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Static rotational and sagittal knee laxity measurements after reconstruction of the anterior cruciate ligament

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Abstract

Purpose The goal of the present study was to evaluate static anteroposterior and rotational knee laxity after ACL reconstructions with two noninvasive measurement devices by comparing the measured results of the operated with the contralateral healthy knees of the patients.

Methods Fifty-two consecutive patients were reviewed after isolated single-bundle transtibial ACL reconstruction using a BPTB graft. At a mean follow-up of 27 months, sagittal AP laxity was tested using a noninvasive knee measurement system (Genourob) with an applied pressure of 67 N, 89 N and 134 N. Rotational laxity was measured using a noninvasive rotational knee laxity device (Rotameter) with an applied torque of 5, 8 and 10 Nm. The results were compared with the measurements of the patients' healthy contralateral knees. Tegner, Lysholm and IKDC score were used in order to evaluate the clinical outcome.

Results Pivot shift was negative (33) or glide (16) in 49 patients with 12 of 16 (75%) patients having also a pivot glide on the healthy contralateral side; Lachman tests were negative in 50 cases. Subjective assessment of the IKDC score was classified according to category A in 44 patients, B in 5 patients and C in 3 patients. Mean Lysholm score was 94.5 ± 9.5, median Tegner score was 7 (3–9) preoperative and 6 (3–9) at follow-up (n.s.). Anteroposterior knee laxity measurements revealed mean side-to-side differences of 0.6–1.3 mm ($P < 0.0001$). Rotational laxity measurements revealed no statistical significant differences between the operated and the contralateral knee (n.s.). The measured differences in the entire rotational range varied from 0.2° to 1° depending on the applied torque. In those 3 patients with a positive pivot shift, differences in the entire rotational range of 4.5° at 5 N, 4.6° at 8 N and 4.1° at 10 N were found.

Conclusion Static knee laxity was quantified after ACL surgery using the introduced noninvasive measurement systems by comparing the measured results of the operated with the contralateral healthy knees. Significant differences were found in AP laxity although they were defined as clinically successful according to the IKDC classification. No significant differences were found in rotational knee laxity measurements. Therefore, the used noninvasive masurement devices might offer a high potential for objective quality control in knee ligament injuries and their treatment.

Level of evidence Retrospective case series, Level IV.

Keywords ACL · Knee-laxity · Tibiofemoral rotation · Measurement device · Single-bundle

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Introduction

Objective assessment of knee laxity after reconstruction of the anterior cruciate ligament was advised in order to further improve clinical outcome and decrease the postoperative development of osteoarthritis.

For the anteroposterior laxity, instrumented measurement devices such as the KT-1000 [8] or the Rolimeter [32] were used. However, there are contrasting results of the used devices regarding the precision and the reproducibility of the measurements [4, 9, 11, 23, 26, 29, 37]. Furthermore, rotational laxity, which becomes more and more in the focus after ACL surgery, cannot be measured.

Currently, there is a lack of objective measurement devices especially to assess rotational laxity [19].

Static knee laxity in the anteroposterior plane can be investigated with the Lachman or the anterior drawer test. Furthermore, there are measurement devices available in order to objectively measure AP laxity. In recent studies a new AP laxity device, the Genourob (GNRB) [29] was introduced which might further improve objective measurements with a more accurate fixation by controlling the tension of the fixation. Furthermore, the performance of the Lachman movement is performed mechanically with a controlled force.

Dynamic rotational stability is examined by the pivot shift test or the dial test to investigate injuries of the posterolateral corner. These tests are highly dependent on the skills of the examiner and there is a lack of objective clinical tools to examine tibiofemoral rotation [19]. The Rotameter, an objective and noninvasive measurement device, has shown a high intra- and inter-observer reliability [20] and further achieved high correlations in the comparison with an invasive knee navigation system [19].

These clinical instruments might be of great value in order to objectively investigate knee laxity and might be used in a wide field to examine the restoration of knee laxity before and after surgical procedures.

The purpose of the present study was to objectively compare side-to-side differences of knee laxity in the anteroposterior plane as well as tibiofemoral rotation in patients after ACL reconstruction with the use of two noninvasive measurement devices.

The hypothesis was that differences in postoperative knee laxity in the sagittal and rotational planes can be objectively quantified in vivo with the introduced devices by comparing the measured results with the results of the contralateral healthy knees of the patients.

Materials and methods

Between 2006 and 2007, 154 ACL reconstructions were performed by the senior author. In order to decrease potential influences on tibiofemoral rotation, patients with associated cartilage damage, meniscal tears, additional ligament injuries or patients with known similar problems on the contralateral control knee were excluded. The remaining 52 patients were available for follow-up for this retrospective case series. All had an isolated reconstruction of the anterior cruciate ligament using a single-bundle reconstruction with a bone-patellar tendon-bone graft. The mean follow-up was 27 ± 6 months after ACL surgery. Twenty-eight men and 24 women with a mean age of 28 (16–52) years were involved. The right side was operated in 30 cases; in 22 patients the left side was affected. Clinical examination was performed by two experienced surgeons. As clinical scores, the IKDC score, Lysholm score and Tegner activity scale were used at follow-up. The preinjury Tegner activity level was also assessed retrospectively. The objective assessment of the knee laxity was examined with the Genourob measurement device and the Rotameter testing device.

Genourob (GNRB)

The Genourob (GNRB) (Fig. 1) is a device that measures the sagittal translation of the tibia at 20° of flexion to reproduce the Lachman position. The leg rests on a thermoformed shell that can be adapted to the length of each patient's leg; the foot is held at a rotation of 0°. An electric jack exerts several levels of pressure on the calf, at the examiner's discretion: 67 N, 89 N, 134 N, 150 N or 250 N. Additionally, surface electrodes can be applied to the posterior surface of the thigh ensure that there is no hamstring muscle activity for the knee being tested (feedback effect). A motion sensor (precise to 0.1 mm) records the anterior drawer shift of the anterior tuberosity of the tibia in relation to the femur. The drawer shift for each pressure level can be chosen. The shift/pressure curves are recorded on a remote PC. Each patient has his own electronic file in which laxity measurements are recorded, as are the specific testing conditions: the tightening force on

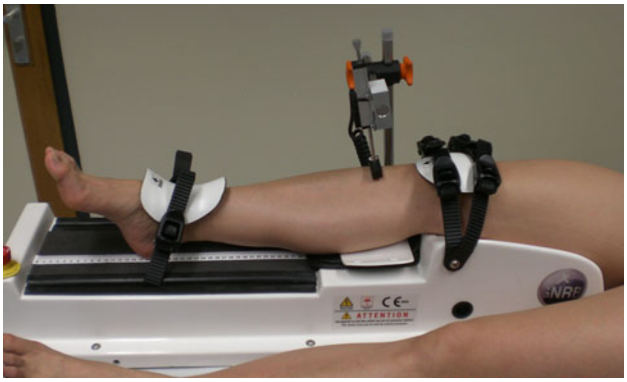

Fig. 1 The GNRB (Genurob) measurement device

the thigh, the level of pressure exerted and the results (shift/pressure curves, extension, stiffness). The system is piloted by a microcalculator that ensures the consistency and precision of the measurements. Comparison tests are performed on each knee; the patient lies on a standard examining table. All data are recorded automatically in the patient's electronic file.

Previous testing has shown promising results regarding precision and inter-observer reproducibility compared to that of the KT 1000 [29].

Rotameter

This measurement device (Fig. 2) consists of the custom-made boot, which allows a comfortable applying of it for the patients. Inside the shoe, the inside part of a VACO®PED foam walker (Oped GmbH, Valley, Germany) is used in different sizes, which can be adjusted according to the patients anatomical condition to fit exactly to the lower extremity of the patient. Outside the boot, custom-made buckles were applied to further minimize soft tissue movement of the lower extremity.

At the sole of the boot, a handle bar is fixed in order to apply different torques digitally controlled to the lower extremity.

To imitate the dial test, the measurements were accomplished in 30° of flexion.

The device consists of an electronic torque key and an electronic sensor with an accuracy of ±0.01° to measure the inclination angle which is connected to a computer system via an external port. The custom-made computer program that was designed for the Rotameter device is able to record the rotation in degrees and the applied torque in Newton metres and will give an acoustical signal at the desired rotation angle or the desired torque.

A previous study showed that a high inter- and intra-observer reliability could be achieved with the device in a population of normal patients [20]. Furthermore, in a recent cadaver study, rotational measurements with the device have shown that partial and total resections of the ACL yielded increases in static tibiofemoral rotation compared to intact knees [18].

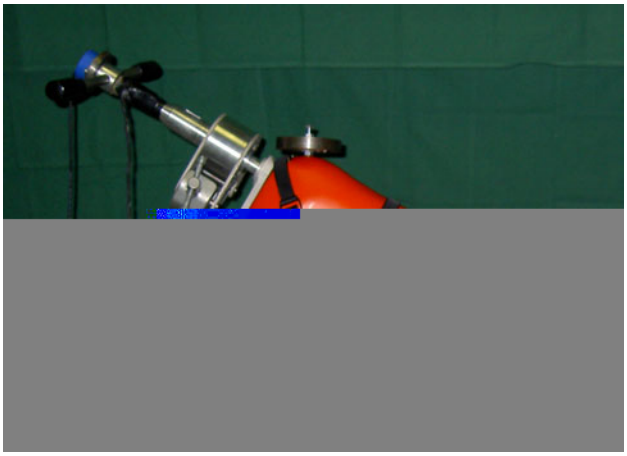

Fig. 2 The Rotameter measurement device

Surgical procedure

Isolated single-bundle ACL reconstruction was performed by the same surgeon in all patients

The tibial tunnel was created in the centre of the ACL footprint. The femoral tunnel was drilled transtibial or through the anteromedial portal in order to reach the area in between the native footprint of the anteromedial and posterolateral bundles. The diameter of the graft varied from 8 to 10 mm thickness. After passing the graft through the drilled tunnels, the graft was secured with two bioabsorbable interference screws (DELTA-Screw, Arthrex, Naples) in the sizes 9–11 mm depending on the size of the graft and the tunnel.

All patients were allowed to immediately bare full weight on the operated knee without wearing a brace. They all received the same postoperative protocol for the physical therapy.

Statistical analysis

Statistical analysis was performed on SPSS 11.5 for Windows software. Statistical tests for nonparametric variables were used. Mann–Whitney test was used to compare pre- and postoperative results of the measurements. Independent *t*-tests were used to compare the laxity measurements of the operated and healthy contralateral knee. Level of significance was set up at $P \leq 0.05$. All data were given in means ± SD.

Results

IKDC laxity measurements

The pivot shift test was negative (33) or glide (16) in 49 patients, 3 patients had a positive pivot shift. Lachman tests were negative in 50 cases and 1 patient had a positive Lachman test with a suspected re-rupture of the ACL. In one patient, the Lachman test was nearly normal.

Knee scores

Subjective assessment of the IKDC knee ligament standard evaluation form qualified within groups showed category A in 44 cases, 6 cases had a B and 2 patients showed a C.

Concerning the IKDC symptoms, 40 patients reached category A, a B was found in 9 patients and 3 patients had a C.

Mean Lysholm score was 94.5 ± 9.5 (median 100 (50–100)), median preinjury Tegner activity level was 7 (3–9) and 6 (3–9) at follow-up (n.s.).

Objective instrumented laxity measurements

GNRB

For the operated knee, the Genourob measured a mean of 2.1 ± 0.7 mm at 67 N, 3.1 ± 0.9 mm at 89 N and 4.9 ± 1.2 mm at 134 N. For the contralateral nonoperated side, 1.5 ± 0.7 mm at 67 N, 2.2 ± 0.8 mm at 89 N and 3.6 ± 1.0 mm at 134 N were measured. The mean side-to-side differences of 0.6 at 67 N, 0.9 at 89 N and 1.3 mm at 134 N were statistically significant ($P \leq 0.0001$), although they were defined as clinically successful according to the current IKDC classification [12].

Rotameter

At 5 Nm of applied torque, 18.2° ± 9.3° were measured for the internal rotation, 31.5 °± 9.4° for the external rotation and 49.8° ± 11.1° for the entire rotational range were seen in the unaffected knee.

For the operated knee, 16.6° ± 8.9° of internal rotation, 33.2° ± 9.5° of external rotation and 50° ± 12.1° of entire rotational range were measured.

At 8 Nm of torque, 28.4° ± 10.6° were found for the internal rotation, 43.9° ± 9.6° for the external rotation and 72.4° ± 13.7° for the entire rotational range. In the surgically treated knee, 26.4° ± 10.1° for the internal rotation, 45° ± 10.5° for the external rotation and 71.4° ± 13.7° for the rotational range.

At highest applied torque of 10 Nm, 34.5° ± 11.9° were measured in the nonaffected side for the internal rotation, 50.9° ± 10.2° for the external rotation and 84.7° ± 16.2° for the entire rotational range.

In the operated knee, 32.2° ± 10.9° were seen for the internal rotation, 51.9° ± 11.4° for the external rotation and 84° ± 15.9° for the entire rotational range.

The mean side-to-side differences for the tibial rotation of the operated knee compared with the noninjured contralateral side are shown in Table 1.

No statistical significant differences were found between the nonoperated knee and the surgically treated knees at all applied torques (n.s.).

In the 3 patients with a pivot clunk (C) in the clinical examination and a firm Lachman test in 2 cases (2 × B, 1 × C), the GNRB measured a mean side-to-side difference of 1.98 mm at 134 N. The entire rotational range in the measurements of the Rotameter device revealed a mean side-to-side difference of 4.5° at 5 Nm, 4.6° at 8 Nm and 4.1° at 10 Nm of applied torque.

Table 1 Mean side-to-side differences of tibiofemoral rotation (°) between the operated versus the contralateral healthy knees

	Internal rotation		10 Nm
	5 Nm	8 Nm	
Side-to-side difference	1.6	2	2.2
P value	0.37	0.38	0.91
	External rotation		10 Nm
	5 Nm	8 Nm	
Side-to-side difference	1.7	1.1	1
P value	n.s.	n.s.	n.s.
	Range (Ext. + Int. rot.)		10 Nm
	5 Nm	8 Nm	
Side-to-side difference	0.3	0.94	0.8
P value	n.s.	n.s.	n.s.

No significant differences were found ($P > 0.05$) at all applied torques

Discussion

The principal finding of the present study is that combined static anteroposterior as well as rotational laxity after single-bundle ACL reconstruction was assessed in vivo with the introduced instrumented noninvasive knee laxity measurement systems by comparing the measured results of the operated knee with the results of the healthy contralateral knees of the patients.

Restoration of the anatomical kinematics is an important issue after ACL reconstruction in order to prevent further increased degeneration of the knee joint. Previous studies have shown that even in knees where the anteroposterior laxity was adequately restored, remaining abnormal knee kinematics were found [10, 28, 35] and single-bundle ACL reconstruction, which mainly addressed the AM bundle was not able to restore rotational stability [38]. However, recently published studies [13, 17, 31] have reported that an anatomically placed single-bundle ACL reconstruction was able to restore equal kinematics compared with double-bundle reconstructions.

In the present study, static knee laxity measurements after ACL reconstruction using a single-bunde BPTB graft were performed. No statistical significant differences in tibiofemoral rotation were found compared with the contralateral healthy side. However, significant differences in AP laxity were found between the operated and the healthy contralateral knees although they were defined as clinically successful according to the IKDC group qualifications.

Clinical outcomes in the literature comparing different surgical techniques of ACL reconstruction methods have been controversial regarding the restoration of rotational stability [1, 2, 14–16, 22, 24, 27, 31, 33–36].

The majority of these outcome studies after ACL reconstruction assessed the restoration of the rotational stability after ACL reconstruction by performing the pivot shift test. It has been described as the most sensitive test for the "functional instability" of the knee [6] and can be assessed clinically as well as quantitatively with the use of a knee navigation system. Colombet et al. [7] could introduce the intraoperative measurement of the pivot shift test with the use of a navigation system, and Robinson et al. [30] were further able to assess tibial translation and rotation during the pivot shift with the same technique. They could show that computer-assisted navigation allowed practical, clinical measurement of the pivot shift test and, therefore quantitative assessment of the effect of ACL reconstruction.

However, if the pivot shift is not performed in a blind manner, a possible bias and influence on the results cannot be excluded. Noyes et al. [25] showed that different examiners produced markedly different kinematics during the pivot shift test on the same cadaver limb; and furthermore, a recently published study by Markolf et al. [21] could demonstrate that a double-bundle reconstruction can also lead to an overcorrection in limiting rotational stability. Therefore, a negative pivot shift does not automatically reflect an anatomical restoration of the rotational stability and might be of limited use in order to clinically assess the restoration of the kinematics of the ACL and to compare single- and double-bundle reconstruction techniques.

This provides further evidence of the need to use instrumented assessment, such as the introduced objective measurement tools, in order to make precise measurements before and after surgery. The Rotameter measurements of the operated knee can be compared with the results of the healthy contralateral side which can be used as a reference for the measurements [20]. The comparison might give important information concerning a possible undercorrection but also an overcorrection of rotational stability or an objectivation of associated injuries.

Three patients showed a pivot clunk (C) with a firm Lachman test in 2 patients (2 × B, 1 × C) in the clinical examination. The objective measurements of the GNRB in these patients showed a mean side-to-side difference of less than 2 mm at 134 N. The rotational range in the measurements of the Rotameter device revealed a mean rotational side-to-side difference of 4.5° at 5 Nm, 4.6° at 8 Nm and 4.1° at 10 Nm of applied torque compared with a mean rotational side-to-side difference of 0.26° at 5 Nm, 0.94° at 8 Nm and 0.77° at 10 Nm in the entire group.

Therefore, the results of the objective measurement devices were in accordance with the clinical findings. Patients with a positive pivot shift also showed increasing tibiofemoral rotation.

Even if the amount of patients with a positive pivot shift was insufficient for a statistical analysis, it showed that static differences in AP laxity but especially the rotational knee kinematics could objectively be quantified with the introduced devices. Even with a restoration of the AP laxity compared to the healthy contralateral side, differences in rotational laxity were found in patients with a positive pivot shift. These clinical findings were supported by previous biomechanical findings [18]. In a human cadaver study, the Rotameter device was able to detect partial and complete ruptures of the anterior cruciate ligament showing a significantly increased tibiofemoral rotation.

Limitations of the study are the retrospective study design. Due to the strict inclusion criteria and the complex measurements on the patients, the amount of patients was limited. Because of the retrospective study design and the lack of a healthy control group, the postoperative measurements could only be compared with the contralateral healthy knees as high correlations of the measurements between both knees in healthy volunteers were described [20]. Therefore, possible differences in tibiofemoral rotation compared to the measurements of healthy volunteers cannot be investigated. Branch et al. [5] obtained rotational knee laxity with a robotic knee testing system and found increased internal rotation and reduced external rotation of the uninjured knees of patients that had previously undergone contralateral ACL reconstruction compared with a group of healthy volunteers. They suggested from their results that, regardless of sex, increased maximum internal rotation may place a person at greater risk of ACL injury.

Moreover, the introduced devices can only perform static measurements which might significantly differ from dynamic measurements. Bignozzi et al. [3] evaluated the clinical relevance of static and dynamic tests after anatomical double-bundle ACL reconstruction using an optical navigation system. They reported no correlation between the laxity during static tests and the pivot shift and concluded that static internal/external rotation may be not sufficient on describing the effect of a double-bundle ACL reconstruction in reducing knee laxity. However, navigation is an invasive method and therefore cannot be used in daily clinical practice. Moreover, the pivot shift test is performed manually and therefore highly dependent on the examiner which questions the reproducibility and the objectivity of the measurements. Furthermore, Bignozzi et al. [3] could also show a significant reduced internal/

external rotation in their postoperative measurements, which supports the findings in the present study. It is not possible to totally quantify the restoration of laxity with a static laxity measurement. However, especially in combination with the pivot shift test, it might add important information.

A possible soft tissue movement especially at higher torques cannot be totally excluded. Therefore, the Rotameter cannot measure real values. However, as the possible measurement error is constant it might be predicted and compensated. Furthermore, it is the intention of the device to compare the measured results which the contralateral healthy knee or the preoperative/preinjury results. This was already shown in previous studies [18, 20].

As rotational knee laxity was assessed by measuring isolated tibiofemoral rotation at 30° of flexion, no information concerning knee kinematics in complex movements can be obtained.

The study has further several strengths. Only patients with isolated ACL ruptures were included. Therefore, possible influences of a partial meniscectomy or associated ligament injuries on the knee kinematics could be excluded. Furthermore, with the introduced mechanical knee laxity devices, knee kinematics can be objectively evaluated in contrast to the pivot shift test or previously described AP laxity devices [8, 32], where a possible bias or influence of the examiner on the tests cannot be excluded.

Conclusions

Static knee laxity was quantified after ACL surgery using the introduced noninvasive measurement systems by comparing the measured results of the operated with the contralateral healthy knees. Significant differences were found in AP laxity although they were defined as clinically successful according to the IKDC classification. No significant differences were found in rotational knee laxity measurements.

Therefore, the used noninvasive measurement devices might offer a high potential for objective quality control in knee ligament injuries and their treatment.

Conflict of interest No potential conflicts of interests are declared.

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