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Migration of tendinous insertions. II. Experimental modifications

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INTRODUCTION

The previous paper (Dörfl, 1980) dealt with the cause and local mechanism of the migration of certain types of insertions of tendons and ligaments during bone growth. The local mechanism permitting the movement of insertions on the bone surface while still maintaining their attachment differs from one insertion to another. It depends on the character of the insertion site, which can be osteogenic, resorptive or both. The proposed cause of the migration is periosteal growth. The periosteum evenly stretched by the action of the epiphyseal plates, pulls on the insertions of tendons and ligaments, resulting in their remaining in the same position relative to the extremities of the bone during growth. This conclusion was based on experiments involving the marking of the periosteum and the insertions with metallic markers and showing that the insertions migrate in the same direction and over the same distance as the local periosteum.

The present paper attempts to confirm by experimental modification of growth conditions that there is a causal relationship between the stretching of the periosteum and the tendinous migration, in other words, that the periosteum drags the insertions. The influence of muscular traction on migration will also be examined.

MATERIALS AND METHODS

Three types of experiment were carried out on rabbits aged 1 to 3 months.

(1) In seven rabbits the proximal epiphyseal plate of the tibia was blocked by staples; also, metallic markers were placed in the periosteum, the superficial part of the patellar tendon and the medial collateral ligament and two stout markers were placed in the diaphysis (Fig. 1 A).

(2) In seven rabbits the distal epiphyseal plate of the tibia was blocked, and two markers were fixed in the superior insertion of the anterior annular ligament and the neighbouring periosteum; a stout marker was placed in the diaphysis proximal to the two mentioned above (Fig. 1 B).

(3) In five rabbits the tendon of the tibialis anterior muscle, which passes with the tendons of the extensors of the digits deep to the anterior annular ligament, was sectioned near its insertion on the base of the first metatarsal bone and then reflected proximally superficial to the ligament and fixed in the belly of its muscle. The anterior annular ligament, the periosteum and the diaphysis were marked as above (Fig. 1 C).

Operations were performed under Nembutal anaesthesia (30 mg/kg, I.V.). Epiphyseal plates were blocked with staples of 700 μm diameter stainless steel wire inserted into holes drilled in the bone. Periosteum and insertions were marked with

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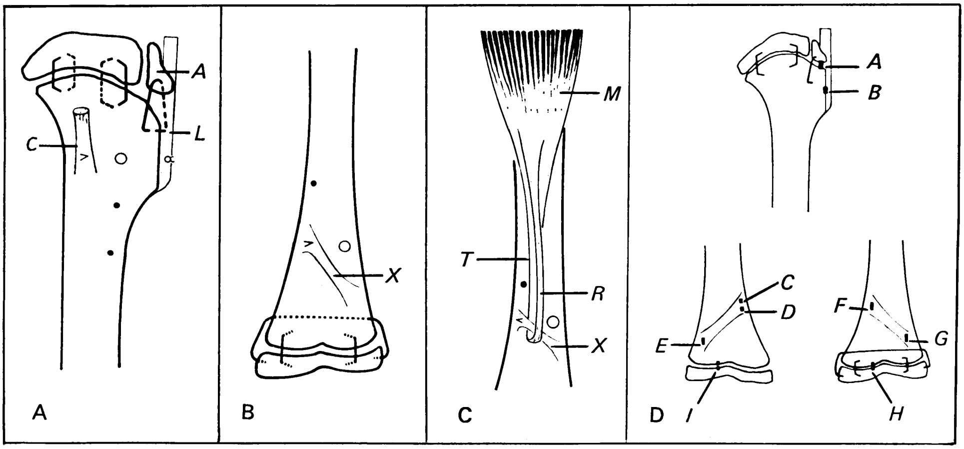


Fig. 1. Diagrams of the three types of experiment and the position of metallic markers. Markers: o, in periosteum; •, in bone; ∀, v, in tendon or ligament. (A) Block of proximal epiphyseal plate of tibia by four staples in the epiphysis and metaphysis. The apophysis is linked to the tibial tuberosity by a loop of wire. *A*, apophysis; *C*, medial collateral ligament; *L*, patellar tendon. (B) Anterior view of inferior extremity of left tibia, with block of distal epiphyseal plate by three staples. X, anterior annular ligament. (C) Section of tendon (*T*) of left tibialis anterior (*M*) near its insertion on the first metatarsal. The tendon is reflected proximally (*R*) in front of the anterior annular ligament (*X*) and fixed in the belly of the muscle. (D) Diagram showing the sites of the regions illustrated in Fig. 4.

70 μm diameter steel wire (Dörfl, 1980). The bony markers allowed the superimposition of radiographs taken every seven days in order to follow the movement of insertions and periosteum. Blocks and tendon sections were performed unilaterally, the other side serving as a control, but in the experiments described under (2) the anterior annular ligament, periosteum and bone were marked bilaterally.

At the end of the experiments, lasting one to four months, the animals were killed by an overdose of Nembutal and the hind limbs of the two sides dissected and compared. The tibias with the insertions were then fixed by immersion in a mixture of 100 % formalin, glacial acetic and absolute ethanol (10:5:85), decalcified in 5 % nitric acid, embedded in paraffin and stained by the method of Herovici (1963).

RESULTS

(1) *Block of proximal epiphyseal plate of tibia* (*Fig.* 1 A)

At the beginning of the experiments the markers in the periosteum, the medial collateral ligament and the superficial part of the patellar tendon were situated at the same level on the metaphysis, and separated by the same distance from the marker in the diaphysis. At the end, 3 to 4 months later, the initial relationships were practically unchanged (Table 1). Figure 2A shows an immediately postoperative radiograph of the tibia of a 60 days old rabbit. Fig. 2B shows the same 109 days later. The markers in the medial collateral ligament, the periosteum and the patellar ligament were at the same level as at the start of the experiment. Their distance from the bony marker had also not changed, apart from a small proximal migration of 0·5 mm in the first week explicable by the fact that the blockage of growth in the epiphyseal plate was not immediate.

The epiphyseal plate block arrests the stretching of the periosteum proximally,

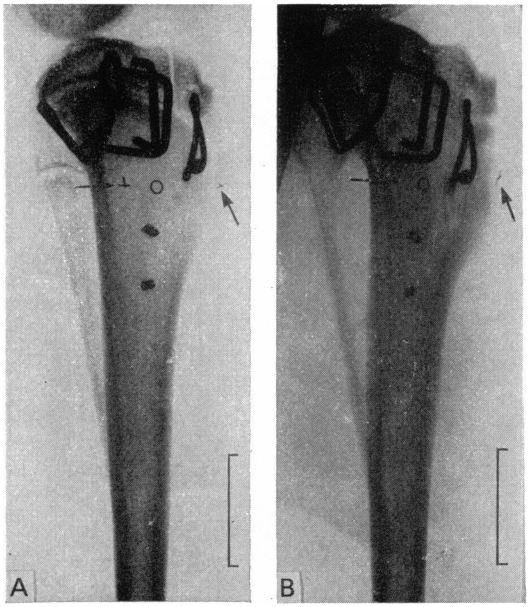


Fig. 2. (A) Radiograph of superior extremity of tibia of 60 days old rabbit immediately after block of epiphyseal plate by five staples. Lateral view. Markers are seen in the medial collateral ligament (thin arrow), periosteum (O) and patellar tendon (thick arrow). There are two heavy markers in the diaphysis. Scale bar = 1 cm. (B) Same 109 days later.

and also the migration of the insertions of the collateral and patellar ligaments. On the other hand interstitial growth in width of the periosteum continues, as seen by the increase in the distance between the markers in the collateral and in the patellar ligament.

Histological examination showed the disappearance of the epiphyseal plate and the union of the epiphysis and diaphysis. The deep part of the patellar ligament, between the inferior surface of the apophysis and the superior pole of the tibial tuberosity, was ossified (Figs. 1D, 4A). The superficial part of the ligament was attached directly to the anterior surface of the tuberosity by bundles of collagenous fibres (Fig. 4B); the layer of precollagenous fibres that forms this attachment during growth was no longer present.

(2) *Block of distal epiphyseal plate of tibia* (*Fig.* 1B)

After unilateral block of the distal epiphyseal plate, the markers in the insertions of the anterior annular ligament and periosteum maintained the same distance from the bony marker during the one to two months of the experiment. On the control limb the markers in the ligament and periosteum migrated distally from the bony marker (Table 1).

In the example shown in Figure 3, the block and marking were done at 45 days of age. Forty one days later there was no migration of the marked regions on the side of the block, apart from a small distal migration of 0·4 mm, in the first week. On the control side the ligamentous and periosteal markers migrated distally by 10 mm in the same period (Fig. 3C, D). As before, the blocking of the epiphyseal plate arrested the stretching of the periosteum and the migration of the ligament.

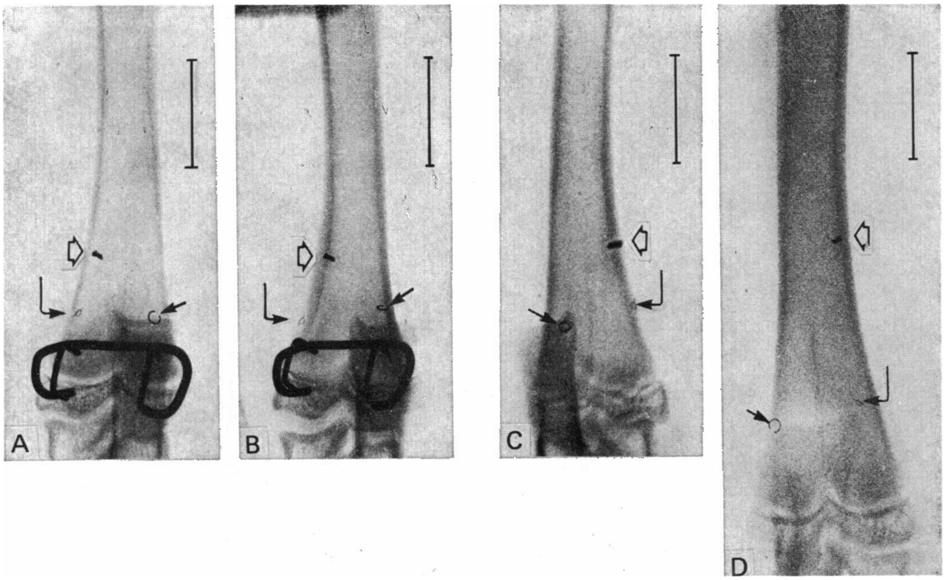
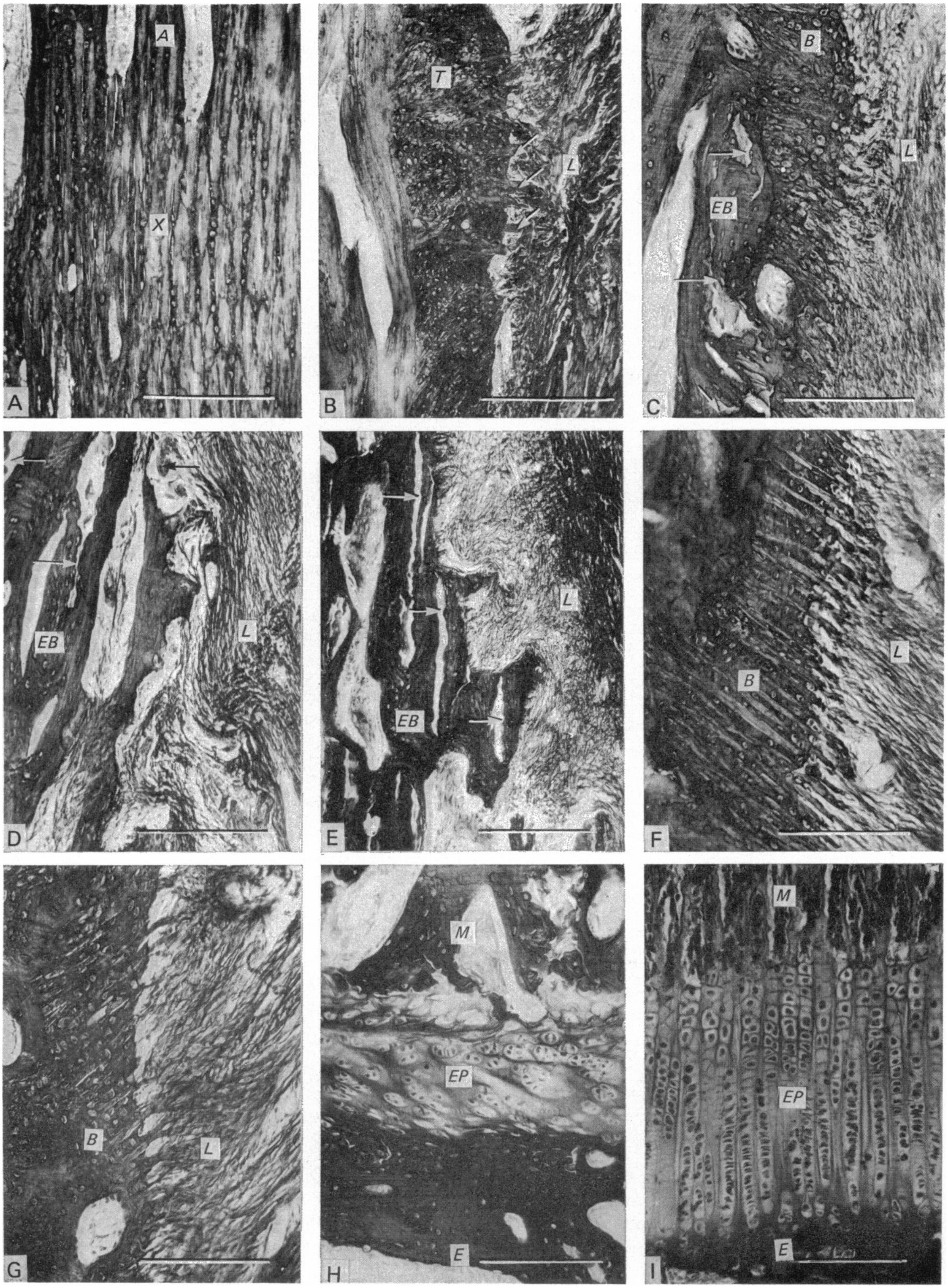


Fig. 3. (A) The inferior extremity of the left tibia of 45 days old rabbit after block of epiphyseal plate. There are markers in the superior insertion of the anterior annular ligament (curved arrow), periosteum (straight arrow) and diaphysis (open arrowhead). Scale = 1 cm. (B) Same as Fig. 3A 41 days later. (C) Inferior extremity of the right (control) tibia of the same animal. (D) Same as Fig. 3C 41 days later.

Histological examination showed significant differences between the blocked and the control tibia.

The superior insertion of the anterior annular ligament on the control side resembled that described in the previous paper (Dörfl, 1980), with osteogenesis in the upper part of the insertion dimple (Fig. 4C) and resorption in the lower part, formed of endochondral bone (Fig. 4D). On the operated side the whole surface of the dimple showed signs of osteogenesis and there were no traces of endochondral bone in the lower part of the dimple (Fig. 4F).

Fig. 4. Photomicrographs of sections stained by the method of Herovici (1963) from the regions indicated in Fig. 1D. Scale bars = 0·2 mm. (A) Sagittal section of the superior extremity of the tibia with epiphyseal block illustrated in Fig. 2B. The deep part of the patellar tendon (*X*) is ossified. *A*, apophysis. (B) Superficial part of the patellar tendon from the same sections as Fig. 4A. The patellar tendon (*L*) is attached to the anterior surface of the tibial tuberosity (*T*) by thick collagenous bundles (arrows). (C), (D), (E) Longitudinal sections of the superior (C, D) and inferior (E) insertions of the anterior annular ligament on the control tibia illustrated in Fig. 3D. (C) Upper part of the insertion dimple, formed by tendinous osteogenesis. This bone (*B*) is very different from the deeper endochondral bone (*EB*). Arrows indicate remains of cartilage. *L*, anterior annular ligament. (D) Lower part of the dimple formed by endochondral bone (*EB*), resorbed at the insertion site of the ligament (*L*). Black arrow, osteoclast; white arrows, cartilage in the endochondral bony trabeculae. (E) Inferior insertion of the anterior ligament (*L*) on the resorbing metaphysis. Symbols as in Fig. 4D. (F), (G) Sagittal sections of the superior (*F*) and inferior (*G*) insertions of the anterior annular ligament on the tibia illustrated in Fig. 3B (with epiphyseal plate block). (F) The whole surface of the superior insertion dimple shows signs of osteogenesis. *B*, bone formed by tendinous osteogenesis; *L*, insertion of ligament. (G) The inferior insertion dimple formed by tendinous osteogenesis. Compare with control side (Fig. 4E). (H), (I) Coronal sections of inferior epiphyseal plate of tibia. (H) Tibia illustrated in Fig. 3B; blocked for 41 days. (I) Tibia of Fig. 3D to show normal epiphyseal plate on control side. *M*, metaphysis; *EP*, epiphyseal plate; *E*, epiphysis.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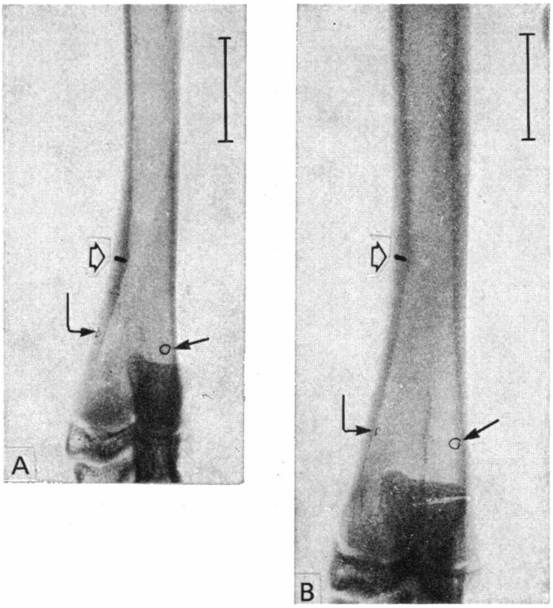

Fig. 5. (A) Anterior view of inferior extremity of the left tibia of a 48 days old rabbit. Tibialis anterior tendon sectioned distal to anterior annular ligament, reflected anteriorly and fixed in the muscle (cf. Fig. 1C). Markers are placed in the superior insertion of the anterior annular ligament (curved arrow), in the periosteum (straight arrow) and in the diaphysis (open arrowhead). Scale = 1 cm. (B) The same tibia 53 days later. Markers in periosteum and ligament have migrated the same distance distally with respect to the bony marker.

The inferior insertion of the anterior annular ligament on the control side was attached to the endochondrally ossified metaphysis. The insertion site is resorptive in character (Fig. 4E). On the side of the blockage the character had changed and was osteogenetic. The endochondral bony trabeculae were completely lacking and the bone deep to the insertion was the result of tendinous osteogenesis (Fig. 4G).

The epiphyseal plate on the blocked side was very thin compared with that of the control side (Fig. 4H, I).

(3) *Section of tibialis anterior tendon* (*Fig.* 1C; *Table* 1)

In this third type of operation the tendon of tibialis anterior was sectioned below the anterior annular ligament and turned proximally to form a loop around the ligament and fixed to the muscle belly in order to hinder the distal migration of the ligament.

At the end of the experiment it was found that the fixation of the reflected tendon to the muscle was good. In addition, the tendon was solidly attached to the anterior annular ligament by fibres: there was a true insertion of tibialis anterior on the annular ligament.

The operation illustrated in Figures 5 and 6 was performed on a rabbit aged 48 days and lasted 53 days. In spite of the resistance caused by the muscle, the annular ligament migrated 10·5 mm distally from the bony marker. The periosteal marker migrated the same distance (Fig. 5). Macroscopic examination (Fig. 6) showed that the annular ligaments of both sides inserted at the same level on the

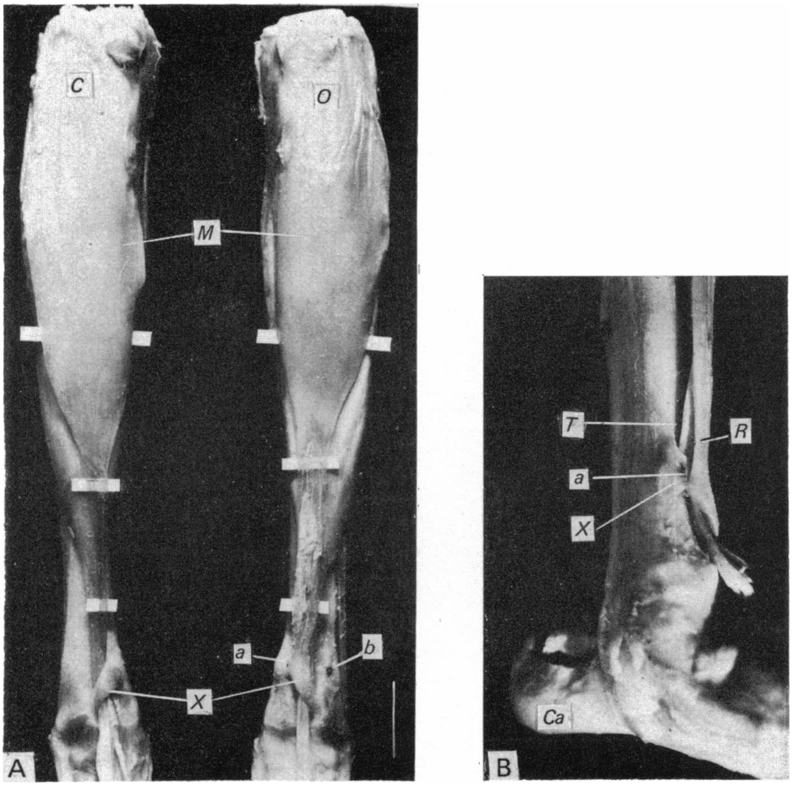

Fig. 6. (A) Operated (*O*) and control (*C*) limbs of third experimental series (cf. Fig. 1C). Anterior view of limbs illustrated in Fig. 5B. 53 days after operation the annular ligaments of both sides are at the same height. (B) Detail of Fig. 6A, operated side. Medial view of anterior annular ligament and the reflected and descending parts of the tibialis anterior tendon. *X*, anterior annular ligament; *M*, tibialis anterior; *R*, reflected part of tibialis anterior tendon; *T*, descending part of tendon; *Ca*, calcaneum; markers in ligament (*a*) and periosteum (*b*).

tibia. The operated tibialis anterior was not atrophied compared with the control side. In all cases the annular ligament on the operated side migrated the same distance as that on the control side during the experiment.

DISCUSSION

Normal migration of tendons and ligaments was modified in two ways: (i) by interfering with the growth of periosteum by blocking the growth of the epiphyseal plates (experimental series 1 and 2); (ii) by changing the nature of the insertion itself (series 3).

The results of the experiments lead to the following conclusions: During normal growth the epiphyses are pushed apart by the action of the epiphyseal plates, thus stretching the periosteum attached around their margins. The periosteum reacts to this stretching by interstitial growth equally along its whole length (Warwick & Willes, 1934; Lacroix, 1949; Hert, 1960). During this growth it slides over the surface of the bone, pulling the insertions of the tendons and ligaments with it. The blocking of the epiphyseal plates prevented the stretching, and thus the growth, of the neighbouring periosteum. The migration of insertions also stopped, although

Table 1. *Summary of results of the three types of operation*

In the first and third type of experiment, both intervention and marking were performed on one side only. In the second type the staples were placed in the left tibia while the periosteum and the insertion of the anterior annular ligament were marked bilaterally. For each type of operation, rabbits were from various impure strains and from several litters.

(A) Block of proximal epiphyseal plate of tibia

No. of animal	Age (in days) at marking and operation	Duration (in days) of experiments	Displacement of markers (P, periosteal; L, in medial collat. lig.; T, in patellar lig.)		
			P	L	T
1	60	109	0·5	0·5	0·5
2	60	118	0·5	1	0·5
3	75	89	0·5	0·5	1
4	82	83	1	1	0·5
5	82	87	0·5	1	0·5
6	83	75	0·5	0·5	1
7	87	130	0·5	0·5	1

(B) Block of distal epiphyseal plate of tibia

No. of animal	Age (in days) at which markers were placed	Duration (in days) of experiments	Displacement of markers on control (C) and operated (O) sides. (P, periosteal; L, in ant. annular lig.)			
			C		O	
			P	L	P	L
1	30	29	7	7	0·5	0·5
2	45	39	9·5	9·5	0·5	0·5
3	45	41	10	10	0·4	0·4
4	45	46	10·5	11	0·5	1
5	52	31	7	7·5	0·5	0·5
6	52	57	9·5	9	0·5	0·5
7	52	57	9	9	0·5	1

(C) Section of tibialis anterior tendon

No. of animal	Age (in days) at operation and marking	Duration (in days) of experiments	Displacement of markers (P, periosteal; L, in ant. annular lig.)	
			P	L
1	40	32	5	5·5
2	40	32	5	5
3	48	39	6·5	6·5
4	48	53	10·5	10·5
5	48	53	10	10

the patellar ligament, for example, was subjected to muscular traction and the medial collateral ligament was stretched by the growing distal epiphysis of the femur.

The third series of experiments did not modify the growth of periosteum but changed the nature of the insertion of the anterior annular ligament. This ligament, normally inserted on the distal part of the tibia where it forms an osteofibrous canal for the extensor tendons, was forced to become the secondary insertion of the tibialis anterior muscle. The direction of the traction of the muscle and the direction of the migration of the ligament were not the same, in contrast to the situation in the first and second series of experiments. The distal migration of the ligament was constantly opposed by a resistance in the opposite direction. In spite of this, the migration of the ligament was normal.

These experiments indicate that muscular traction plays no role in the migration of tendons and ligaments. After block of the proximal epiphyseal plate of the tibia, the traction exerted on the patellar ligament caused no migration, and in the third series of experiments the traction opposing the migration was unable to arrest it. This study confirms the conclusion in the previous paper (Dörfl, 1980), that the relationship between periosteal growth and the migration of insertions is not fortuitous but causal, with the principal role belonging to the periosteum.

SUMMARY

The relationship between the migration of tendinous insertions, periosteal growth and muscular traction was studied in young rabbits. Normal growth was modified in two ways: (i) the growth of the proximal and distal epiphyseal plates of the tibia was arrested by staples. As a consequence, the neighbouring periosteum, no longer stretched, stopped growing in length; insertions were thus no longer dragged by the periosteum and ceased to migrate. (ii) The nature of the insertion of the anterior annular ligament of the tibia was changed by sectioning the tendon of the tibialis anterior muscle near its insertion and reflecting it proximally in a loop around the ligament. In this case the ligament migrated normally in spite of the muscular traction in a direction opposite to the direction of migration.

It is concluded that the direct cause of the migration of muscular and ligamentous insertions is periosteal growth.

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