Mechanoreceptors in the anterior cruciate ligament contribute to the joint position sense

Nobuo Adachi, Mitsuo Ochi, Yuji Uchio, Junji Iwasa, Koji Ryoke and Masakazu Kuriwaka

Department of Orthopaedic Surgery, Shimane Medical University, Izumo, Shimane, Japan. E-mail: mitsuo@shimane-med.ac.jp
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ABSTRACT – We have investigated the correlation between the number of mechanoreceptors in anterior cruciate ligament (ACL) remnants and the joint position sense just before an ACL reconstruction in 29 patients.

The number of mechanoreceptors was evaluated histologically, using the Gairns gold chloride method. Mechanoreceptors were also found in patients who had a long interval between injury and the operation. A joint position sense test was done within 3 days before surgery.

We found a positive correlation between the number of mechanoreceptors and accuracy of the joint position sense, suggesting that proprioceptive function of the ACL is related to the number of mechanoreceptors. Therefore, we should consider preserving ACL remnants during ACL reconstruction.

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Schultz et al. (1984) published the first detailed description of mechanoreceptors in human ACL and suggested that they may have a proprioceptive function. Schutte et al. (1987) reported that human ACL is extensively innervated and that neural elements comprise about 1% of the area of the ligament. Proprioceptive function of the knee has been measured in various ways, such as with the joint position sense test (Skinner et al. 1984, Corrigan et al. 1992), threshold to detection of passive motion (TTDPM) (Barrack et al. 1989), and latency of reflex hamstring contraction (Solomonow et al. 1987, Beard et al. 1993). It has been reported that in an ACL-deficient knee, proprioceptive function is less than that found in a normal knee.

Although mechanoreceptors in the ACL seem to play an important role in proprioceptive function, we have found no studies of the correlation between the number of mechanoreceptors in ACL and proprioceptive function. Since it is difficult to study this in a normal knee, we evaluated mechanoreceptors in ACL remnants obtained from ACL reconstructions and measured joint position sense before reconstruction.

Patients and methods

Between April 1997 and January 1999, we studied 29 knees in 29 patients (17 women) who underwent ACL reconstruction. Their median age was 27 (14–47) years. The median interval from injury to operation was 8 months (2 months–10 years). 28 injuries had been caused by sports and 1 by a fall. None of these patients had undergone previous knee surgery. Before the operation, written informed consent was obtained from each patient to remove the ACL remnant.

Clinical measurements

Joint position sense tests and anterior instability measurements were done 3 days before the operation.

Joint position sense tests evaluate the ability of patients to reposition their knee to a previously placed angle. The test was done using Skinner et al.'s (1984) method with a Cybex II dynamometer. First, an examiner extended the knee of the sitting patient at a slow steady rate of about 10° a second from the 90° starting position. The leg was then

stopped at a random angle between 5° and 25° and held by the examiner for 3 seconds. The patient was asked to remember the position of the leg. The knee was then returned to the starting angle, and the patient was asked to return the leg to the previous position. Inaccuracy was recorded as a difference between perceived angle and actual angle of flexion. This measurement was made 10 times in both knees, and the average inaccuracy was calculated for each knee. Final inaccuracy was expressed as the difference between the average inaccuracy for the injured knee and that for the normal knee.

Anterior displacement of the tibia was measured using the KT-2000 knee arthrometer with 20° of flexion, while applying an anterior force of 133 N to the tibia. Both injured and uninjured knees were assessed. The laxity was recorded as the difference (in mm) in displacement between the injured and uninjured knees.

Arthroscopy and resection of ACL remnants

With the patient under general anesthesia, we performed a routine arthroscopic inspection through the lateral and medial infrapatellar portal using a 30° oblique arthroscope. Only patients whose ACL remnants still bridged the femur and tibia were included in this study. Patients whose ACL remnants were completely ruptured and no longer bridged the femur and tibia or that could not be found were excluded.

After cutting both femoral and tibial attachments, the ACL remnant with its synovium was removed as a whole or, in some cases, we had to resect the ACL remnant piece by piece. The remnant was weighed immediately in the operating room (wet weight) and refrigerated at 4 °C. Within 1 hour, the remnant was placed in a freezing medium, flash-frozen at –196 °C in liquid nitrogen, and stored at –80 °C, pending sectioning and staining.

Staining

After rapid thaw, the ACL remnant was washed in physiological saline solution for 5 minutes, and then cut into cross-sectional segments about 5 mm thick. Neural elements were stained with Gairns (1930) gold chloride method, as modified by Zimny et al. (1985).

Stained segments were put in the freezing medium and were again flash-frozen at –196 °C in liquid nitrogen. Segments were sectioned with a sliding microtome to a thickness of 100 μm. When sectioning these stained segments, we were careful to make cross-sections of the ACL remnants. All serial sections were examined under a light microscope, using the morphological criteria of Freeman and Wyke (1967). These mechanoreceptors are referred to as Ruffini receptors, Pacini receptors, Golgi tendon organ-like receptors and free nerve endings. Since it was impossible to count the exact number of free nerve endings, we excluded them from our count. The total number of mechanoreceptors was counted in all serial sections. The density of mechanoreceptors was determined by dividing the total number of mechanoreceptors by the wet weight of the ACL remnant. All histological examinations were done by one of the authors who was blinded to all clinical data, including the joint position sense results.

Statistics

We used the Wilcoxon signed rank test to compare the inaccuracy of the joint position sense in the normal and injured knees. Spearman's correlation coefficient was calculated for the total number of mechanoreceptors in each ACL remnant with the wet weight of the remnant, the final inaccuracy of the joint position sense, the patient's age, the interval from the injury to the operation, and anterior laxity of the knee. We also determined correlations between the density of mechanoreceptors and other variables and between the anterior laxity of the knee and the final inaccuracy of joint position sense. All these analyses were done on Statview. P-values of less than 0.05 were considered statistically significant.

Results

The median wet weight of ACL remnants was 0.7 (0.3–1.4) g. We found mechanoreceptors in all ACL remnants, most commonly subsynovially or on the superficial layer of the ligament (Figure 1). The median total number of mechanoreceptors in an ACL remnant was 18 (8–30), and the median density of mechanoreceptors was 25 (12–69)/g. We found no significant correlation between the total number of mechanoreceptors and the wet

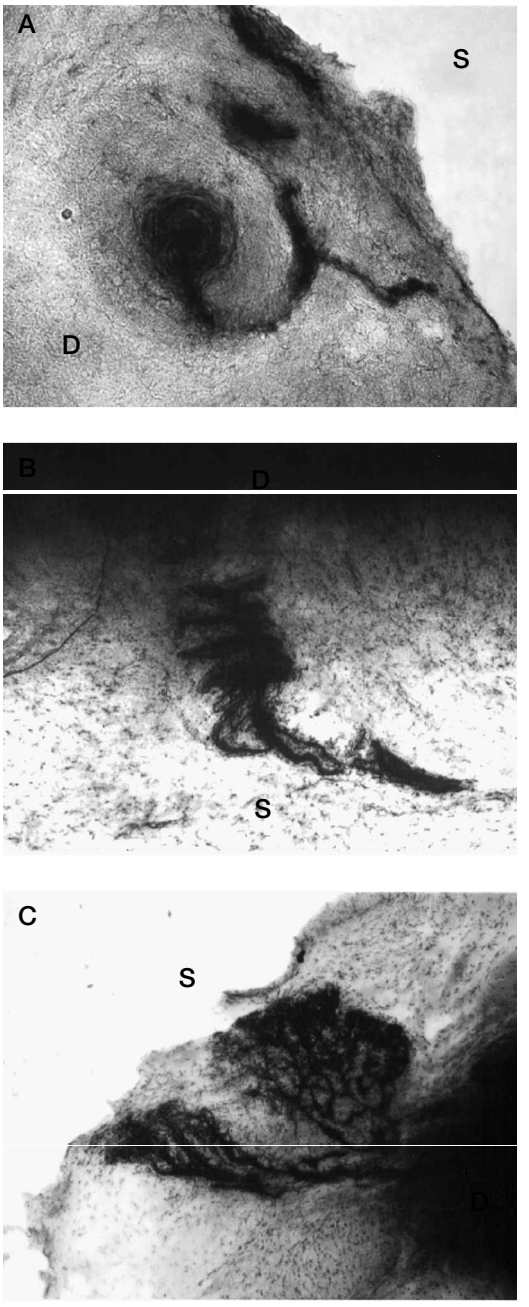

Figure 1. Morphology of mechanoreceptors seen in an ACL remnant (gold chloride stain).
A. Pacini receptor (400×).
B. Ruffini receptor (200×).
C. Golgi tendon organ-like receptor (100×).
(S superficial layer, D deep layer of the ligament).

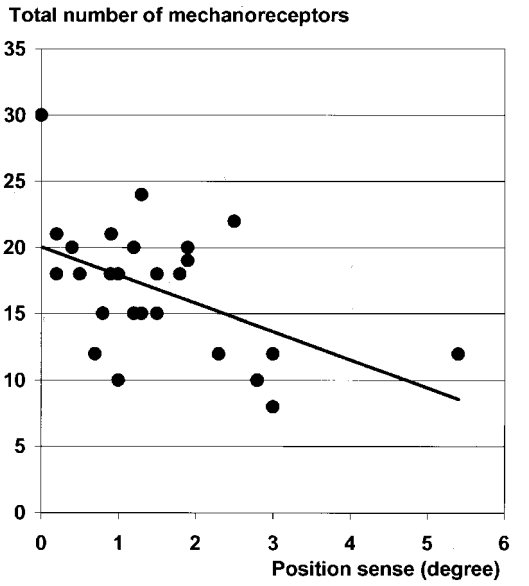

Figure 2. Correlation between the total number of mechanoreceptors in an ACL remnant and the inaccuracy of joint position sense. There is a significant inverse correlation between the total number of mechanoreceptors and the final inaccuracy of joint position sense ($r = -0.41$, $p = 0.03$).

weight ($r = 0.13$, $p = 0.5$).

The average inaccuracy of the joint position sense in the normal knee was 2.4 (1.1–6.1)° and that in the injured knee was 3.9 (1.8–10.9)° ($p < 0.001$). The median final inaccuracy of the joint position sense was 1.3 (0–5.4)°. There was an inverse correlation between the total number of mechanoreceptors and the final inaccuracy of joint position sense ($r = -0.41$, $p = 0.03$) (Figure 2).

We also found no significant correlation between the density of mechanoreceptors and the final inaccuracy of joint position sense ($r = -0.14$, $p = 0.5$).

The median anterior laxity of the knee was 5 (2.5–8.0) mm. There was no correlation between the total number or density of the mechanoreceptors and age of the patient ($r = -0.03$, $p = 0.89$, and $r = -0.12$, $p = 0.6$), interval from injury to the operation ($r = -0.01$, $p = 0.9$, and $r = 0.11$, $p = 0.6$), and anterior laxity of the knee ($r = -0.13$, $p = 0.5$, and $r = 0.16$, $p = 0.4$). However, we found mechanoreceptors histologically even in patients who had a long interval from the time of injury to the operation (Figure 3).

The correlation between the anterior laxity of the knee and the final inaccuracy of joint position sense was not significant, indicating that joint position sense was not affected by the instability of the knee.

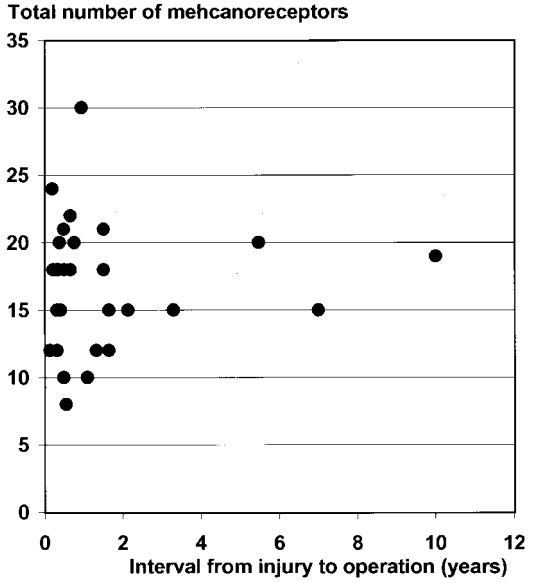

Figure 3. Correlation between the total number of mechanoreceptors and the interval from injury to operation. There was no significant correlation between the total number of mechanoreceptors and the interval from injury to operation. Mechanoreceptors were found even in patients with a long interval before the operation.

Discussion

Our findings suggest that mechanoreceptors in the ACL remnant contribute to the proprioceptive function of the knee. Of course, the proprioceptive function is affected not only by the ACL, but also by the other structures, including the joint capsule and muscle spindles. Therefore, information from a deformed joint capsule or muscle spindles abnormally activated as a result of joint laxity may affect the proprioceptive function of the knee. However, we found that the degree of anterior laxity was not correlated with inaccuracy of joint position sense, suggesting that the laxity did not affect the proprioceptive function of the knee.

After Schultz et al. (1984) reported the existence of mechanoreceptors in the human cruciate ligament and suggested their proprioceptive role, others have reported similar findings (Kennedy et al. 1982, Zimny et al. 1986, Schutte et al. 1987). It is now accepted that the normal ACL is extensively innervated by mechanoreceptors with important afferent functions. Recently, more attention has been paid to this proprioceptive function and the mechanical function of the ACL (Ochi et al 1999). Schutte et al. (1987) reported that the human ACL is extensively innervated and that neural elements, including free nerve endings, comprise about 1% of the area of the ligament. Krauspe et al. (1995), using monoclonal antibody stain, identified 17 mechanoreceptors in the ACL ligament of a 3-year-old child. Denti et al. (1994) also found mechanoreceptors histologically in human ACL remnants obtained arthroscopically. We identified median 18 mechanoreceptors in ACL remnants obtained in ACL reconstructions. The number of mechanoreceptors was not proportional to their wet weight in this study. One explanation of this fact may be individual variation in the densities of mechanoreceptors. Another explanation may be that the ACL remnants we investigated were from injured ACL with a large variation in the amounts of scar tissue.

Currently, the ACL remnant is completely resected in preparation for a newly reconstructed ACL graft. If the ACL remnants could be preserved during reconstruction, the mechanoreceptors of the remnants might also be preserved to some extent, which may help maintain proprioception after reconstruction. Indeed, we have performed an arthroscopic ACL augmentation using autologous hamstring tendons or allogenic fascia lata without sacrificing ACL remnants in patients whose ACL continued to bridge the femur and tibia (Adachi et al. 2000). Patients in the augmentation group had better anteroposterior stability and terminal stiffness of the ligament than did those in the ACL reconstruction group. More importantly, the final inaccuracy of joint position sense in the ACL augmentation group was significantly better than that in the ACL reconstruction group.

One weak point is our method of identifying mechanoreceptors. Many authors have studied mechanoreceptors in ACL. However, the criteria used to identify mechanoreceptors have not always been the same, and the terminology for discussing mechanoreceptors has varied. When stained with gold chloride, small vessels and mechanoreceptors in the ligament are very similar (Koch et al. 1995, Mclain 1995). To avoid this confusion and ensure accurate identification, we classified mechanoreceptors in serial sections.

Another weak point is that we did not study mechanoreceptors in intact normal ACL. There-

fore, our results cannot be applied directly to normal ACL. However, if ACL remnants play a substantial role in proprioceptive function of the injured knee, it seems likely that a normal intact ACL may be still more important.

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