OBSERVATIONS ON THE STRUCTURE AND PROPERTIES OF THE PLANTAR CALCANEO-NAVICULAR LIGAMENT IN MAN

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The plantar calcaneo-navicular ligament in man unites the anterior margin of the sustentaculum tali to the tuberosity of the navicular. It is a broad, flat, yellowish band approximately 2–3 mm. thick, 25 mm. long, and 12 mm. wide at its mid-length in the adult. Looked at from above its general shape is rhomboidal with its longer side on the tibial aspect. It forms the greater part of the inferior surface of the joint at the head of the talus, converting the anterior talo-calcanean joint and the talo-navicular joint into a partial socket for the head of the talus. The upper surface of the ligament is covered (at least in its lateral part) with articular cartilage. It is commonly known as the 'spring' ligament, and is presumed, by its position, to control the descent of the head of the talus. No opinion is expressed in standard text-books of anatomy or histology as to its physical properties, and its synonym leads frequently to the view that it is elastic in nature and so allows descent of the head of the talus in various movements of the foot. The present observations have been made in order to throw further light upon this question.

MATERIAL

For determining whether the head of the talus in the human foot does in fact descend, standard radiographs taken by a method described elsewhere by Venning & Hardy (1950) were used. It was found that this method made possible the production of successive radiographs of any individual foot, from which measurements could be taken within certain definite limits of accuracy. It was found, for instance, that, in measuring the 'arch-height' dimension (see below), in an average measurement of 45 mm. a standard deviation of $\pm 1{\cdot}5$ mm. occurred. This deviation takes into account the errors due to mensuration, to the optical limitations of the skiagraphic method, and to variations in the subject's foot from time to time. From these films measurements were also made of the amount of separation between the bony attachments of the spring ligament and of the long (vertical) axis of the navicular.

The association between histological structure and physical properties of ligaments was investigated in the cat. Of a number of ligaments examined two were found suitable for illustrating this association: the ligamentum patellae and the ligamentum flavum. These ligaments had the great advantage that they could be rapidly removed from the animal together with their bony attachments, a fact which made them easy to handle.

Four fresh specimens of human plantar calcaneo-navicular ligament were used to study the histological structure of the spring ligament itself.

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Radiography of human foot. A series of lateral (medio-lateral) radiographs was taken of each foot of ten subjects (students under 30 years of age; five of each sex) under the following three different conditions:

(*a*) Standing upright, with knee extended, and the whole body weight borne on one foot ('standard' position).

(*b*) Standing with the whole body weight borne on one foot with knee flexed, and trunk, thigh and leg internally rotated as far as possible (a one-legged, squatting position). As the foot is fixed by having its inferior surface applied to the ground and by bearing the whole body weight through that area of contact its relation to the horizontal is barely altered. It is however subjected to what may be called 'passive eversion and extension'.

(*c*) Standing as described in (*a*), but exercising an active contraction of the tibialis posterior muscle. This was a practised movement often requiring some minutes of precept and example before it was mastered. The foot was kept in a relatively stable position as before by the weight-bearing contact of its inferior surface with the ground, and was subjected to what may be called 'active inversion and adduction'. The tibialis posterior (the function of which is described by Duchenne (1867) as the approximation of the tuberosity of the navicular to the tibial malleolus) is here acting between two relatively fixed points—the standing leg and the weight-bearing foot—so that its force will be exerted upon its points of deflexion, behind and beneath the tibial malleolus and beneath the head of the talus, with the spring ligament interposed.

Measurements of three dimensions on each set of twenty radiographs thus obtained were made as follows:

(i) The distance from the lowest point on the head of the talus to a base-line (Pl. 1, fig. 1, *AB*) joining the lowest point of the sesamoids of the first metatarso-phalangeal joint to the lowest point of the calcaneum (hereinafter referred to as the 'arch-height' dimension; Pl. 1, fig. 1, *CD*).

(ii) The apparent length of the plantar calcaneo-navicular ligament, measured as the distance between a point midway on the anterior margin of the sustentaculum tali and a point midway down the posterior border of the tuberosity of the navicular (hereinafter referred to as the 'spring-ligament' dimension; Pl. 1, figs. 2 and 3, *EF*).

(iii) The apparent length of the long (vertical) axis of the navicular itself (Pl. 1, figs. 1, 2 and 3, *GH*).

Tables 1, 2 and 3 give the results of these measurements as the mean and standard deviation of each group, the mean differences between the 'standard' position, and those of 'passive eversion' and 'active inversion' respectively, with a *t*-test for the significance of the differences observed between each two groups.

Table 1. '*Arch-height*' (*mean of measurements of twenty radiographs*) *under conditions described in the text*

Position	Mean measure (mm.)	Mean difference (mm.)	S.D. of differences (mm.)	Value of '*t*'	Probability ($f=19$)	Significance
(*a*) Standard	45·0	(*a* – *b*) 7·6	±3·8	9·02	<0·001	Significant
(*b*) 'Passive eversion'	37·4	(*c* – *b*) 10·0	±4·5	10·11	<0·001	Significant
(*c*) 'Active inversion'	47·4	(*c* – *a*) 2·4	±1·7	6·48	<0·001	Significant

Pl. 1, figs. 1–3 show typical radiographs of the right foot of one subject in each of the three positions described.

Table 2. *'Spring-ligament length' (mean of measurements of eighteen* radiographs)*

Position	Mean measure (mm.)	Mean difference (mm.)	S.D. of differences (mm.)	Value of '*t*'	Probability ($f=18$)	Significance
(*a*) Standard	19·7	(*a* – *b*) 0·5	±1·3	0·60	>0·5	Not significant
(*b*) 'Passive eversion'	19·2	(*c* – *b*) 0·7	±1·0	0·74	>0·4	Not significant
(*c*) 'Active inversion'	19·9	(*c* – *a*) 0·1	±1·0	0·19	>0·8	Not significant

* One case showed bilateral absence of the sustentaculum tali, so that no measurement could be made.

Table 3. *Long axis of navicular (mean of measurements of twenty radiographs) under same conditions as Tables* 1 *and* 2

Position	Mean measure (mm.)	Mean difference (mm.)	S.D. of differences (mm.)	Value of '*t*'	Probability ($f=19$)	Significance
(*a*) Standard	33·7	(*b* – *a*) 3·4	±1·5	5·33	<0·001	Significant
(*b*) 'Passive eversion'	37·1	(*b* – *c*) 6·3	±2·5	8·53	<0·001	Significant
(*c*) 'Active inversion'	30·7	(*a* – *c*) 3·7	±1·8	4·85	<0·001	Significant

PHYSICAL PROPERTIES OF LIGAMENTS

Classical work on the breaking strain of human and animal ligaments and tendons has been done by Cronkite (1936), and on the elasticity of small strips of fascia lata by Gratz (1931). The object in the present investigation was to find two ligaments of compact formation with entirely different functions, and for the reasons outlined above the ligamentum patellae and the ligamentum flavum of the cat were used. The function of the former, which is a tendon developmentally and morphologically but nevertheless a collagenous structure uniting two bones, is clearly to transmit the force exerted by the contraction of the quadriceps femoris to the tibia, via the patella. The function of the ligamenta flava is, however, very different; they may be said to exert a controlling effect upon the neural arches in flexion of the spine, and presumably tend to restore them to apposition with one another against the force of active flexion.

These two ligaments were selected to determine the relationship between histological structure and physical properties, in particular the occurrence of elasticity, which for the purpose of this paper is defined as the ability to regain the original length after stretching.

Only brief mention need be made of the work on these ligaments, and their characteristic histology is well known.

The ligamentum patellae, when subjected to longitudinal loading, breaks before any visible stretching occurs. In one instance (the ligament of a 14 lb. cat) the breaking load was 56 lb. on the fresh material used. This ligament is entirely collagenous in structure. The ligamentum flavum, on the other hand, stretches to approximately 140 % of its original length under comparatively small loads and regains its original length immediately the load is removed. Histologically it contains a very large amount of elastic tissue.

The four plantar calcaneo-navicular ligaments were obtained from four female subjects aged 14 years (death from liver disease), 26 years (death from obstetric shock), 42 years (death from stem-cell lymphoma) and 59 years (from a leg amputated below the knee for diabetic gangrene of the great toe). In each case the specimens were fixed, within 24 hr. of death or amputation, in 10 % formol-saline. Longitudinal sections were made, after fixation under tension, by mounting in wax and celloidin. Haematoxylin and van Gieson's stains were used to show the general histological structure of all the ligaments, and Weigert's elastin stain was used for the specific purpose of determining whether elastic tissue was present.

Owing to the fact that elastic ligaments lose their characteristic physical properties within an hour or so after removal from the body it was not possible to perform valid tests of loading upon the human material. It is not, however, without interest to observe that it was impossible to produce any perceptible stretching in the one human 'spring ligament', examined within 5 hr. of amputation, under a load of 56 lb. applied in the manner described above.

Histologically the human plantar calcaneo-navicular ligament (Pl. 2, figs. 4, 5) consists of dense bundles of collagen fibres, partly parallel in their arrangement but partly interlacing in appearance. In the substance of the ligament no elastic fibres could be detected by Weigert's elastin stain, although elastic tissue was clearly seen in the walls of blood-vessels and to some extent in the associated peri-articular connective tissue.

CONCLUSIONS

It is concluded from radiographic evidence that there is an apparent descent of the head of the talus in relation to the rest of the foot, which is not associated with any significant increase in the distance between the bony attachments of the plantar calcaneo-navicular ligament. The head of the talus descends towards a given baseline, under the influence of 'passive eversion' of the foot, by an amount which is equivalent to approximately 17 % of the total distance measured, a statistically highly significant difference. The distance between the bony attachments of the 'spring ligament' shows an increased separation in the same position of 2·5 %, which is not significant. Although this evidence is not sufficient in itself it is borne out by the histological evidence. If a purely collagenous ligament is subjected to longitudinal loading it is found that it breaks before it stretches; the ligamentum flavum, on the other hand, which is largely composed of elastic tissue, will stretch under load to approximately 140 % of its unstretched length, and then regain the original length when the load is removed. Histologically the plantar calcaneo-navicular ligament belongs to the former class.

It therefore appears likely that this ligament does not possess elastic properties. It is, however, observed that as the head of the talus descends the apparent long axis of the navicular itself (i.e. the length of its shadow) increases by approximately 10 % of its total length. This apparent change in length is presumed to represent a rotation of the navicular about its short (inter-articular) axis. It is suggested that this rotation is concerned in a movement of the anterior attachment of the plantar calcaneo-navicular ligament laterally and downwards which allows descent of the head of the talus in the circumstances described.

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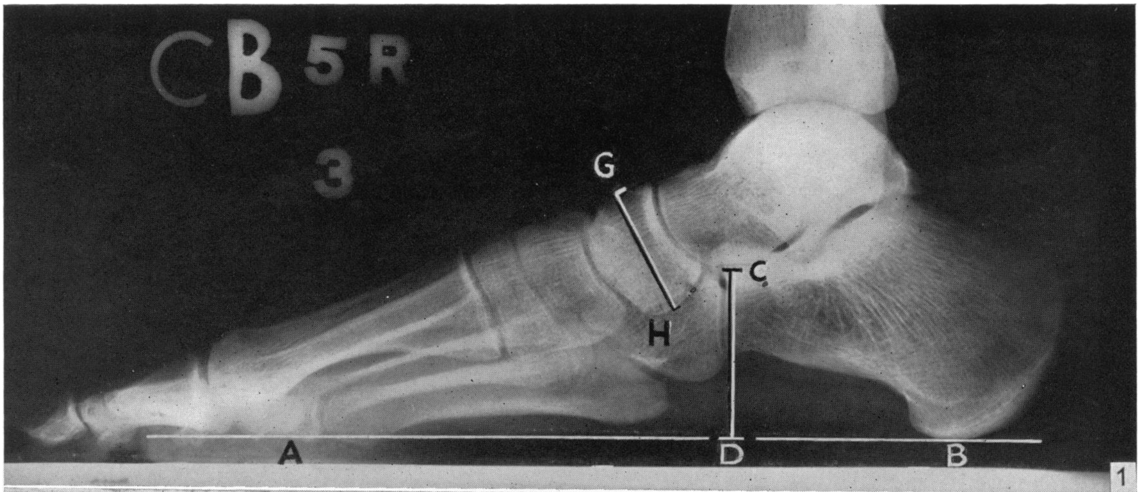

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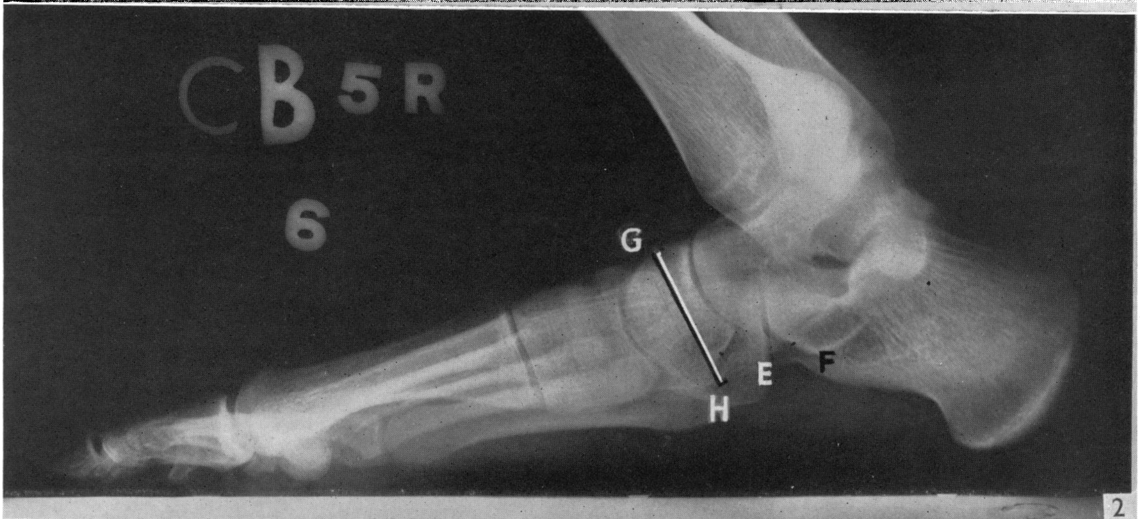

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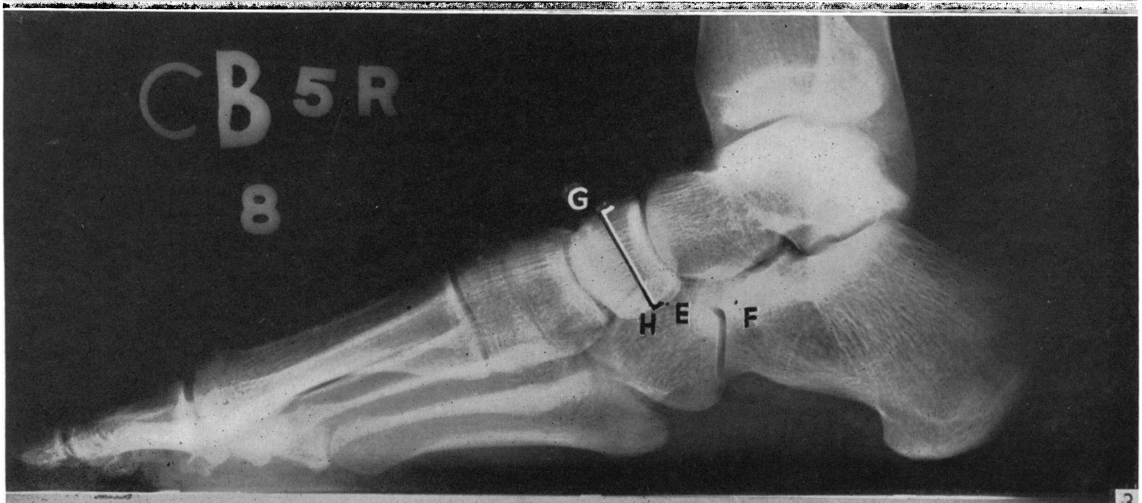

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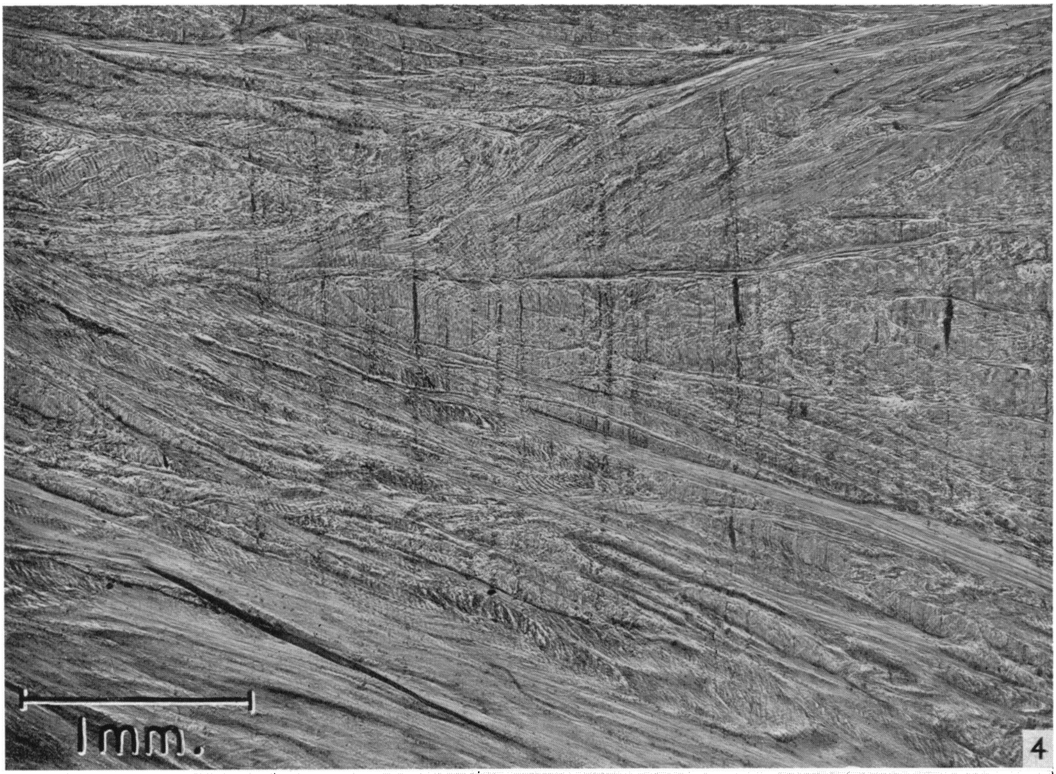

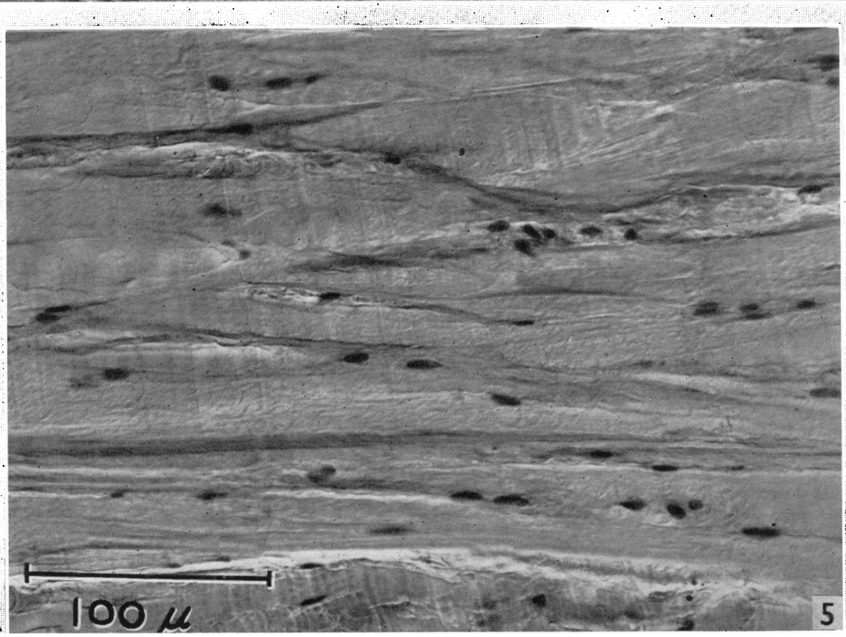

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EXPLANATION OF PLATES

PLATE 1

Fig. 1. Lateral radiograph of foot in 'standard' position. *AB*, base-line; *CD*, arch height; *GH*, long axis of navicular.

Fig. 2. Lateral radiograph of foot in position of 'passive eversion'. *EF*, bony insertions of 'spring' ligament.

Fig. 3. Lateral radiograph of foot in position of 'active arching' (contraction of tibialis posterior).

PLATE 2

Fig. 4. Human plantar calcaneo-navicular ligament sectioned at 8μ (Ehrlich's haematoxylin). $\times 30$.

Fig. 5. As fig. 4. $\times 320$.