arrows, fluorescence in endochondral bone deep to the epiphyseal plate; arrowheads, fluorescence at the superior pole of the tibial tuberosity. (B) Detail of area within rectangle in Fig. 5A. Symbols as in Fig. 5A. (C) Detail *A* of Fig. 5B. Fluorescent bone covers the trabeculae of endochondral bone (white arrows) deep to the epiphyseal plate (filled triangle). Black arrows indicate remains of cartilage in the bony trabeculae. (D) Detail *B* of Fig. 5B. Fluorescence of a needle of bone in the superior pole of the tibial tuberosity. The bony substance forms bands separated by rows of osteocytes. One row is indicated by black arrowhead. Other symbols as in Fig. 5A. (E) Longitudinal section of the proximal extremity of femur of 60 days old rabbit, passing through the insertion pit of quadratus femoris. Arrows indicate fluorescence of the surface of the insertion pit. *mc*, medullary cavity; *d*, diaphysis. (F) Detail of Fig. 5E. (G) Superior extremity of femur with insertion of quadratus femoris. Superimposition of two stages to show 'migration' (in direction indicated by arrow) of the pit due to osteogenesis (dotted) in the insertion site. Resorbed bone is cross hatched.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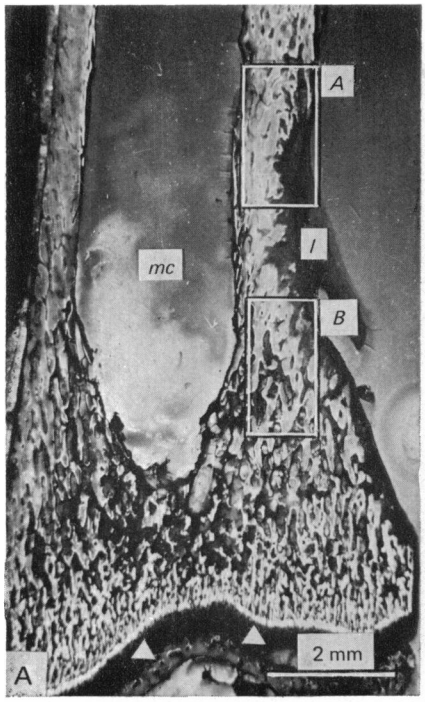
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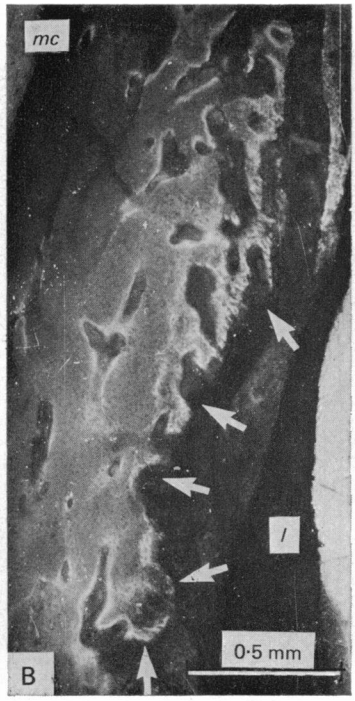
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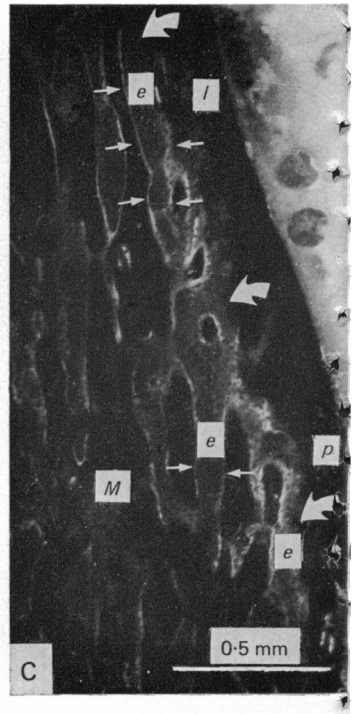
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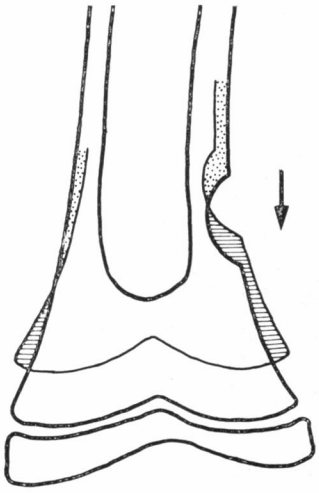
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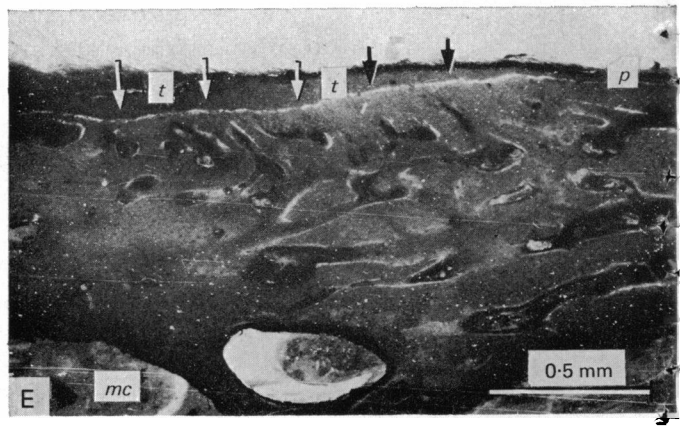
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(A) *Insertion of the patellar tendon* (Fig. 5A–D)

On a sagittal section through the tibial tuberosity, there was little fluorescence on the anterior aspect of the tuberosity. In contrast, its superior pole was intensively marked, along a saw-toothed line. This appearance correlates well with the superior extremity of the tuberosity, formed by sharp trabeculae upon which inserts the deep part of the patellar tendon (Fig. 5B, D). Another fluorescent zone was visible below the epiphyseal cartilage, due to the endochondral ossification within the metaphysis (Fig. 5A, C).

(B) *Insertion of quadratus femoris* (Fig. 5E–G)

The muscle inserts by a solid tendon in a depression on the posterior surface of the femur. After injection of tetracycline the whole surface of the depression is formed of fluorescent bone (Fig. 5E, F) signifying that the insertion site of this muscle is purely osteogenic. The proximal migration is the result of the apposition of bone tissue at its surface (Fig. 5G).

(C) *Insertion of the anterior annular ligament* (Fig. 6A–D)

The inferior extremity of the ligament inserts entirely on the metaphysis, and therefore on a resorptive surface in which tetracycline cannot be incorporated. The superior extremity is attached at the bottom of a dimple (Fig. 6A) where, during growth, two opposing processes operate: the resorption of its inferior part (Fig. 6C), corresponding to the metaphysis, and osteogenesis in its superior part (Fig. 6B), resulting in fluorescent bone.

The migration of the dimple is provoked by the migration of the ligament and brought about by the simultaneous operation of the two processes (Fig. 6D).

(D) *Insertion of tibialis anterior*

After the tetracycline injection a very thin layer of fluorescence marks the site of insertion (Fig. 6E). The tibialis anterior tendon does not migrate, and osteogenesis of its insertion serves only for the growth in width of the metatarsal bone.

Fig. 6. Seventy hours after tetracycline injection. Incident light. (A) Coronal section of distal extremity of tibia of 40 days old rabbit through the superior insertion of the anterior annular ligament. Filled triangles, inferior epiphyseal plate; details of upper (*A*) and lower (*B*) parts of the insertion pit are seen in Figs. 6B, C. (B) Detail *A* of Fig. 6A. The upper part of the insertion pit is covered with fluorescent bone (arrows), indicating osteogenesis deep to the superior part of the ligamentous insertion. (C) Detail *B* of Fig. 6A. The inferior part of the insertion is on the metaphysis (*M*). The endochondral bony trabeculae (*e*) are resorbed (curved arrows) deep to the insertion of the ligament (*l*) and, more distally, under the periosteum (*p*). The trabeculae are covered by fluorescent bone within the metaphysis (small arrows). (D) Drawing of the inferior extremity of the tibia with the superior insertion pit of the anterior annular ligament. Superimposition of two different stages shows the 'migration' of the insertion due to a combination of osteogenesis in the upper part (dotted) and resorption in the lower part (cross hatched). (E) Longitudinal section of the first metatarsal of a 50 days old rabbit. *t*, tendon of tibialis anterior; *mc*, medullary cavity; *p*, periosteum. Arrows indicate fluorescence (osteogenesis) at the insertion of the tendon.

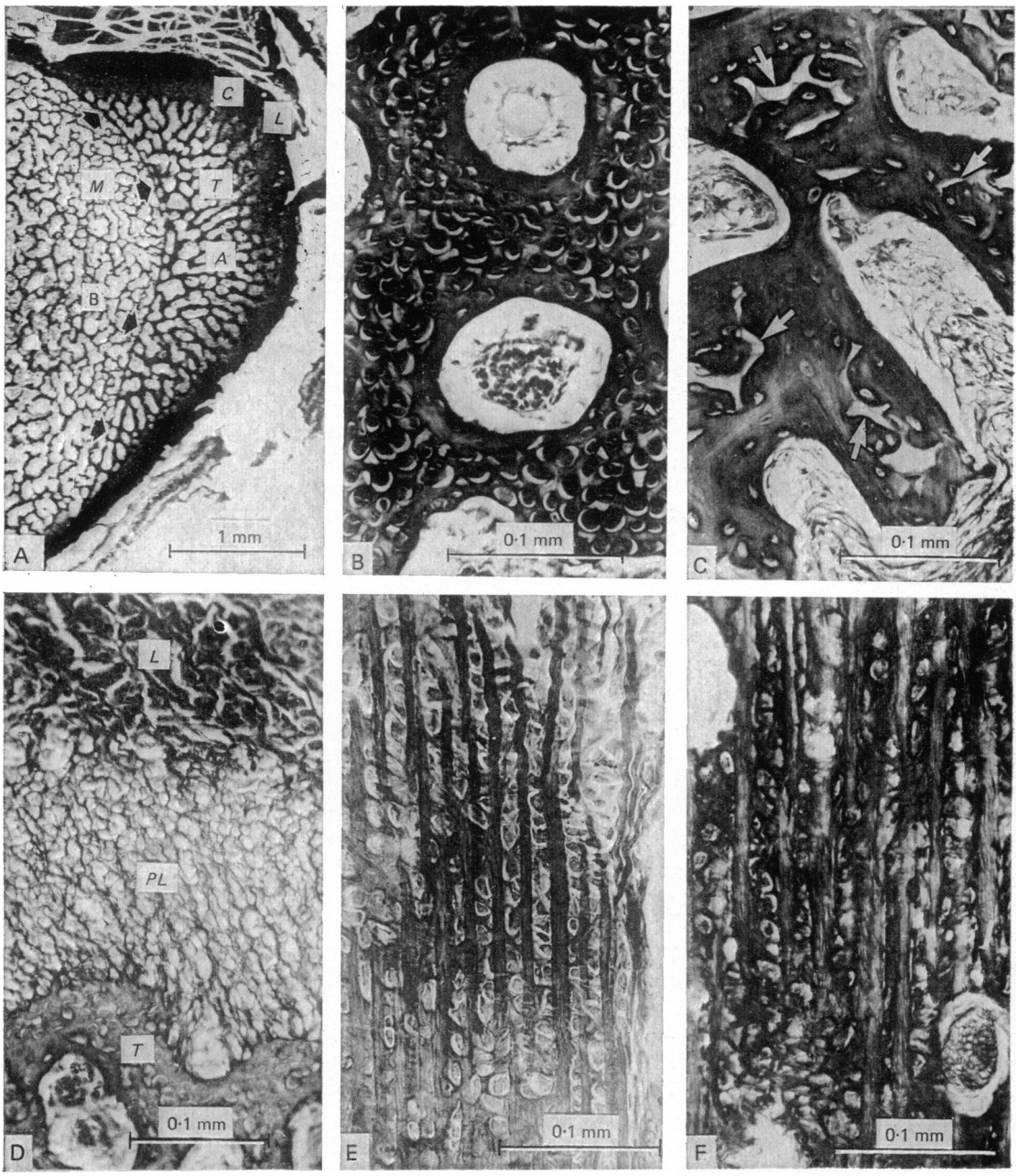


Fig. 7. Rabbit aged 47 days. Herovici stain. (A) Transverse section of superior extremity of tibia through the tuberosity. *L*, patellar tendon; *T*, tibial tuberosity; *M*, metaphysis. Arrowheads indicate the abrupt change in structure between tuberosity and metaphysis. (B) Detail *A* of Fig. 7A. The tuberosity is formed of cell-rich bone as a result of osteogenesis in the deep part of the patellar tendon. (C) Detail *B* of Fig. 7A. The metaphysis has a very different structure from the tuberosity with typical trabeculae of endochondral bone containing remnants of cartilage (arrows). (D) Detail *C* of Fig. 7A. The superficial part of the patellar ligament (*L*) is attached to the tibial tuberosity (*T*) by a plexus of precollagenous fibres (*PL*). (E) Sagittal section of the deep part of the patellar ligament. Thick bundles of collagenous fibres are separated by columns of cells. (F) Sagittal section of the tibial tuberosity. Arrangement of cells and ground substance as in Fig. 7E.

(3) *Histological examination*

(A) *Insertion of the patellar ligament*

The patellar ligament inserts on the tibial tuberosity in two ways:

Its deep layer stretches between the inferior surface of the apophysis and the superior pole of the tuberosity. It is composed of thick collagenous fibres separated by rows of cells that are fusiform near the apophysis and cuboid near the superior pole of the tuberosity (Fig. 7E). The same arrangement of fibres and cells can be recognized in the bony architecture of the tuberosity, where the cells become osteocytes (Fig. 7F).

The superficial layer of the patellar ligament is attached to the anterior surface of the tuberosity by a plexus of precollagenous fibres (Fig. 7D). At the level of the inferior edge of the tuberosity the plexus contains many osteoclasts (Fig. 8A).

(B) *Insertion of quadratus femoris*

The collagenous fibres of the tendon insert directly on the bone, without intermediate precollagenous fibres. The terminal part of the tendon is characterised by parallel fibres separated by rows of fusiform cells that become cuboid towards the surface of the bone and are finally enclosed in the bone (Fig. 8B, C), a picture very similar to that of the deep layer of the patellar ligament (Fig. 7E).

(C) *Insertion of the anterior annular ligament*

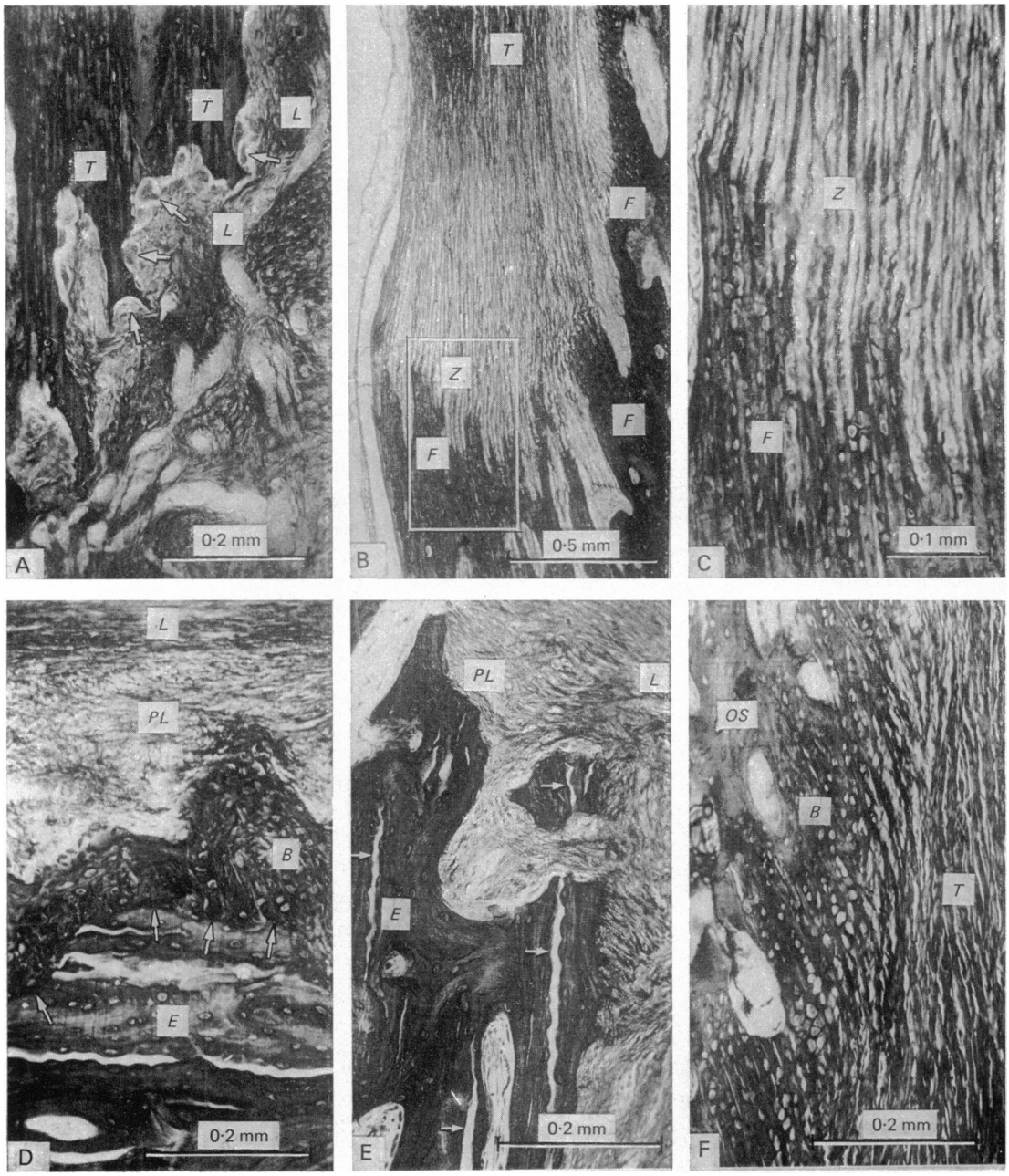
The two extremities of the ligament insert in two qualitatively different regions. The inferior extremity inserts on the metaphysis, which is in the process of resorption. The ligament is linked to the endochondral bone by a thick layer of precollagenous fibres, rich in cells that are differentiated into osteoclasts at the apices of the endochondral trabeculae (Fig. 8E). The superior extremity of the ligament is also attached to the bone by a plexus of precollagenous fibres. Its insertion is in a dimple formed by two types of bone, different in both origin and structure. The inferior part of the dimple is part of the metaphysis and is formed of endochondral trabeculae in the process of being resorbed at their extremities. The superior part is formed of bony tissue resulting from osteogenesis in the insertion of the ligament. This type of bone is characterised by numerous osteocytes with no particular order and by its matrix in which the fibres equally show no clear stratification. This bone resulting from tendinous osteogenesis is clearly delimited from the deeper endochondral bone (Fig. 8D).

(D) *Insertion of tibialis anterior*

The tendon of this muscle inserts directly in the bone by collagenous fibres that are slightly divergent towards the bony surface. Amongst the fibres are numerous cells sometimes forming short columns. The fibres can be followed into the substance of the bone (Fig. 8F).

DISCUSSION

During growth in length of a bone, ligaments and tendons migrate in conditions that are specific for different insertions. Some are subject to muscular traction, such as the patellar tendon, and the insertions of quadratus femoris and tibialis anterior. Others are not; for instance the medial collateral ligament of the knee,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attached proximally to the medial condyle of the femur, is stretched by the growth of the condyle and by the proliferation in the superior epiphyseal cartilage of the tibia. The anterior annular ligament, inserted obliquely on the distal part of the tibia, depends for its migration exclusively upon the periosteum with which it exchanges fibres. The distances moved by insertions during migration, which can be regarded as an index of the 'speed' of migration, are also very different. They are determined by the relationship between the insertion and the epiphyseal plate and the neutral centre of the bone. The neutral centre can be defined as the place where the periosteum during growth is pulled in the two opposite directions (Lacroix, 1949). Its position depends upon the proportion of the total length of the diaphysis contributed by each epiphyseal plate. For example, 65 % of the diaphysis of the femur of the rabbit is formed by the distal plate and 35 % by the proximal (Hert, 1960*b*). Thus the neutral centre of the femur is approximately between the superior and middle thirds. Insertions far from the neutral centre and near the epiphyseal cartilage migrate rapidly, and *vice versa*. Thus the insertions of the patellar ligament, the medial collateral ligament and the anterior annular ligament migrate rapidly, and that of quadratus femoris slowly, while the insertion of tibialis anterior, practically at the neutral centre, does not migrate. Grant & Hawes (1977) and Grant *et al.* (1978) confirmed that the nearer the insertion to the extremity of the bone, the greater is the migration. This conclusion was, however, made on the assumption that the contribution of the two epiphyseal plates to the total length of the bone was equal, which is not the case.

Muscular traction does not seem to play a decisive role in migration, which is limited to the period of growth of the bone and periosteum and ceases with the end of this period although the muscles continue to develop.

The characteristic feature common to all insertions investigated is their connexion to the periosteum with which there is fibrous continuity.

The experiments with metallic markers show that all these insertions, although exposed to different influences, migrate in the same direction and at the same speed as the neighbouring periosteum. If, as with tibialis anterior, the periosteum does not migrate, the insertion does not migrate either. The present study leads to the conclusion that migration is caused by the dragging of the insertion by the periosteum, itself pulled by the epiphyses as they are pushed apart by the activity of the epiphyseal plates. Compared with muscular traction, the traction exerted by the

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Fig. 8. Rabbit aged 47 days. Herovici stain. (A) Sagittal section of the inferior pole of the tibial tuberosity. *T*, inferior pole of tuberosity; *L*, superficial part of patellar ligament attached to the tuberosity by a plexus of precollagenous fibres. Arrows indicate osteoclasts resorbing the inferior pole of tuberosity. (B) Longitudinal section of the superior extremity of femur through insertion of quadratus femoris. *T*, tendon; *Z*, insertion zone; *F*, insertion pit. (C) Detail of Fig. 8B. Bundles of collagenous fibres and rows of cells of the insertion zone (*Z*) are continuous with the bony substance and its rows of cells. (D) Longitudinal section of the inferior extremity of the tibia through the upper part of the superior insertion of the anterior annular ligament (cf. Fig. 6B). Anterior annular ligament (*L*) inserting on the bone by a plexus of precollagenous fibres (*PL*). *B*, bone formed by osteogenesis in the tendon at the site of insertion. This bone is clearly delimited (arrows) from the deeper endochondral bone (*E*). (E) Longitudinal section through the lower part of the superior insertion of the anterior annular ligament (cf. Fig. 6C). The ligament (*L*) inserts on endochondral bone (*E*) by a plexus of precollagenous fibres (*PL*). Arrows indicate the remains of cartilage in the endochondral bone (cf. Fig. 6C). (F) Longitudinal section of the first metatarsal through the insertion of tibialis anterior. *T*, tendon; B, bone formed at the insertion site; *OS*, secondary bone.

Table 1. *Summary of results of the experiments with metal markers*

(Results are grouped in 4 classes, A, B, C and D, according to description in text (see also Fig. 1). The displacements of markers in periosteum and insertions are measured with respect to the bony markers and are expressed in mm to the nearest ½ mm. All displacements were away from bony markers, except in the two cases of experiment D, in which the distance of the displacement is preceded by minus sign: there, the distance decreased. Rabbits were from various impure strains. In experiments A, C and D, animals from several litters were used. Experiment B was carried out on rabbits from one litter only.)

No. of animal	Age (in days) at which markers were placed	Duration (in days) of experiments	Displacement of markers					
			P	L	L^1	T	T^1	T^2
			(A) Insertion of patellar ligament					
1	45	42	8	8	—	8·5	—	—
2	52	40	7	7·5	—	7	—	—
3	52	53	8·5	8·5	—	8·5	—	—
4	56	65	11·5	11	—	11	—	—
5	56	72	12·5	12·5	—	12	—	—
6	56	130	18	19	—	16*	—	—
7	60	49	10	10·5	—	10	—	—
8	60	49	10	9·5	—	10	—	—
9	60	92	14	14	—	14	—	—
10	60	92	15	15	—	14	—	—
			(B) Insertion of quadratus femoris					
1	35	55	4	—	—	—	4	—
2	35	55	5	—	—	—	4·5	—
3	35	55	4	—	—	—	4·5	—
4	35	55	4	—	—	—	4	—
5	35	55	4·5	—	—	—	4·5	—
6	35	38	3·5	—	—	—	4	—
			(C) Insertion of anterior annular ligament					
1	30	11	3	—	3	—	—	—
2	30	22	6	—	6	—	—	—
3	36	20	4	—	4·5	—	—	—
4	36	39	8	—	8·5	—	—	—
5	36	41	8·5	—	9	—	—	—
6	40	39	6	—	6·5	—	—	—
7	40	50	9·5	—	9	—	—	—
8	40	53	10	—	10	—	—	—
			(D) Insertion of tibialis anterior					
1	45	49	0	—	—	—	—	0
2	45	49	0	—	—	—	—	0
3	45	49	0	—	—	—	—	1
4	49	42	0	—	—	—	—	0·5
5	49	42	−0·5	—	—	—	—	−0·5
6	60	48	0	—	—	—	—	0·5
7	60	50	0	—	—	—	—	0
8	60	50	−0·5	—	—	—	—	−0·5

P, periosteal; L, in medial collat. lig.; L^1, in ant. annular lig.; T, in patellar lig.; T^1, in insertion of quadratus femoris; T^2, in insertion of tibialis ant.

* Marker had detached itself from ligament.

periosteum is regular and continuous, and this is perhaps the decisive factor for migration.

The mechanism of migration is not the same in all cases. The experiments with tetracycline and the histological examinations show that there are several possibilities according to the characteristics of the bony surface at the insertion. This study involves three different insertion surfaces: (1) osteogenic surfaces (patellar ligament, quadratus femoris, tibialis anterior); (2) resorptive surfaces (the inferior insertion of the anterior annular ligament and the medial collateral ligament); (3) combined osteogenic and resorptive surfaces (superior insertion of the anterior annular ligament).

The tendon of quadratus femoris and the deep part of the patellar ligament are attached to the bone by a special osteogenic zone that, by interstitial growth, pushes the tendon away from the neutral centre of the bone. The tendon migrates for a distance that is equal to the depth of the bony layer formed under the insertion site. In these two examples the tendons do not slide over the bony surface and their migration is due to interstitial growth at the insertion site. As the orientation of the fibres of the tendon is parallel to the direction of the osteogenesis, the fibres are not interrupted during their migration, but are constantly elongated at the insertion site. This could explain the absence of precollagenous fibres in this type of insertion. What is valid for the patellar ligament and quadratus femoris also holds for the insertion of tibialis anterior, except that its tendon does not migrate in relation to the neutral centre, and the osteogenesis at the insertion site serves only to increase the diameter of the base of the first metatarsal. In contrast, the superficial part of the patellar ligament actually slides over the surface of the tibial tuberosity, to which it is attached by fibres, during its migration. The interruption and re-attachment of fibres, a pre-requisite of this mechanism of migration, take place at the insertion site that is formed by a plexus of precollagenous fibres, rich in cells.

The inferior insertions of the anterior annular and medial collateral ligaments are attached to the metaphysis, that is to a resorptive surface by a thick layer of precollagenous fibres containing many cells. Fibres resulting from a decalcification of the bone could be shortened at the insertion site, another mechanism allowing migration while ensuring a continuous insertion.

Finally, in the case of the superior insertion of the anterior annular ligament, migration is achieved by the interaction of osteogenesis and resorption, for the insertion is at the border between appositional growth of the diaphysis and resorption of the metaphysis. The insertion site is characterised by a massive layer of precollagenous fibres, which, in the inferior, resorptive part of the insertion, are the result of the destruction of endochondral bone, and in the superior part will become part of the bony substance by tendinous osteogenesis.

The present findings shed some light on the much discussed and arguable question of whether there is periosteum in insertions. In all the cases studied a special zone was found between the tendon and the bone. Although morphologically similar to tendon, it is functionally periosteum in that it can resorb or form bone. Biermann (1957) considered this insertion zone as a special type of periosteum with osteogenic capabilities. The present findings are that this zone can also be resorptive or that the two processes can be combined.

SUMMARY

The cause and mechanisms of the migration of tendons and ligaments were studied in young rabbits.

Three techniques were used: (1) Marking of insertions, the neighbouring periosteum and the diaphysis with metallic markers. (2) Marking of insertion sites by tetracycline as an indicator of osteogenesis. (3) Histological examination.

The insertions used in the study were of three different characters: (1) Insertions subject to muscular traction (patellar ligament, quadratus femoris muscle, tibialis anterior muscle). (2) The distal insertions of the medial collateral ligament of the knee, stretched by the activity of the proximal epiphyseal cartilage of the tibia. (3) The proximal and distal insertions of the anterior annular ligament of the tibia, inserted solely in bone and periosteum.

The cause of migration is the growth of periosteum dragging the insertions during its stretching, caused itself by the activity of the epiphyseal plates.

The local mechanism governing migration while ensuring a continuous connexion with the bone is not the same in all sites. It depends upon the character of the bony surface at the insertion and of the function of the insertion zone, which can be osteogenic, resorptive or both.

A plexus of precollagenous fibres is present at all resorptive insertion sites, and at some of the osteogenic sites.

I thank Prof. H. Van der Loos for critical reading and helpful suggestions during the preparation of this paper and Prof. L. J. Garey for translation of the article and editorial comments.

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