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Innervation of the anterior cruciate ligament

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Summary. *The innervation of 21 human anterior cruciate ligaments (ACL) obtained at autopsy or during operation was studied by light microscopy. Nerves and nerve endings were found in the synovium and interfascicular connective tissue. The nerves were myelinated and/or unmyelinated and had terminal nerve structures with free nerve endings which provide nociception and supply the blood vessels, Ruffini corpuscles and Pacini corpuscles, which are mechanoreceptors in the ligaments.*

Résumé. *Etude en microscopie optique de l'innervation du ligament croisé antérieur à l'aide de 21 spécimens obtenus lors d'une intervention ou d'une autopsie. Des nerfs et des terminaisons nerveuses ont été trouvés dans la synoviale et dans le tissu conjonctif intra-fasciculaire. Les nerfs sont myélinisés et/ou non, et présentent des structures terminales libres qui assurent la nociception et innervent les vaisseaux sanguins, ainsi que les corpuscules de Ruffini et de Pacini, qui constituent les récepteurs de l'allongement de ces ligaments.*

Introduction

Müller has demonstrated the differentiated anatomical structures of the knee joint and the principles of their function which are governed by bio-"precision mechanics" [14]. We can anticipate that there is an adequate sensory innervation to form the basis of these mechanisms, especially in the case of the anterior cruciate ligament (ACL) which has a central stabilising function.

As early as 1904 Fick gave an account of the nerves in the knee and ACL [3] which others elaborated later [5, 11–13, 18]: The ACL is well supplied with nerves. Nerve-ending corpuscles have been described [7, 17, 18, 21], but the structures shown needed to be interpreted with great imagination by the reader. We therefore attempted to demonstrate the nerves and nerve endings more clearly by using other techniques for embedding the specimens.

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Material and methods

Twenty-one ACL with their synovium, 19 taken from cadavers and 2 at operation, were examined by light microscopy. Each ligament was divided transversely into a femoral, middle and tibial third and divided further into three parts during the 48 h fixation process. Two thirds of the specimens were then embedded at random in either glycolmethacrylate[1] (GMA) or Epon. The GMA embedded material and about half of the Epon embedded material was then sectioned in the transverse plane and stained.

Results

The ACL consists of collagenous fascicles and a synovial sheath. The subsynovial layer and the tissue lying between the fascicles are in close communication with each other [11]. The nerves and vessels run through the subsynovial layer and between the fascicles but not through the fascicles themselves.

A fibrous synovial layer on the anterior surface of the ACL, an areolar synovium on the posterior surface and an areolo-adipose synovium on the posterolateral aspect of the ACL can be distinguished [11]. We were able to establish that the largest numbers of nerves with a diameter of up to 250 μm, lie in the areolo-adipose synovium.

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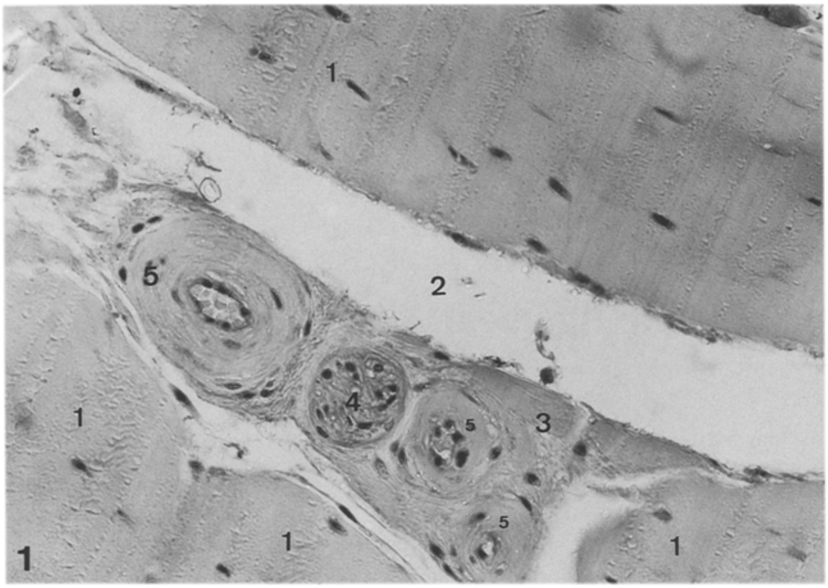


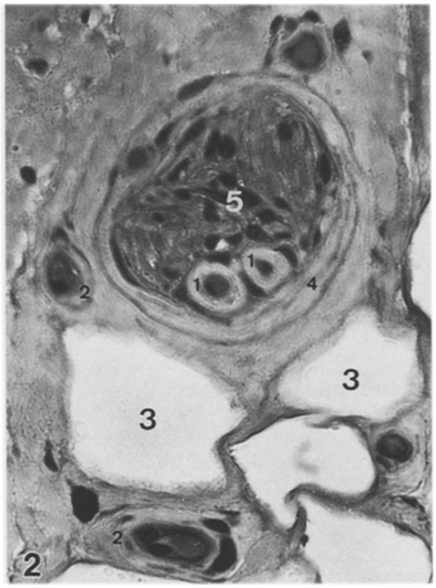
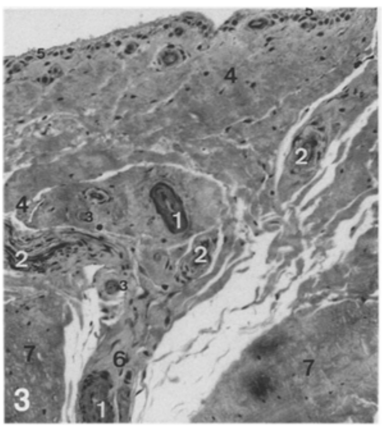
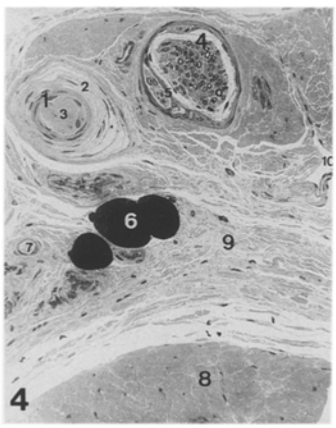


Fig. 1. Interfascicular bundle of vessels and nerves. Collagenous fascicles (*1*), interfascicular space (*2*), interfascicular connective tissue (*3*) with nerve (*4*) and vessels (*5*). Magnification 240 x (GMA)

Fig. 2. Mixed nerve, containing 2 blood vessels. Capillaries (*1*), venules (*2*), vacuoles of fat (*3*), perineural sheath (*4*), nerve fibres with Schwann cells (*5*). Magnification 450 x (GMA)





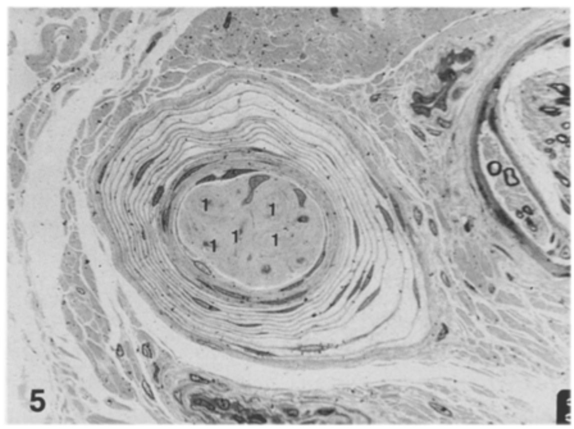


Fig. 3. A section of the area of the areolar synovium. Arterioles (*1*), venules (*2*), small nerves (*3*), subsynovial tissue (4), layer of synoviocytes (*5*), interfascicular connective tissue and its septa-like radiation (*6*), fascicles of the ACL (*7*). Magnification 85 x (GMA)

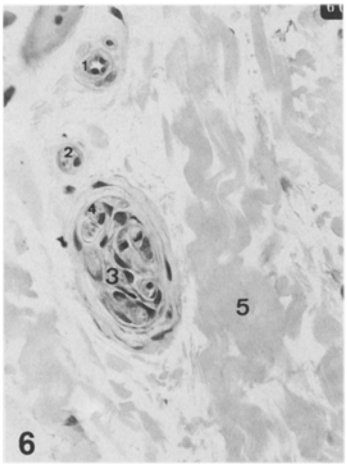
Fig. 4. Pacini corpuscle in the subsynovial border area between the anterior and posterior cruciate ligament. Pacini corpuscle (*1*) with multiple lamellae (*2*) and several inner cores (*3*), mixed somatic nerve (**4**) with unmyelinated and myelinated nerve fibres, perineural septa (*5*), fat cells (*6*), small unmyelinated nerve (*7*), fascicles of the ligament (*8*), subsynovial tissue (*9*), lymph vessel (*10*). Magnification 140 x (Epon)

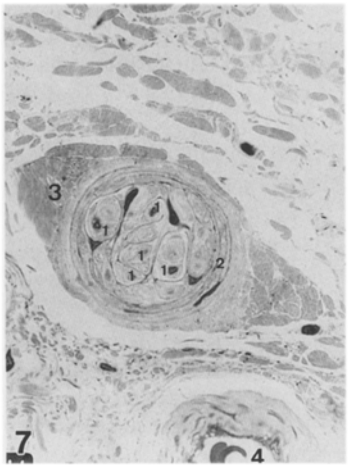
Fig. 5. Greater magnification of the same Pacini corpuscle. Several inner cores (*1*). Magnification 300 x (Epon)

Fewer nerves of a smaller size run into the area of areolar synovium (Fig. 3) and in rare cases in the fibrous synovium. Nerves radiate from the subsynovial layer between the single collagenous fascicles where smaller nerves of up to 130 μm can be found.

Four kinds of peripheral nerves were distinguished within the ACL:

1. Small nerves with unmyelinated nerve fibres (Figs. 3 and 4)
2. Mixed nerves with myelinated and unmyelinated nerve fibres (Figs. 1 and 8)





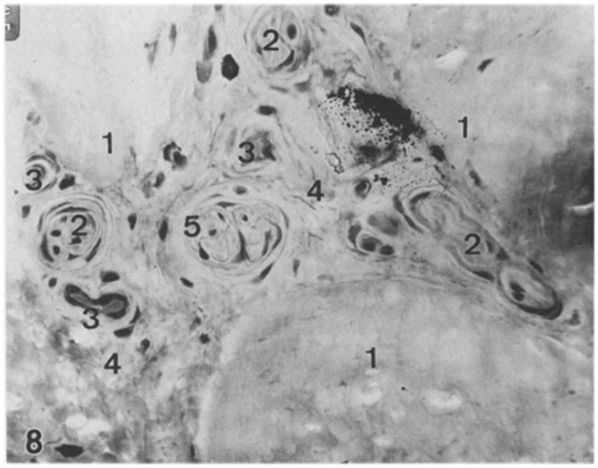


Fig. 6. Ruffini corpuscle (areolar synovium). Companion vessel (*1*), myelinated nerve (*2*), Ruffini corpuscle (*3*) with 2 myelinated nerve fibres (*4*), collagenous strands of connective tissue (*5*). Magnification 250 x (GMA)

Fig. 7. Interfascicular Ruffini corpuscle with cylindrical septal substructure. Cylinders with Schwann cells (*1*), perineural sheath (*2*), tight collagenous tissue (*3*), venule (*4*). Magnification 360 x (Epon)

Fig. 8. Interfascicular Ruffini corpuscle. Collagenous fascicles of the ACL (*1*), nerves (*2*), venules (*3*), interfascicular connective tissue (*4*), Ruffini corpuscle (*5*) with septa and three myelinated nerve fibres (*above right*) as well as a perineural capillary. Magnification 250 x (GMA)

3. Mixed nerves with 1–3 vessels at their margins (Fig. 2)
4. Mixed nerves with vessels at their margins and an additional perineural sheath (Fig. 4).

In the larger nerves, myelinated nerve fibres from 2 to 10 μm in diameter could be clearly demonstrated (Fig. 4). Smaller nerves with unmyelinated nerve fibres lie often in close proximity to blood vessels.

Our investigations confirmed that the typical articular nerve endings described by several authors [1, 4, 5, 8, 9] were present in the ACL, namely free nerve endings, Ruffini corpuscles (Figs. 6, 7, and 8) and Pacini corpuscles (Fig. 4 and 5). Altogether 21 Ruffini corpuscles and 5 Pacini corpuscles could be definitively identified by light microscopy. Free nerve endings were not distinguishable from small nerves by light microscopy, but were seen on electron microscopy [10].

In the transverse plane nine of 21 Ruffini corpuscles were found in the interfascicular region (Fig. 7 and 8), 10 were in the subsynovial layer (Fig. 6) and 2 in the border zone between the ligament and the synovium. In the sagittal plane 10 of the 21 Ruffini corpuscles could be found in the femoral third of the ACL, 5 in the middle third and 6 within the tibial third. They were oval or round in shape, with a diameter of about 120 μm. They were surrounded by a perineural capsule of several layers (Fig. 7). One to three myelinated axons, diameter 3–5 μm, could be identified in all corpuscles which were themselves subdivided by cylindrical perineural septa containing at least one vessel (Figs. 6 and 8).

In the transverse plane the 5 Pacini corpuscles were all found only in the subsynovial layer. In the sagittal plane 2 of the 5 Pacini corpuscles were located in the femoral third of the ACL, 1 in the middle third and 2 in the tibial third. Their maximum size was about 150 μm. The best demonstration of their substructure was seen in an Epon-embedded sample (Figs. 4 and 5). It was the first time that the characteristic pear-shaped form, with a perineural sheath of 15 fine lamellae and 10 inner cores, had been demonstrated in the ACL with such clarity. This corpuscle was found in the middle third of the ligament, exactly where the subsynovial tissue separated the ACL from the posterior cruciate ligament.

Discussion

An interesting finding is that in one specimen a Pacini corpuscle was present in the common subsynovial border zone separating the anterior and posterior cruciate ligament. The winding-up and unrolling of these ligaments during rotational movements seems to be controlled by a nerve ending corpuscle. This may be regarded as a "limit-detection function" of the physiological tolerable limit of movement [6, 15, 16], or it can be interpreted as the control of small movements via the perception of acceleration [19].

The latent period of conduction in nerve fibres, from the stimulus of the nerve ending structure to the muscle reaction, points to the vulnerability of a possible ligamento-muscular feedback control system, the so-called "ACL-reflex" [7]. This additional dynamic muscular stabilisation works in parallel with the static stabilisation produced by the collagenous structure of the ACL. The mechanism can be put of action by forces which are swift and beyond physiological limits. When rupture of the ACL occurs, there is a loss of both mechanical stability and proprioception.

Further evidence of the nervous elements familiar in clinical practice is the flexion contracture after fresh ruptures of the ACL. In most cases the anterior drawer sign cannot be elicited since, as a result of nerve injury (demarcation potential) caused by the rupture, there is probably stimulation of the hamstrings. In spite of this reflex contraction, Lachman's sign [20] can be elicited in most cases. This is because the moment of leverage of the hamstrings can be overcome more easily at a small angle of flexion with a short lever arm, and because the hamstrings cannot develop their full power as a result of pre-stretching [2] at 15° of knee flexion.

For the first time nerve ending corpuscles were demonstrated in specimens of the human ACL embedded in GMA and Epon. It was possible to assess the structure of these corpuscles and their topographical relationship to the synovium and collagenous fascicles in the ligament. Mechanical stabilisation and proprioceptive function are combined within this small space.

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