Proprioceptive skills and functional outcome after anterior cruciate ligament reconstruction with a bone–tendon–bone graft

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Abstract Several studies have shown that patients with anterior cruciate ligament (ACL) reconstruction have an improved proprioceptive function compared to subjects with ACL-deficient knees. The measurement of functional scores and proprioception potentially provides clinicians with more information on the status of the ACL-reconstructed knees. To evaluate proprioception in patients following ACL reconstruction with a bone–tendon–bone (BTB) graft, we used the angle reproduction in the sitting, lying and standing positions and the one-leg hop test. Forty-five patients between 19 and 52 years of age were investigated in a 36-month period after the operation. For functional performance measurement, the International Knee Documentation Committee (IKDC) score was used. Very good and good results were seen in 95% of cases. All patients returned to the same activity level as seen before ACL repair. There was a significant difference in the active angle reproduction test between the ACL-reconstructed knees and normal knees in the active sitting position. Tests with passive angle adjustment in the sitting, lying and active standing positions did not show any differences in proprioceptive skills. Good to very good results in the one-leg hop test we found in 95% of patients. After ACL reconstruction, deficiencies in the active angle reproduction test were very small but, nevertheless, were still observed. Overall, the functional and proprioceptive outcomes demonstrate results to recommend the procedure.

Résumé Plusieurs études ont montré que des patients ayant bénéficié d'une reconstruction du ligament croisé antérieur ont été améliorés sur le plan de la fonction proprioceptive surtout si on compare les sujets à des sujets non traités gardant un déficit au niveau du ligament croisé antérieur. La mesure des différents scores, fonction et proprioception, donne un certain nombre d'informations sur ces genoux qui ont été opérés. Nous avons évalué la proprioception de patients opérés par greffes du ligament croisé antérieur par un greffon de type BTB et évalué cette proprioception en position assise, debout, en appui monopodal et après tests de sauts. 45 patients entre 19 et 52 ans ont été analysés sur une période de 36 mois après l'intervention chirurgicale. Le score IKDC a également été mesuré. Les résultats ont été considérés comme très bons dans 95% des cas. Les patients ont repris une activité au même niveau que celle qu'ils avaient avant la réparation. Il n'y a pas de différences significatives entre les genoux reconstruits et le genou normal, notamment en ce qui concerne les tests en positions assises. Un très bon résultat des tests de sauts est retrouvé chez 95% des patients. On peut considérer après reconstruction du ligament croisé antérieur, que la récupération fonctionnelle et proprioceptive est excellente et confirme la nécessité de reconstruire les ligaments après rupture.

Introduction

Knee joint function is complex and does not depend on ligament stability alone but also on the dynamic interaction between the central nervous system and the periarticular muscles. This is achieved by means of various mechanoreceptors and free nerve endings, which have been identified in the articular and periarticular knee joint structures [21]. They are found in particularly high numbers in the area close to the

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insertion of the anterior cruciate ligament (ACL) [1, 21]. The totality of neuromuscular interaction is referred to as proprioception [16]. Although some evidence has been presented suggesting that ruptures of the anterior cruciate ligament might not result in changes in proprioception [11], the majority of studies [7, 8] have demonstrated significant impairment. Although slight improvements were seen after several months of rehabilitation, a complete recovery was not achieved. Consequently, a successful reconstruction of the anterior cruciate ligament must accomplish both the restoration of ligament stability and the restitution of proprioception. This is supported by studies in which patients demonstrated poor functional results despite mechanically satisfactory cruciate ligament reconstruction, while other patients experienced good subjective function despite postoperative laxity. Subjective instability following cruciate ligament reconstruction might be caused by the persistent impairment of proprioception. Various methods exist to investigate differences in proprioceptive performance between the operated and normal knee joint following cruciate ligament replacement surgery. In general, it can be stated that no standard method for evaluating knee joint proprioceptive performance has been established to date [9]. Apart from the threshold to detection of passive motion (TDPM) test, the joint position sense (JPS) test and the one-leg hop test (OLHT) can be used to test the functional status [4]. The effectiveness of these tests is the subject of much debate. Pap et al. [19] regard measuring TDPM as insufficient to adequately describe knee joint proprioception. In contrast, certain other authors favour TDPM as the test of choice [22]. The diagnostic value of the one-leg hop test is questioned by Jensen et al. [15], without offering alternatives. In general, the joint position sense test is the recognised method for describing knee joint proprioception [5, 17, 25].

While there is widespread agreement on the surgical technique appropriate for the management of injuries to the anterior cruciate ligament, no unified concept of postoperative-specific rehabilitation has been established to date [6]. The postoperative measurements of proprioception may serve, in addition to stability testing, as a parameter to evaluate the quality of surgical and rehabilitative measures.

Material and methods

Data on knee joint proprioception and functional outcome were collected from 45 patients in follow-up examinations over an average period of 36 months following anterior cruciate ligament reconstruction using a patellar tendon auto-graft (bone–tendon–bone, BTB). Thirty-five of the patients were male and 10 were female. The average age was 31 years old, with the youngest patient aged 19 years and the oldest aged 51 years. The surgical intervention had been performed on 25 right and 20 left knee joints by the same surgical method 4 to 6 weeks after the injury. All procedures started with harvesting the mid-third of the patellar tendon. For tibial tunnel placement, the Howell tibial guide [13] was used in full knee extension. The bump was positioned inside the notch facing the intercondylar roof between the PCL and the lateral femoral condyle (Fig. 1). The tibial tunnel was drilled with fully fluted cannulated drills. In 90° flexion, the size-specific femoral aimer was placed by using the transtibial technique in the “over the top” position. The femoral tunnel was reamed with the acorn reamer to a depth of 25 to 30 mm. In 15 patients, the BTB graft was fixed with a titanium blunt nose screw from the lateral aspect. The cross-pin technique with bioabsorbable Rigid Fix implants were used in 30 patients. The tibial bone block was fixed with titanium interference screws in all patients. All patients attended a rehabilitation programme with partial weight bearing for 3 weeks, physiotherapy and special training.

For clinical and functional outcome studies of ACL repair, the International Knee Documentation Committee (IKDC) score is widely accepted. Regarding Peters et al. [20], the score was modified into numeric parameters for 15 selected groups of IKDC score (see the underlined groups in Table 1). All 15 categories were rated from 4 to 1 points (category A=4, B=3, C=2, D=1). A maximum of 60 points was achievable for a very good result in the modified IKDC score.

All joint position sense test measurements of the knee joint angles were made by the same investigator. An electrogoniometer manufactured by Penny & Giles was

Fig. 1 In situ placement of the Howell tibial guide and femoral aimers

Table 1 International Knee Documentation Committee (IKDC) score ($n=45$)

Groups	A <i>n</i> (%)	B <i>n</i> (%)	C <i>n</i> (%)	D <i>n</i> (%)
1. Patient subjective assessment	Normal	Nearly normal	Abnormal	Severely abnormal
Activity level after ACL repair	44 (98)	1 (2)	0 (0)	0 (0)
Function of treated knee	28 (62)	8 (18)	9 (20)	0 (0)
2. Symptoms	Never	At the highest activity level	At the lower activity level	Always
Pain	35 (78)	9 (20)	0 (0)	0 (0)
Swelling	44 (98)	1 (2)	0 (0)	0 (0)
Partial giving way	40 (89)	4 (9)	1 (2)	0 (0)
Complete giving way	43 (96)	1 (2)	1 (2)	0 (0)
3. Range of motion	<3°	–5°	6–10°	>10°
Lack of extension	40 (89)	3 (7)	2 (4)	0 (0)
	0–5°	6–15°	16–25°	>25°
Lack of flexion	37 (82)	8 (18)	0 (0)	0 (0)
4. Ligament examination	1–2 mm	3–5 mm	6–10 mm	>10 mm
Lachman test (Rolimeter)	4 (9)	36 (80)	5 (11)	0 (0)
AP translation in 70° flexion	25 (55)	12 (27)	8 (18)	0 (0)
Posterior sag in 70° flexion	41 (92)	2 (4)	2 (4)	
Medial joint opening	28 (63)	10 (22)	5 (11)	2 (4)
Lateral joint opening	36 (80)	7 (16)	2 (4)	0 (0)
	negative	+	++	+++
Pivot shift	45 (100)	0 (0)	0 (0)	0 (0)
Reverse pivot shift	45 (100)	0 (0)	0 (0)	0 (0)
5. Compartmental findings	None	Moderate	Severe	
Crepitus patellofemoral	26 (57)	16 (36)	3 (7)	
Crepitus medial	36 (80)	7 (16)	2 (4)	
Crepitus lateral	23 (52)	20 (44)	2 (4)	
6. X-ray findings	None	<50%	>50%	
Narrow medial cartilage space	19 (44)	24 (56)	0 (0)	
Narrow lateral cartilage space	42 (98)	1 (2)	0 (0)	
7. Functional test	100–90%	89–76%	75–50%	<50%
One-leg hop	35 (83)	7 (17)	0 (0)	0 (0)

used to measure the respective angles. Initially, the end blocks were fixed with the patient standing and adjustment to zero was undertaken with fully extended knee joints. Measurements were made in the sitting, lying and standing positions (Fig. 2). Each test was repeated three times. In addition, measurements in the sitting and lying positions were undertaken actively and passively. In the lying position, the active motion device Artrofit-K was used for

guided movements. For the active measurements, the patient used the control to move their leg to a self-selected angle and then set this angle again in a second attempt. For the passive measurements, the patient allowed his/her leg to be moved to an angle determined by the investigator. Then, he/she reproduced the angle actively. The measurement was repeated twice, each time with a different angle; the patients held the respective angles for 5 s. Finally, proprioception

Fig. 2 Active and passive ankle reproduction in the sitting, lying and standing positions

was measured in a standing position. To allow the patient to hold on to something, measuring was undertaken on a non-moving treadmill. Following this, the same set of measurements was taken for the opposite knee joint. For each measurement, the initial (pre-set value) and the second value (actual value) was recorded and the difference between them was calculated. Both the operated and the normal knee joint were measured. The one-leg hop test involved the patient hopping with his/her normal leg the greatest possible distance and then repeating this procedure with the operated leg. The results were stated as the percentage of how far the patient hopped with the operated knee joint as compared with the normal knee joint. The *t*-test for paired samples was used to determine whether there was a difference between the mean values for the same measurements on the operated and normal knee joints. The difference of $p \leq 0.05$ between the means of the same measurements for the operated and normal knees was considered to be statistically significant.

Results

Clinical results regarding the IKDC score

After follow-up examination, all subjective assessments and clinical results were rated into IKDC categories. Table 1 demonstrates particular results in groups and categories with overall very good and good outcome. The modified IKDC score [20] showed a mean of 55 points, with a range from 46 as the lowest (one patient) to 60 in four patients as the highest numeric score (Fig. 3).

One-leg hop test

Using their operated leg, 35 patients (79%) achieved 90–100% and seven patients (16%) achieved 76–89% of the distance hopped with the normal leg. Two patients refused

to carry out the test. One female patient had to be excluded from this test because she was pregnant. Thus, good to very good one-leg hop test results were found in 95% of patients.

Angle reproduction test

The mean values (in °) of the variance between the various measuring positions for the active and passive variants of the test on the operated and normal knee joints were calculated from all patients' measurements (Fig. 4).

Sitting position

For passive measurements, no statistically significant variance was found between the operated (3.16) and the normal knee joints (3.44°). Only the mean variance for active measurements in a sitting position differed significantly between 2.78° for the operated and 2.06° for the normal knees ($p=0.012$).

Lying position

With $p=0.688$ for passive tests in the lying position, the *t*-test did not show any significance (4.41/4.25°). In the active tests, no statistically significant difference between the operated and the normal joints (2.37° vs. 2.52°) was proved ($p=0.465$).

Standing position

A mean of 1.80° for the operated and 1.98° for the normal knees was calculated for active ankle reproduction in the standing position ($p=0.402$).

Discussion

Considering the disruption of afferent nerves conducting mechanoreceptor information as a result of a rupture of the anterior cruciate ligament, the question is raised whether an autograft reconstruction of the affected ligament can restore the proprioceptive capabilities of the knee joint. Fremerey et al. [8] investigated this question in a study in which proprioception was assessed both preoperatively and postoperatively. Six months after reconstructive surgery, a complete recovery of proprioception was found at the points close to full extension and flexion. In the intermediate motion range, no improvements could be demonstrated. However, a significantly poorer proprioception was also found for this range in healthy control subjects. Al-Othman [2] was also able to demonstrate the complete recovery of proprioception following anterior cruciate ligament reconstruction. By contrast,

Fig. 3 Modified numeric IKDC score results ($n=45$)

Fig. 4 Differences in the angle reproduction test measurements (mean and standard deviation)

Bonfim et al. [3] did not find an improvement of proprioceptive function following anterior cruciate ligament reconstruction in comparison with a control group. Other authors also report persistent impairment of proprioception [5, 18]. Especially in cases with additional associated injuries, permanent reduction of mobility was found [24]. In our study, an investigation was conducted into function and proprioception following surgical reconstruction of the anterior cruciate ligament using a bone–tendon–bone (BTB) autograft. A comparison between the operated and the normal side was made using the one-leg hop test and the joint position sense test.

In the one-leg hop test, good to very good results were achieved by 95% of patients. These results match those of Jensen et al. [15] following anterior cruciate ligament reconstruction surgery. It is generally accepted that differences of less than 20% between the operated and normal joints are normal.

The joint position sense test was criticised by Jerosch and Prymka [16], as they found an accompanying contralateral proprioceptive deficit in the acute phase following rupture of the cruciate ligament. Since at least three years had passed after the rupture of the anterior cruciate ligament in the patients investigated in our study, the comparison of proprioception in the operated and the normal side is considered to be an appropriate approach for evaluating the restoration of proprioceptive function in the operated knee joint. After the acute phase and following proper treatment, Fremerey et al. [8] found a complete recovery of proprioception in the affected joint. The authors further held the opinion that not so much the absolute values as the intra-individual differences between the affected and the non-affected knee joint within a group of patients should serve as a measure for proprioceptive function.

The part of study involving the joint position sense test with active and passive assessments in a sitting, lying or standing position was designed in accordance with Wilke and Froböse [25], who applied and analysed these tests to quantify the proprioceptive performance of knee joints. In our study, no significant difference between the operated and the normal side was found regarding the passive reproduction of the joint angle in a sitting position. For the reproduction of the joint angle in the lying (active and passive) and standing positions (active), again no significant differences were found between the two knee joints. However, the joint angle reproduction of the operated leg was significantly inferior ($p=0.012$) to that of the normal leg in a sitting position. To help answer the question whether this observation was due to chance or whether a deficit of proprioceptive performance of the operated knee joint was indeed present, we need to look to the findings of other authors. Wilke and Froböse [25] found that the patient's position influenced the results of the joint position sense test. Proprioceptive information is different in the supine position as compared with standing and sitting positions because muscle recruitment is altered in the horizontal position. Thus, even for the normal knee joint, it is difficult to reproduce exactly, the respective angle. Furthermore, angle adjustment while lying is rarely used in everyday life and, consequently, it is a poorly trained activity. Even for the normal knee joint, tests in a lying position are a demanding task, resulting in less accurate angle reproduction. Possible deficits in the operated knee joint are, thus, less obvious in a lying position. Consequently, both the passive and the active test in a lying position provide less information than tests in a sitting or standing position. Furthermore, Wilke and Froböse [25], as well as Jensen et al. [15], mention that the active angle reproduction differs from the passive. Voluntary control of

motion by the central nervous system precedes the active bending of the knee joint to the angle that should be reproduced later during the test. On repetition, the stored re-afferent feedback can be used, thus, making it possible to reproduce the exact angle. By contrast, feedback is lacking if the knee joint is passively bent to the target angle. Therefore, measuring angle reproduction using the passive setting of the target angle needs other sources of information to be taken into account. These would then have to be considered as mechanisms of compensation for the missing afferent signals from the anterior cruciate ligament and to provide proprioception of the knee joint.

Bearing this in mind, the results of this study only show a significant variance in the proprioceptive performance between the operated and the normal knee joints with regard to active angle reproduction in a sitting position. This may indicate that, although proprioceptive function has recovered three years after the surgical reconstruction of the anterior cruciate ligament, the lack of afferent information from the mechanoreceptors of the anterior cruciate ligament can still be noticed. Several authors [10, 12, 14, 23] have reported on the restitution of proprioception following reconstruction of the anterior cruciate ligament. Nevertheless, in cases of poor active angle reproduction in a sitting position, it is certainly possible to speak of an incomplete recovery of proprioception.

Conclusion

After anterior cruciate ligament (ACL) reconstruction, deficiencies in active angle reproduction tests were very small but were nevertheless observed. This may be caused by minor proprioceptive information resulting from the ACL lesion and poor afferent neural feedback from the graft.

Overall, the functional outcomes based on the International Knee Documentation Committee (IKDC) score demonstrate results to recommend ACL reconstruction with a bone–tendon–bone (BTB) graft.

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