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PROPRIOCEPTION IN POOR- AND WELL-FUNCTIONING ANTERIOR CRUCIATE LIGAMENT DEFICIENT PATIENTS

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The aim of this study was to examine proprioception with and without muscle tension and knee function in two groups of chronic (>1 year post-injury) patients with deficient anterior cruciate ligaments with distinctly different functioning levels. The well (WF) and poor functioning (PF) group was defined as those with a Tegner/Lysholm score equal to or greater than 6/95 (WF, $n = 7$), and equal to or less than 4/83 (PF, $n = 7$), respectively. Clinical examination included a Lachman, and a Pivot shift test, as well as a KT2000 arthrometer assessment. Single and triple hop tests assessed one-legged performance. Proprioception was measured as threshold of passive movement detection, and as the ability to reproduce flexion angles with (20% and 50% MVC) and without muscle tension. Mean Tegner/Lysholm scores were: WF: 7 (range 6–8)/98 (range 95–100), PF: 2 (range 1–4)/71 (range 62–80). There were significant differences between the Pivot shift tests of the groups ($p = 0.01$). The laxity (KT2000) assessment yielded a significant (3 mm, $p < 0.05$) side-to-side difference in both groups. One-leg hop tests yielded no side-to-side differences in any of the groups or between the groups. There were no significant differences between the groups in any of the proprioceptive tests, except in one of the angle reproduction tests with muscle tension (20%, $p < 0.05$). WF had larger mean errors than PF. There was not found any side-to-side difference in any of the proprioceptive tests, except in one of the angle reproduction tests with muscle tension (WF, 20%, $p < 0.05$). In conclusion, these data suggest that subjects with long standing anterior cruciate ligament deficiency in the present study did not have a knee joint proprioceptive deficit as measured by some commonly accepted methods. There was no difference in proprioception between the two groups despite their markedly different function levels and pivot shift evaluated knee laxity.

Key words: anterior cruciate ligament, knee function, knee laxity, proprioception.

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INTRODUCTION

It is well known that rupture of the anterior cruciate ligament (ACL) can lead to excessive anterior tibial translation and symptoms of instability. The available treatments for ACL deficiency are conservative rehabilitation and reconstruction of the ACL. However, the outcomes of these treatments differ: some patients return to their sports activities, even cutting sports, while others cease to participate in sports due to daily experiences of functional instability (1).

Proprioception encompasses sensation of joint movement and joint position. The status of proprioceptive ability as a determining factor in functional instability of the knee joint has been studied in recent years. It is believed that apart from being a mechanical stabilizer of the knee joint, the ACL also has a possible sensory role. The posterior articular nerve (PAN) is the major nerve supply to the ACL (2) and the presence of mechanoreceptors in the human ACL and in other knee structures (capsule, menisci and other ligaments) is well documented (2–9). Mechanoreceptors in the ACL: Ruffini-, Pacini- and free nerve endings are believed to function as transducers, which receive mechanical stimuli and retransmit them as electrical impulses (3, 5, 8, 9). Several neuro-physiological studies (10) have reported that afferents from the PAN and the medial articular nerve (MAN) are discharged during movements of the knee joint, especially toward extremes of joint motion (10–12).

The above-mentioned factors suggest that mechanoreceptors of the ACL and of the other knee structures (capsule, menisci and other ligaments) play a role in proprioception. However, it is unclear how significant a part the ACL plays in signalling proprioception and therefore how the absence of the ACL will affect knee proprioception. Proprioception has been measured in various ways. The most frequently used methods are based on the ability to detect a passive movement, and the ability to reproduce a knee joint position by visual estimation or by active repositioning of the knee. Some studies on proprioception in ACL-deficient patients demonstrate a significant side-to-side difference using the above-mentioned methods (13–15), while others have been unable to document such a side-to-side difference (16, 17). Few have tested the relation between proprioceptive abilities and the function of ACL-deficient patients. However, Barrett (18) reported that proprioception correlated well with both function and patient satisfaction in ACL-reconstructed patients. Roberts et al. (19) also reported

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Table I. *Bispebjerg Hospital's modified Tegner Activity Score*

10	Soccer—elite (1st and 2nd division)
9	Soccer (3rd division), other elite: contact sports (handball, basketball, ice-hockey) athletics (jumping), tennis, squash
8	Other contact sport, tennis (competitive but not elite), elite: running, cross-country track findings
7	Soccer (3rd division), cross-country track findings, other competitive sports
6	Heavy labour, jogging at least 5 times per week, recreational tennis/squash, elite cycling
5	Jogging 3–4 times per week
4	Moderately heavy labour (e.g. nursing aid)
3	Light labour, jogging 1–2 times per week
2	Light labour, recreational: cycling, swimming
1	Light labour. Only walks
0	Sick leave or disability pension because of knee problems

that ACL-deficient patients with severe symptoms had an inferior proprioceptive ability in some measurements compared with asymptomatic patients. However, there was no difference in Tegner activity score between their groups, and the grouping was based on patient satisfaction and desire to undergo reconstruction.

Therefore, the purpose of this study was to examine proprioception and knee function in two groups of ACL-deficient patients with distinctly different functioning levels as determined by a combination of Tegner and Lysholm scoring systems.

The proprioceptive measurements used today do not reflect the proprioceptive demands during functional activities, where forces on the knee joint are different from the forces in a resting position. Therefore, another purpose of this study was to come closer to measuring proprioception during functional activities by testing proprioception during muscle tension activities in both groups of ACL-deficient patients. We wished to test the hypothesis that impaired proprioception would be altered in both groups during muscle tension activities.

MATERIALS AND METHODS

Selection

The subjects were selected from the Bispebjerg Hospital's register of ACL-deficient patients from 1990 to 1998, and were included in the study if they met the following criteria: (a) born between 1960 and 1980; (b) arthroscopically or MRI proven ACL rupture—partial or complete; (c) age of injury ≥1 year, and (d) address in Copenhagen and its suburbs. The patients were excluded for any of the following reasons: (a) reconstruction of ACL or suture of the ACL; (b) actual symptoms of meniscus injury in ACL-deficient limb; (c) history of injury/symptoms of contra-lateral limb; (d) history of chronic diseases such as neurological or metabolic diseases; (e) pregnancy, and (f) ongoing participation in a rehabilitation program.

Ninety-six patients were contacted by mail. Fifty-three patients responded positively and from these 27 were excluded because of the above-mentioned reasons. Twenty-six patients were called for an interview. During the interview, the knee function was evaluated with the Lysholm knee score (range, 2–100) (20) and the activity level with a modified Tegner activity-level score (range, 0–10) (20) (Table I) in order to place the patients in one of two groups. The inclusion criteria for the groups were as follows:

- The well-functioning group (WF): Tegner score ≥6—equals: participates in cutting sports (Table I) *and* Lysholm ≥95—equals: excellent function (21).
- The poor-functioning group (PF): Tegner score ≤4—equals: moderately heavy labour (Table I) *and* Lysholm score ≤83—equals: fair to poor function (21). Lysholm score of instability ≤15 points: Patient cannot participate in sports because of experiences of giving way or he/she has daily symptoms of instability.

These criteria were chosen to ascertain a clear difference between the group's activity levels. That is, instability was the major problem in the PF group and the major reason for low activity and that a high Lysholm score was not due to protective low activity.

Twelve patients did not meet these criteria and were therefore excluded. Fourteen patients were finally selected for participation.

Subjects (Table II)

Well-functioning group. Our study sample included 7 subjects in the WF group: 6 males and 1 female mean age [SD] 31.1 ± 4.5 years (range 26–38). Mean age [SD] of injury at the time of testing was 4.4 ± 2.8 years (range 1–8). Two of the subjects had no associated lesions at the time of arthroscopy, 5 had minor meniscus, collateral ligament, or cartilage lesions. The mean Tegner score before injury was 7 (range 6–8). The mean [SD] values of the Tegner and Lysholm score were 7.0 ± 0.8 (range 6–8), and 98.3 ± 2.3 (range 95–100) respectively, at the time of testing. None of the subjects showed symptoms of instability during sports activities. Two of the subjects did not have regular activities that equalled 6 in Tegner. Their yearly 1-week skiing trips, the fact that they had not changed their level of activity after the injury and the fact that they did not have any symptoms of instability justified their inclusion in the WF group.

Poor-functioning group. Our study sample included 7 subjects in the PF group: 3 males and 4 females mean age [SD] 30.1 ± 2.6 (range 26–34). Mean age [SD] of injury at the time of testing was 6.4 ± 2.1 years (range 4–10). Three of the subjects had no associated lesions at the time of arthroscopy, four had meniscus or collateral ligament lesions. The mean Tegner score before injury was 7 (range 6–9). The mean [SD] values of the modified Tegner and Lysholm score were 2.3 ± 1.3 (range 1–4) and 71.4 ± 7.1 (range 62–80), respectively. All the subjects experienced knee instability in daily activities occasionally, except one who suffered from knee instability in sports activities frequently.

Each subject completed the examinations and tests listed below. The testing time was 4–5 hours spread over 2 separate days for each patient.

Clinical examination

To confirm ACL deficiency, the anterior drawer test and the Lachman test were performed. The pivot shift test was performed to evaluate knee function. In WF the pivot shift tests in four of the subjects was graded as negative and three subjects were graded with 1+ (Table II). In PF the pivot shift tests in six of the patients were graded with 2–3+. One subject in PF was graded with a negative pivot shift test (Table II). None of the subjects had symptoms of meniscus injuries.

Laxity assessment

The KT-2000 arthrometer with 89-N anterior displacement force was used to measure the saggital knee laxity. It was measured in a standard position of 30° of flexion on both knees 3 times each and the largest value was chosen. One of the subjects in WF was excluded from the

Table II. *Description of study subjects (well-functioning (WF) and poor-functioning (PF))*

Subject	Sex	Age	Injured limb	Age of injury (years)	Tegner before/after	Lysholm now	ACL tears (arthroscopy)	Associated lesions (at the last admission)	Pivot shift (grade)
WF									
1	M	38	R	6	7/7	100	Complete	None	0
2	M	35	R	2	7/7	100	Complete	Cartilage lesion on patella	1+
3	M	34	L	5	8/7	99	Complete	None	1+
4	M	29	R	1 1/2	8/8	99	Complete	Cartilage lesion on femoral condyl	1+
5	M	29	L	7	6/6[1]	95	Partial	Cartilage lesion on patella	0
6	M	27	L	1	8/8	100	NA	Partial lesion of MCL Partial collateral lesion/meniscus suture	0
7	F	26	L	8	6/6[1]	95	Partial		0
Mean ± SD		31.1 ± 4.5		4.4 ± 2.8	7/7 ± 0.8	98.3 ± 2.3			0.4
PF									
1	F	34	L	8	7/2	62	Partial	Complete MCL lesion	2+
2	M	32	L	6	9/2	67	Partial	Minor menisci lesion	3+
3	M	31	L	4	7/1	79	Partial[2]	Minor menisci lesion	0
4	F	30	L	7	9/1	80	Complete	None	2+
5	F	30	L	5	6/2	76	Complete	None	2+
6	M	28	R	10	7/4	65	Complete	None	3+
7	F	26	R	5	6/4	71	Complete	Minor menisci lesion	2+
Mean ± SD		30.1 ± 2.6		6.4 ± 2.1	7/2 ± 1.3	71.4 ± 7.1			2.0

[1] This subject did not participate in sports either before or after injury, except for an annual 1 week skiing trip.
[2] MRI demonstrated a partial rupture.
NA = Not applicable (No MRI or arthroscopy has been performed). ACL = anterior cruciate ligament; MCL = medial collateral ligament.

laxity assessment. His knee laxity was larger in the normal knee than in the injured knee because of an extension defect of 5°.

Functional tests

Functional tests included the one-leg hop tests: single hop (22) and triple hop tests (23) after approximately 5 minutes of low load stationary cycling. The subject was instructed to jump with his/her hands behind the back. He/she had 2–3 trials before measurements were recorded. If the subjects failed to find their balance immediately after landing that attempt was discarded. The best of three attempts was recorded unless the third jump showed an increase of more than 10 cm, in which case the subject was asked to jump once again in order to ascertain that the maximal hop length had been determined (increasing less than 10 cm). Both legs were tested—the normal limb served as a control.

Proprioception tests

Proprioception was determined with two different methods:

1. Test bench protocol. The subject was placed in a supine position on a custom-built test bench (Fig. 1). The lower limbs and thighs were cuffed with pneumatic bags inflated to a pressure of 20 mmHg to reduce cutaneous sensation. The subject's limbs were placed in the troughs so that the knee's centre of flexion/extension movement corresponded to the central axis of trough movement. The troughs could be moved either by hand or by a motor at a rate of 0.5°/second. Electrogoniometers were placed on the troughs to allow the position data to be sampled on a computer.

(a) Threshold of passive movement detection (TPMD) was determined first from a starting position of 20° of flexion towards extension. Blindfolding and earphones with music eliminated visual and auditory cues. The investigator activated one of the motors moving the troughs. The subject was instructed to activate a switch that stopped the movement as soon as a movement in the knee was detected and thereafter to signal the moving limb. The degrees of extension were recorded. The subject had two test trials, one for each leg before sampling. Five trials for each limb were recorded in a counterbalanced testing order.

(b) The passive–active reproduction ability (PA) of the knee positions at 35°, 25° and 15° of flexion was determined next. The limbs and troughs were this time balanced with counterweights at 25° of flexion (the middle range of test positions). The subject was blindfolded. The tester moved the trough/limb to a pre-selected knee position (passive positioning) and the subject was instructed to concentrate on this position. After 2–3 seconds, the trough/limb was bent to 60° of flexion and the subject was then instructed to return the limb to the test position (active reproduction). The difference between the pre-selected knee position and the subject's estimate was sampled and calculated. The subject had three trials before the actual sampling. The three different

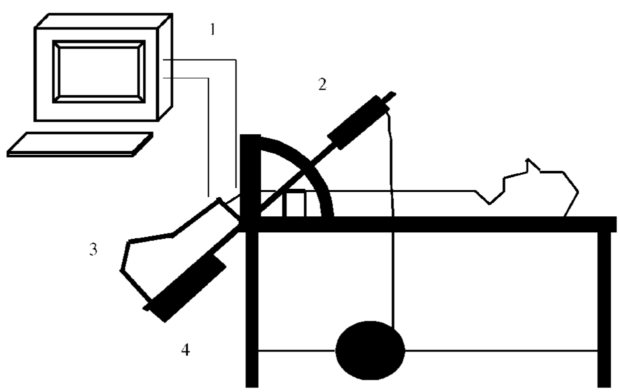


Fig. 1. Test bench.
1. Sampling computer connected to electrogoniometers. 2. Counterweight. 3. Pneumatic bag. 4. Trough.

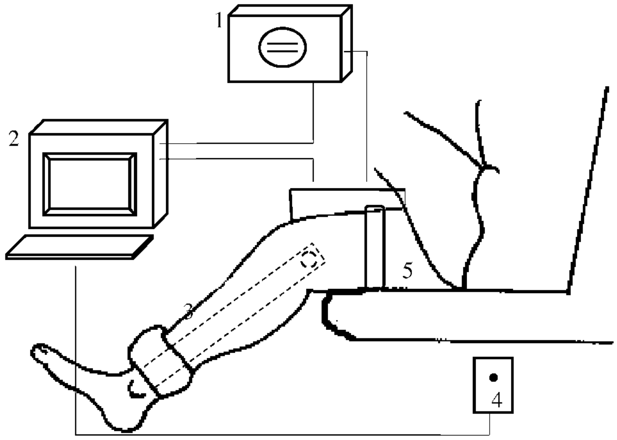


Fig. 2. Isokinetic dynamometer.
1. Oscilloscope. 2. Sampling computer. 3. Lever arm. 4. Trigger. 5. Strap.

angles were tested 4 times each in a mixed pre-set sequence to avoid learning. The testing order was counterbalanced relative to the injured and non-injured limbs.

2. Isokinetic dynamometer test protocol. The subject was seated in the isokinetic dynamometer (Kin Com®, Chattecx Corp., Chattanooga, USA) (Fig. 2) so that the knee's centre of rotation corresponded to the rotation axis of the dynamometer. A strap was positioned over the distal thigh of the tested limb and the lower limb was attached to the lever arm approximately 5 cm above the medial malleolus. A tray was placed in front, preventing the subject from seeing the test limb. The knee positions and the subjects' estimations, indicated with a trigger, were sampled on a computer and the difference between the test position and the subject's estimation was calculated. The same knee positions and sequence as described above were evaluated. The testing order was counterbalanced relative to the injured and non-injured limbs. The subject performed the following three tasks:

(a) Passive–passive reproduction of knee positions without muscle tension activity (PP0%). From the start position of 60° of flexion, the subject's test limb was passively extended at an angular velocity of 5°/second. The investigator stopped the movement at a pre-selected knee position (passive positioning). After approximately 2 seconds, the limb was returned to the start position with a movement rate of 50°/second. The subjects' limb was again passively extended at the rate of 5°/second and as soon as the subject felt that the limb reached the previously marked knee position, he/she was instructed to activate the trigger (passive reproduction).

(b) Active–active reproduction of knee positions with muscle tension activity (AA20%, AA50%). MVC was estimated as the maximal isometric quadriceps strength at 25° of flexion (middle range of the test positions). The best of three estimates were selected. An oscilloscope was calibrated so that two lines would converge into one line when either 20% MVC (AA20%) or 50% MVC (AA50%) was performed at 25° of flexion. During the extension of the knee, the subject was instructed to press in the same direction while using the oscilloscope lines for guidance about how much to press (active positioning). When the movement was stopped in the pre-selected test position, the subject was instructed to continue to press until the lever arm was moved back to the start position of 60° of flexion. When the subject had to reproduce the pre-selected knee position, he was instructed to press in the same way and trigger when he felt the limb had reached the test position (active reproduction). The subject had 3–4 trials before the actual testing. AA20% was determined before AA50%.

Test–retest reliability on both the TPMD, PA and AA20% has been established in a previous study at $r = 0.9$ ($p < 0.01$); $r = 0.8$ ($p < 0.01$); $r = 0.6$ ($p = 0.02$) respectively.

Statistics

The Wilcoxon's signed rank test was used for between-limb comparisons and the Mann-Whitney U-tests for between-group comparisons in the ACL-deficient groups of patients. A p-value below 0.05 was considered significant.

The lack of a statistically significant difference does not preclude that the investigation missed an effect due to small sample size and/or large data scatter. Therefore, in all cases without significant side-to-side, or between group differences a power analysis was performed.

RESULTS

Age or age of injury did not differ between the groups. There were significant differences between the Tegner and Lysholm scores ($p < 0.01$). There was no significant gender difference between the groups calculated with a χ^2 test.

Laxity assessment (Table III)

The laxity assessment yielded a significant side-to-side difference in both groups (WF mean 2.58 mm, $p < 0.05$ and PF mean 3.00 mm, $p < 0.05$). There were no significant differences between the groups bilaterally. There was a significant difference between the Pivot shift grades of the groups (WF mean 0.4 and PF mean 2.0, $p = 0.01$) (Table II).

Functional tests (Table III)

There were no significant side-to-side differences in any of the tests for the groups. Further the side-to-side differences did not differ between the groups.

Proprioception tests

Limb and group comparisons (Table IV). None of the proprioceptive tests revealed significant side-to-side differences for the groups, except in AA20% for WF (side-to-side difference of 2.51°, $p < 0.05$). Group comparisons did not detect any significant differences bilaterally, except for AA20% test. WF performed significantly worse ($p < 0.05$) with the injured limb (mean 8.56°) than PF (mean 5.56°). This was not observed when comparing the non-injured limbs. Analyses of side-to-side differences when the two groups were pooled together revealed no new significant differences.

Analysis of each test position in the reproduction tests. When analysing each of the pre-set test positions for side-to-side differences no new significant differences were demonstrated, except in PA 35° for the WF (mean injured 5.08°, non-injured 3.36°, $p < 0.05$). In the group comparisons, the analysis of each of the test positions showed that the WF group performed significantly worse in the reproduction of 35° than the PF group ($p < 0.05$) in all the reproduction tests except in PP0%.

Comparison of the various reproduction tests in the isokinetic dynamometer. When comparing the different reproduction tests for PF, there were no significant differences between them bilaterally.

When comparing the PP0% test with any of the other tests for

WF, no significant differences were demonstrated. However, the injured limb had significantly larger mean errors in AA20% than in AA50% (mean AA20%: 8.56° and mean AA50%: 5.37°, $p < 0.05$). In the case of the non-injured limb, this difference was not observed.

Calculation of the physical determinates of proprioceptive deficits. We translated proprioceptive deficits of 0.5°, 1°, 3° and 10° into their physical determinates during the swing face of the gait. A proprioceptive deficit of 1° equals 0.3 cm during walking, i.e. the patient will miscalculate the distance between his/her heel and the ground by 3 mm (Fig. 3).

DISCUSSION

This study indicates that there is no difference in proprioceptive ability between poor- and well-functioning groups of ACL-deficient patients and that proprioception is not impaired in chronic ACL-deficient patients. The KT2000 assessments did not yield a clear difference in laxity between the groups while the Pivot shift test clearly separated the groups.

The present threshold of passive movement detection (TPMD) results are in accordance with Roberts et al. (19), who studied TPMD in a side-lying position in two groups of patients with different severity of symptoms. There was no significant difference between the ability of their groups to detect a movement from 20° of flexion towards extension. Roberts et al. (19) also tested TPMD from 20° towards flexion and TPMD from 40° towards extension and, in these tests, a significant difference, of 1° and 0.5° respectively, between the asymptomatic and symptomatic groups of patients were demonstrated. Based on these results, it was concluded that joint function is related to an impaired proprioception. However, Roberts et al. was unable to demonstrate any significant difference between the patient groups and a reference group of healthy subjects in TPMD from 20° towards flexion and in TPMD from 40° towards extension. Roberts et al. explained the lack of difference between the symptomatic group and the reference group by suggesting a possible proprioceptive enhancement in the symptomatic group. However, this explanation might be weakened by the fact that there was no significant difference between the asymptomatic group and the reference group and therefore no proprioceptive enhancement in the asymptomatic group.

The present study did not demonstrate any differences between the groups in the reproduction tests, except in AA20% tests, where the WF performed *worse* than the PF which is inconsistent with logic. The results of the reproduction tests are in accordance with Roberts et al., who was unable to demonstrate a difference between two groups of patients in active reproduction tests. Barrett (18) reported a strong correlation between the reproduction tests and patients' satisfaction and sports activity in ACL-reconstructed patients. The discrepancies between Barrett's, Roberts' and our results might be explained by the fact that Barrett used correlation analysis in contrast to our comparisons of two differently functioning groups. We decided not to use correlation analyses because of several associated sources of error. A correlation analysis might not reveal the reason for the strong correlation between proprioceptive ability and function. A strong correlation might be caused by factors other than a direct relation between proprioception and function, such as age and age of injury. In our study of group comparisons, such a source of error is avoided by ensuring that there is no difference in age, age of injury, and in the Tegner activity levels before injury between our groups. We thereby eliminate other factors than the ones being examined.

Lysholm scoring system has been criticised because it fails to detect a false high score due to a reduced activity level, and because it is a purely subjective system (21, 24). Some of the criticisms of Tegner scoring system are that it fails to detect patients who participate in sports activities despite a low functional level of their knee and that it does not detect an alteration in sports participation caused by changes in non-knee related factors (25). These matters could blur the distinction between the present study's two groups of patients. However, our group definitions and inclusion criteria were based on a strict combination of both scoring systems and on the use of pivot shift examination to support the functional difference between the groups—thus avoiding the above-mentioned sources of error and ensuring the distinctiveness between the groups. In contrast, Roberts et al. have based their group definitions on a purely subjective scoring system and on the patients' desire to undergo reconstruction of ACL. Roberts et al. also used Tegner scoring system for determining the activity level of the subjects, but were unable to demonstrate any difference between the groups. Additionally, Roberts et al. have not used the same parameters for the classification of symptomatic and asymptomatic groups as in the present study. The asymptomatic group was classified on the basis of physical examination, laxity and functional tests and the lack of desire for reconstructive surgery, whereas the symptomatic group was classified on the basis of the patients' experiences of giving way, satisfaction and their desire to undergo reconstructive surgery.

Another concern regarding our groups of subjects, as demonstrated by Barrack et al. (26) and Lephart et al. (27) with TPMD tests of ballet dancers and gymnasts, is that sports activity improves the proprioceptive ability. The low–activity patients, included in WF, could lower the proprioceptive abilities of the WF group. However, the low-activity subjects did not distinguish themselves from the rest of the group when their results were studied separately. Another of our concerns is that we have included a subject in the study with an extension defect of 5°. This extension defect could have been caused by a capsular defect, which might have changed his proprioceptive ability. However, he did not distinguish himself from the rest of the WF group and a withdrawal of his results from the study did not alter the outcome of the study.

The present study did not demonstrate a significant side-to-side difference in any of the groups in any of the proprioceptive tests, except in the AA20% in WF. The fact that this difference is

Table III. *Mean (SD; range) for laxity assessments and one-leg hop tests (well-functioning (WF) and poor-functioning (PF))*

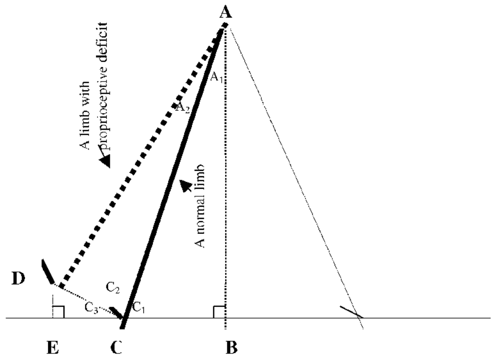
	Laxity (mm)		Single hop test (m)			Triple hop test (m)		
	Injured	Non-injured	Injured	Non-injured	Δ	Injured	Non-injured	Δ
WF group	7.9 (2.5; *5.0–11.0*)[2]	5.3 (2.0; *2.5–8.0*)	1.66 (0.32; *1.04–2.05*)	1.65 (0.33; *1.05–2.07*)	−0.01	4.96 (0.78; *3.54–5.99*)	4.97 (0.75; *3.63–6.05*)	0.01
PF group	9.4 (1.3; *7.0–10.5*)[2]	6.4 (0.8; *5.0–7.5*)	1.31 (0.41; *0.80–1.82*)	1.44 (0.29; *1.09–1.84*)	0.13	3.83 (0.84; *2.62–5.27*)	3.99 (0.55; 3.44–4.86)	0.16
p values[1]	NS	NS	–	–	NS	–	–	NS

[1] *p* values for in-between group comparisons.
[2] Significant side-to-side difference ($p = 0.02$).
Δ non-injured ÷ injured.

Table IV. *Mean values (SD, range) in the various proprioceptive tests (well-functioning (WF) and poor-functioning (PF))*

	TPMD		PA		PP 0%		AA 20%		AA 50%	
	Injured	Non-injured	Injured	Non-injured	Injured	Non-injured	Injured	Non-injured	Injured	Non-injured
WF group	**1.3** (0.4) *(0.6–1.7)*	**1.2** (0.4) *(0.6–1.7)*	**5.2** (2.6) *(3.0–9.5)*	**4.3** (1.8) *(2.0–7.9)*	**7.0** (2.1) *(4.1–10.8)*	**6.0** (2.1) *(3.3–9.2)*	**8.6** (1.4)[2] *(6.5–10.8)*	**6.1** (1.9) *(3.7–8.0)*	**5.4** (1.4) *(3.3–7.0)*	**5.4** (1.9) *(3.1–7.6)*
PF group	**1.2** (0.5) *(0.8–2.1)*	**1.2** (0.5) *(0.9–2.4)*	**3.4** (0.9) *(2.1–4.7)*	**3.5** (1.4) *(1.5–5.9)*	**7.5** (5.5) *(2.6–17.5)*	**6.2** (3.8) *(2.0–11.5)*	**5.6** (2.2) *(2.7–9.3)*	**5.2** (1.8) *(3.1–8.6)*	**5.1** (2.9) *(2.2–10.9)*	**4.8** (2.0) *(1.2–7.3)*
p values[1]	NS	NS	NS	NS	NS	NS	0.04	NS	NS	NS

[1] *p* values for in-between group comparisons.
[2] Significant side-to-side difference ($p = 0.04$).
TPDM: Threshold of passive movement detection.
PA: The passive-active reproduction test.
PP 0%: Passive-passive reproduction of knee positions without muscle tension activity.
AA 20%: Active-active reproduction of knee positions with muscle tension activity (20% maximal voluntary contraction (MVC)).
AA 50%: Active-active reproduction of knee positions with muscle tension activity (50% MVC).



A. Knee's centre of rotation **B.** Plumb line's crossing with the ground
C. Heel strike **D.** Heel of limb with proprioceptive deficit
E. Misjudged heel strike in a limb with proprioceptive deficit
A_2. Proprioceptive deficit of 0.5°, 1°, 3° or 10°

Assumptions

1. Distance between the knee's centre of rotation and the heel (AC) = 50 cm
2. Distance between the plumb line and the heel (BC) = ¼ x step length = 15 cm
3. There is no proprioceptive deficit in the hip joint

Formulars used

1. $AB^2 + BC^2 = AC^2$ 2. tanA = a/b 3. sinA = a/c

Calculations of DE for a deficit of 1°

1. $AB=\sqrt{(AC^2 - CB^2)} = \sqrt{(50^2 - 15^2)} = 45.3$ cm
2. tanA• = 15 / 45.3 • A• = 18.3°
3. C_1 = 180° – 90° – 18.3° = 71.7°
4. C_2 = (180° - 1°) / 2 = 89.5°
5. C_3 = 180° - 71.1° - 89.5° = 19.4°
6. $\sin(A_2/2)$ = ½DC / 50 cm ⇒

   DC = sin(1°/2) x 50 x 2 = 0.9 cm
7. DE = sinC x DC ⇒

   DE = sin (19.4°) x 0.9 = **3 mm**

Equally

0.5° ~ 1 mm

3.0° ~ 9 mm

10° ~ 35 mm

With a step length of 100 cm (BC = 25 cm) the corresponding DEs are:

0.5° ~ 1 mm, 1° ~ 4 mm, 3° ~ 14 mm, 10° ~ 49 mm

Fig. 3. Calculation of the physical determinant of proprioceptive deficits (0.5°, 1°, 3°, 10°).

not found in any of the other reproduction test and that it is not found in PF indicates that this result is inconsistent with logic. Previous studies on proprioception in ACL deficient patients (13–18, 28, 29) have come up with varying and contradictory reports. Some studies have registered impaired proprioception only in the extended positions while other studies have registered it only in the flexed positions. However, we studied proprioception in both extended and flexed positions and did not demonstrate a proprioceptive deficit in any of the knee positions. Jerosch & Prymka (30) have suggested a generalized impaired proprioception in some ACL deficient patients, in which case our use of the contralateral knee as control group could explain why we did not demonstrate a proprioceptive deficit. However, if the contralateral knee has an impaired proprioception, it must also be symptomatic—otherwise, it is difficult to see how proprioception can have any clinical relevance and how injury can have any effect on proprioception.

Several histological studies of ACL and other knee structures (2–9) have demonstrated a presence of proprioceptive receptors and that these receptors are stimulated by mechanical changes of the knee structures (10–12). Morgan-Jones & Cross (31) discovered an interconnecting band with nerve supply between the ACL and the posterior cruciate ligament—the 'intercruciate band'. These studies indicate that ACL is part of the larger neurological complex of the knee joint which signal proprioception. The question is whether the methods we use today enable us to measure these complex proprioceptive abilities of the knee joint. The test–retest of the methods clearly indicates that the methods are reproducible; however, it does not prove the validity of the proprioceptive measurements. Krauspe et al. (10) claimed that there is no output from mechanoreceptors when the knee is in a resting position of 30° of flexion. From this perspective, one could question whether the reproduction of knee positions provides an appropriate measurement of proprioception. We might primarily measure the subject's short-time memory for the movement. One could argue that during the movement, until the position is reached, the receptors would generate impulses, which the subjects will be able to use during reproduction. To minimize the importance of short-term memory, the period of the positioning has been shortened in our test protocol for the test bench. In the protocol of the isokinetic dynamometer, the short-term memory is not important—the subjects were instructed to press during the positioning and therefore received afferent input. However, we did not demonstrate a proprioceptive deficit in any of the reproduction tests.

Another concern is that proprioceptive measurements do not reflect proprioceptive demand during functional activities where the forces on the knee joint, especially the ACL, are different. We added a method to measure proprioception during muscle tension in order to come closer to measuring proprioceptive demands during functional activities. However, the results did not demonstrate enhanced ability to reproduce knee positions despite the increased muscle tension in PF. The WF group did demonstrate an enhanced ability to reproduce knee positions when muscle tension was increased from 20% (AA20%) to 50%

(AA50%). However, this result appears meaningless in view of the fact that WF did not have any increased ability when the results of AA50% were compared with PP0%.

What may reflect a clinically relevant difference with respect to proprioception is unknown. Prior studies have demonstrated a significant side-to-side difference of 1°. If a 1° difference is considered clinically meaningful the present data yielded a statistical power that varied between 13–98% for the PA and PP tests. On the other hand, 3° yielded a statistical power of 83–100% for the same tests. Similarly, 1° produced a power of 30–76%, and 3° a power of 93–100% for the AA tests. Therefore, while the chance of having committed a type II error may be considerable for a theoretical difference of 1°, it seems small for a theoretical value of 3°. The chance of committing a type II error for TPMD appears marginal.

As the proprioceptive methods used by most researchers detect an impaired proprioception while the limb is being moved in space, we decided to determine the importance of the proprioceptive deficit during the swing face of the gait. The calculations on the physical determinates (Fig. 3) demonstrate that proprioceptive deficits of less than 3° do not have any physical importance during normal walking. That is, the importance of reported proprioceptive deficits of less than 1°, stressed by several authors, can be questioned on the basis of these calculations.

Therefore, the proprioceptive deficits may best be studied in a standing position with the feet on the ground because this is the position in which the patients experience giving way. At the same time it would be of interest to study proprioception during more complex movements such as extension combined with rotation, where the demand for the ACL is largest (10).

The present results of the one-leg hop tests did not demonstrate a significant side-to-side difference in either group. Moreover, there was no difference between the groups. Several studies question the sensitivity of the one-leg hop tests, when used alone, to estimate the patient's functional disability (22, 23, 32–34), however all of them demonstrated a significant side-to-side difference. Because of the lack of a significant side-to-side difference in the present study it becomes relevant to address the issue of how much power the study had to find various hypothetical differences if they in fact existed. Exactly what represents a clinically relevant difference is difficult to ascertain. However, for the one-leg hop tests it is commonly accepted that a 20% difference is considered abnormal. If a 20% or 30% difference is considered clinically meaningful the present data yielded a statistical power of 76–99% and 93–100%, respectively. Considering the major instability in the PF group (6 out of 7 had a positive pivot shift) the lack of a side-to-side difference is notable. One explanation could be that the one-leg hop test is a movement primarily in the sagittal plane without involvement of rotational forces. Alternatively, the test may not be challenging enough since subjects are instructed to land and immediately find their balance. Further studies with differently functioning groups involving rotational force and unbalanced landings would be of interest.

We demonstrated a significant side-to-side difference in the laxity assessments with KT2000 in both groups. There were no significant differences between the groups bilaterally. This is in accordance with previous studies of functionally different groups of patients (1, 35). Therefore, while the KT2000 measures anterior knee joint laxity, it does not provide insight into knee function as indicated by the difference in functional status of the two groups. On the other hand, the PF group had more severe pivot shift grades than the WF group, which suggests that the Pivot shift might be a better indicator of knee function than the KT2000 assessment and the one-leg hop tests.

CONCLUSION

The present study suggests that subjects with a longstanding ACL deficiency do not have an impaired knee joint proprioception as measured by commonly accepted methods with or without muscle tension. Further, there is no difference in proprioception between two groups of patients with markedly different function levels and pivot shift evaluated knee laxity. Additionally, this study suggests that one-leg hop tests and KT2000 measurements cannot be used as indicators of knee function.

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