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Knee joint proprioception in ACL-deficient knees is related to cartilage injury, laxity and age

A retrospective study of 54 patients

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Background ACL-deficient patients have been found to have proprioceptive defects, but the cause of these defects has not been identified nor has the relationship between proprioception and subjective function, laxity, activity level and age been adequately studied.

Patients and methods Therefore, we analyzed proprioception, defined as the threshold to detect a slow passive motion (TTDPM), in relation to activity level, laxity, meniscal injuries, collateral ligament injuries, cartilage injuries, age and subjective function in 54 patients with a previous ACL rupture. We used multiple pair-wise correlation analyses, followed by a stepwise linear regression model.

Results We found that poorer proprioception was related to lateral cartilage lesions, increased laxity and older age while a high activity level before injury was related with better proprioception after injury. The results also suggest a relation between proprioception and subjective knee function.

Interpretation Anatomical injury classification may need to be considered when discussing proprioceptive ability in patients with an ACL injury, laxity is related to proprioception and proprioception may decrease with age.

corpus adiposum infrapatellare (Krenn et al. 1990). Such receptors, muscle spindles and receptors in tendons and skin form a complex system for knee joint proprioception with spinal and cortical projections (Johansson et al. 1991).

Clinically, most studies on ACL-deficient patients show a reduction in proprioceptive ability measured as the threshold to detection of passive movement, active or passive reproduction of a passive angle change (Barrack et al. 1989, Corrigan et al. 1992, Fridén et al. 1996, Jerosch and Prymka 1996, Beynnon et al. 1999, Pap et al. 1999, Fischer-Rasmussen and Jensen 2000, Fremerey et al. 2000). Proprioception has also been found to be correlated with subjective knee function in ACL-deficient (Fridén et al. 1999) and ACL-reconstructed patients (Barrett 1991).

Since a knee injury, involving ACL rupture, in many cases also damages collateral ligaments and menisci, as well as cartilage of the femoral and tibial surfaces, it is difficult to determine the cause of the proprioceptive loss. The various injury patterns may affect the patients in different ways as regards proprioception, which may change outcome of the injury. A change in the pattern of movement or muscular atrophy after the injury may contribute to the proprioceptive defects and reduce the activity level. An age-related decline in proprioception has also been described (Skinner et al. 1984), which may also affect the proprioceptive status at the time of injury and perhaps the ability to compensate for proprioceptive loss during rehabilitation. Moreover, it can not be excluded that

Mechanoreceptors have been found in the joint capsule (Grigg and Hoffman 1982, 1984, Halata et al. 1985), menisci (Zimny et al. 1988, Assimakopoulos et al. 1992), cruciate ligaments (Schultz et al. 1984, Schutte et al. 1987, Sjolander et al. 1989), collateral ligaments (Sojka et al. 1991) and

Table 1A. The frequencies of medial collateral ligament (MCL), lateral collateral ligament (LCL), medial meniscal (MM), lateral meniscal (LM), medial cartilage (CM) and lateral cartilage injuries (CL)

Lesion	MCL	LCL	MM	LM	CM	CL
No	47	54	36	33	49	47
Yes	7	0	18	21	5	7
Total	54	54	54	54	54	54

congenital proprioceptive defects in some cases may predispose to the injury.

We therefore analyzed proprioception in relation to the pattern of injury. We also evaluated other variables having a potential relation to proprioception, such as age, activity level, laxity and subjective function.

Patients and methods

This study is retrospective and data were collected about other groups, including 15 patients followed consecutively after a non-operatively treated ACL injury (Fridén et al. 1997), 16 patients with symptomatic ACL deficiency (Fridén et al. 1996) and 23 unselected patients with ACL injury. The total sample consisted of 54 patients, 20 women. Their mean age was 28 (16–42) years. In all patients, a standardized data-based arthroscopy protocol used by the clinic was available. Patients whose complete standardized information regarding associated injuries could not be obtained from the file were excluded, as also were patients with significant other injuries of the lower limbs, or general diseases that might interfere with central or peripheral neural function. All patients had a complete ACL rupture, verified with arthroscopy, in most cases within 10 days of the injury. Testing sagittal laxity, done during anesthesia, before the arthroscopy, included the anterior drawer, Lachman and pivot shift tests. The results of the three tests were graded separately from 0 to 3 where 0 meant no increase in laxity, 1 meant a slight increase in laxity, 2 an obvious increase in laxity (> 5 mm) and 3 a marked increase in laxity. The Lachman test was chosen for the statistical analysis because it was the most generally accepted, reliable and reproducible manual laxity test.

Table 1B. The frequencies of different gradings on the Lachman test

Grade	Lachman
0	3
1	10
2	34
3	7
Total	54

Laxity tests using instruments, such as KT-1000, were not standard procedures in the Department and we had no results of such tests on all the patients, since the study is retrospective. Collateral ligament lesions were diagnosed when there was a clear increase in laxity (grades 2 and 3) in varus/valgus at 20° of knee flexion. Meniscal tears were divided by compartment (medial or lateral) in the protocol and included any tear in the substance or menisco-capsular avulsion. The lesions were analyzed as follows; 1. Untreated minor rupture . 2. Rupture requiring partial meniscectomy or suture. 3. Rupture requiring total meniscectomy. Cartilage lesions included sharp disruption of, or a defect in, the femorotibial cartilage surfaces, and were divided into compartments (medial or lateral) in the protocol. Degenerative cartilage was not recorded. The aim was to evaluate the possible proprioceptive effect of acute, severed cartilage lesions associated with the knee trauma. It should be noted that a single surgeon performed 36/54, while the other surgeons performed 18/54 arthroscopies, which may bias the classification of the laxity tests and associated injuries. However, all participating surgeons formed a highly experienced team of knee surgeons with a close intercollegial relationship. We therefore assume that this should not have any great effect on the classification. The frequencies of associated injuries, and grading of laxity tests, are given in Table 1.

The Research Ethics Committee at Lund University Hospital approved the study and all subjects gave their written informed consent to participation.

The median Tegner activity score was 5 (3–10), which is equal to heavy labor or recreational sports, such as jogging on uneven ground at least twice a week. On a patient satisfaction scale, range 0-10 where 10 meant good knee function, such as that before injury and 0 meant total disability, such as



The tests of knee proprioception were done with the test person in a lateral decubitus position on a specially-designed platform. This test person is not a participant in the study.

that just after the injury, the patients had a median score of 5 (0–9).

In the proprioceptive tests, we placed a platform on the floor (Figure). This apparatus has been used and described in detail previously (Fridén et al. 1996). No statistical differences were found between two measurements with an interval of one month when a previous control group was evaluated (Fridén et al. 1996).

The measurements of proprioception were made in the patients at a mean of 2.7 (SD 2.7) years after arthroscopy. In this study, we used a “proprioceptive index” in the statistical analyses. This index is the total sum (in degrees) of the four threshold values towards extension and flexion from 20° and 40°: threshold towards extension from 20° + threshold towards extension from 40° + threshold towards flexion from 20° + threshold towards flexion from 40°. The statistician suggested this method as a mean of obtaining a single overall proprioceptive value for each patient, which may facilitate individual comparisons between the patients, but also simplify the analysis and interpretation of the results.

Statistics

In step one, multiple pair-wise correlation tests were done, to evaluate the data, with Spearman’s rank correlation test. In step two a stepwise linear regression model was used in which proprioception was defined as the dependent variable and the variables activity level before and after injury, Lachman test, lateral cartilage injury, medial cartilage injury, lateral meniscal injury, medial meniscal injury, medial collateral injury and age were defined as independent, in the model. Here, the variable “subjective function” was excluded for causality reasons since, theoretically, proprioceptive ability would not depend on, or be explained by subjective function. We also aimed to minimize the effect of multicollinearity. Instead, another linear regression model with only the variables subjective function and proprioception was analyzed. The significance level for the pair-wise correlation analyses was defined as $p = 0.05$, while the default setting of $p =$ less than 0.15 for entering the model was used in the stepwise linear regression model. However, p -values more than 0.05 were regarded as not significant when interpreting the model. The statistical programs used were Minitab 10 (Minitab, State College, PA), SAS 6.10 (SAS, Cary, NC) and Axum 7 for Windows (MathSoft Engineering & Education, Inc., Cambridge, MA).

Results

The multiple pair-wise correlation tests showed a significant correlation between proprioception, measured as “threshold index”, and subjective function, laxity (Lachman test) and lateral cartilage injury (Table 2). As regards these cartilage injuries, 3 were femoral, 3 tibial and 1 femoral and tibial. When the stepwise linear regression model was analyzed, higher threshold values (poorer proprioception) were related with lateral cartilage lesions ($p = 0.003$), age ($p = 0.03$) and increased laxity (Lachman) ($p = 0.04$). A higher Tegner activity level before injury was related with lower threshold values—i.e., better proprioception ($p = 0.04$) (Table 3). We found no statistically significant relation between proprioception and Tegner activity after injury, lateral or medial meniscal injury, medial cartilage injury or gender.

Table 2. The results of multiple pair-wise correlation analysis with the proprioceptive index in relation to clinical variables. Spearman correlation coefficients and corresponding p-values

Variable	Proprioceptive index	
	Coeff.	P-value
Age	0.249	0.07
Tegner activity score before	0.002	1
Tegner activity score after	−0.260	0.06
Subjective function	−0.357	0.01
Lachman	0.330	0.02
Lateral cartilage injury	0.307	0.02
Lateral meniscal injury	0.009	0.9
Medial cartilage injury	0.056	0.7
Medial meniscal injury	0.085	0.5
Medial collateral lig. injury	−0.192	0.2
Gender	0.013	0.9

As regards subjective function, the pair-wise correlation test suggested a significant correlation with proprioception (Table 2). The linear regression model with subjective function as the dependent variable and proprioception as the independent one showed a tendency towards a significant relation ($p = 0.06$) in which an increase in threshold values would lower subjective function (Table 3).

Discussion

It has been suggested that the proprioceptive defect seen after ACL rupture is greater than can be explained by simple loss of the anterior cruciate ligament alone (Corrigan et al. 1992). Proprioceptive deficits have been found after lesions of the medial meniscus (Jerosch et al. 1996) and, in a previous study, we noted a significant correlation between proprioception and chondral and meniscal lesions in a group of 16 patients followed consecutively from the time of injury and onwards (Fridén et al. 1999).

Our present results, in a group of 54 ACL-deficient patients, suggested that the existence of a macroscopically-visible lateral cartilage injury is related to a proprioceptive defect. In most cases, the arthroscopy was done within a few weeks of the first injury. Therefore, the cartilage injury was presumably caused by this injury. It is difficult to say whether the proprioceptive defect related to this injury was the result of just a higher energy

Table 3. The results of the multiple regression analysis^a

	Value	Std. error	T-value	P-value
A. Dependent variable: Proprio _{inj leg}				
Age	0.4	0.2	2.3	0.03
Tegner before	−0.8	0.4	−2.1	0.04
Lachman	2.4	1.1	2.1	0.04
Cartilage lat.	2.6	0.8	3.1	0.003
Lat. meniscus	1.5	0.9	1.7	0.1
B. Dependent variable: Subjective function				
Intercept	5.3	0.5	11.3	< 0.001
Proprio _{inj leg}	−0.1	0.06	−1.9	0.06

A. Multiple R-squared: 0.4598, F-statistic: 7.66 at 5 and 45 degrees of freedom, p-value 0.00003.
B. Multiple R-squared: 0.06641, F-statistic: 3.699 at 1 and 52 degrees of freedom, p-value 0.06.

^a The results of the multiple regression analysis after stepwise selection with the default setting of P-value of less than 0.15 for entering the model, with injured leg proprioception, Proprio_{inj leg}, in A, and subjective function in B, as the dependent variable. The coefficient value with the standard error shows how Proprio_{inj leg} in A, or subjective function in B, is changed, per increased unit of the independent variable. T-value, with corresponding P-value, shows the test result whether the coefficient differs significantly from zero. Multiple R-squared represents the proportion of variance in the dependent variable, indsk in A or subjective function in B, is explained by the model. F-statistic tests indicate whether at least one of the coefficients, excluding the intercept, differ significantly from zero, with the corresponding P-value.

at injury, with more widespread effects overall, or if it was due to damage of neural structures in the chondral, subchondral and osseous tissue. Substance-P and calcitonin gene related peptide (CGRP)-immunoreactive nerve fibers have been found in bone, bone marrow and periosteum (Bjurholm et al. 1988) and CGRP-immunoreactive nerve fibers have also been found in the hyaline cartilage of the rat knee joint, where they have been thought to mediate trophic activity (Schwab and Funk 1998). Apart from also being nociceptive, these fibers seem to have many efferent qualities, such as vasodilatation, stimulation of hemato- and myelopoiesis, inhibition of bone resorption and proinflammatory activity (Imai et al. 1997). Speculations about an indirect effect on proprioceptive receptors, at their confirmed location, by these nociceptive fibers can be made, but we have found no studies to support this. Nor have we seen evidence of the existence of proprioceptive mechanoreceptors in these tissues. In view of this,

the possibility that the cartilage injury is a result of proprioceptive defects must also be discussed. Even if most patients, as noted, were examined arthroscopically a few weeks after injury, it can not be excluded that disturbed proprioception caused further minor, or even major, trauma to the knee shortly after the first injury, with a secondary cartilage injury as a result. However, these patients were extensively examined at frequent follow-ups initially and no such patient was found.

Our findings indicate that greater laxity after injury may be related to poorer proprioception, which is supported by some previous investigations (Barrack et al. 1989), but not by others (MacDonald et al. 1996, Beynnon et al. 1999). It should be noted that the Lachman test was used, which may be examiner-biased and not objective. It reflects the surgeon's opinion of the laxity and the results should therefore be interpreted accordingly, which means that it is the surgeon's evaluation of an increase in laxity that is correlated to proprioceptive defects. Thus, the results differ to some extent, but so do the methods of measurements and the patients. In the latter study, the patients had a higher mean age (40 years) (Beynnon et al. 1999), than in our study (28 years), which makes comparisons difficult, since age seems to be related to proprioception, as regards the present results. They also comment that they had no patients with instability on activity (Beynnon et al. 1999), which may also affect the results. We included patients with a wider range of laxity, Lachman 0-3, which may show a correlation, that would not be obvious with a narrower range of laxity. An explanation of the present results may be that receptors in the ligaments and capsule are adapted to a looser tension of these structures, which could increase the threshold for detection of slow motion. However, we can not exclude the possibility that a proprioceptive disturbance causes an increase in laxity—a disturbed neuromuscular control may increase the frequency of giving way/instability episodes with joint swelling and distended capsule and ligaments which may cause a still greater increase in laxity.

Previously, subjective function has been correlated with proprioceptive ability, rather than knee joint laxity, in ACL-reconstructed patients (Barrett 1991, Fremerey et al. 2000). Subjective function is a complex, but valuable, estimation, which

includes defined, and probably undefined, symptoms and abilities. Proprioception seems to be one factor of importance, and is, in turn, affected by many other variables that may overlap. This complexity makes it difficult to design models that explain one of the variables, and should be considered when interpreting the results.

There seems to be no evidence that training, or a high level of activity, increases proprioception in healthy persons in its strict definition of kinesthesia and joint position sense (Ashton-Miller et al. 2001). We found a relation between a high level of activity before injury, and better proprioceptive ability after injury. It is tempting to believe that the better proprioception seen among these former athletes or sportsmen/women results from many years of training at a high physical level. However, it may also reflect their ability to focus on a challenging task, such as the measurement session (Ashton-Miller et al. 2001).

An age-related decline in proprioception in normal knees has been reported in a group aged between 20–82 years (Skinner et al. 1984). Our findings indicate that also in a group of ACL-deficient patients with a narrower range of age, 16–42 years, higher age is related to poorer proprioception, which may be of importance when discussing treatment and rehabilitation of these patients.

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