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Jonas Isberg
Eva Faxèn
Sveinbjörn Brandsson
Bengt I. Eriksson
Johan Kärrholm
Jon Karlsson

KT-1000 records smaller side-to-side differences than radiostereometric analysis before and after an ACL reconstruction

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J. Isberg (✉) · E. Faxèn · S. Brandsson
B. I. Eriksson · J. Kärrholm · J. Karlsson
Department of Orthopaedics,
Sahlgrenska University Hospital,
Göteborg University,
41685 Göteborg, Sweden
E-mail: jonas.isberg@vgregion.se
Fax: +46-31-3434092

Abstract The KT-1000 and similar non-invasive arthrometers are used as a complement to clinical examination in the diagnosis of anterior cruciate ligament (ACL) rupture and during the follow-up after surgery. We compared the two methods, KT-1000 and Radiostereometric analysis (RSA), when used to measure anterior-posterior knee laxity (A-P laxity) in patients with ACL rupture, before and after the reconstruction of this ligament, in a prospective, comparative study. Twenty-two consecutive patients (14 men, 8 women) with a median age of 24 years (range 16–41) were studied. All the patients had a unilateral ACL rupture and an intact contralateral knee. The patients were operated on by one experienced surgeon using the bone-patellar tendon-bone (BTB) autograft. Preoperatively and 2 years after the reconstruction, all the patients were evaluated using KT-1000 and RSA measurements of A-P laxity. The side-to-side differences between the injured and the intact knees, that is, total A-P laxity for both knees, are presented. Preoperatively, the median side-to-side differences using the two methods (KT-1000/RSA) were 4.0 (0–10)/7.4 mm (2.2–17.4) ($P < 0.0001$). The total A-P laxity on the injured side was 11.0 (6.0–18.0)/10.9 mm (6.2–19.6) (n.s), while it was 8.0 (6.0–10.0)/3.1 mm (0.2–8.6) on the intact side ($P < 0.0001$). A side-to-side difference of more than 3.0 mm was defined as the cut-off value for indicating ACL rupture. Using the KT-1000, 11 of 22 (50%) patients had a cut-off value above 3.0 mm, while the corresponding figure for RSA was 21/22 (95%) patients. At the 2-year follow-up, the median side-to-side differences using the two methods (KT-1000/RSA) were 0.5 (−1.5 to 4.0)/2.8 mm (−1.8 to 10.7) ($P < 0.0001$). The total A-P laxity on the operated side was 9.5 (7.5–14.0)/6.5 mm (2.4–14.1) ($P < 0.0001$). We conclude that the KT-1000 recorded significantly smaller side-to-side differences than did the RSA, both before and after the reconstruction of the ACL using a BTB autograft. Before it was mainly an effect of larger A-P laxity recordings with KT-1000 on the intact side, and after the reconstruction, the KT-1000 still recorded larger A-P laxity on the intact side and also larger A-P laxity on the reconstructed side than RSA.

Keywords Anterior cruciate ligament · Rupture · Reconstruction · KT-1000 · Radiostereometric analysis · RSA

Introduction

The anterior-posterior knee laxity (A-P laxity) of the knee joint is an important parameter for evaluating a knee with anterior cruciate ligament (ACL) insufficiency. Clinical grading is, however, difficult. The Lachman's, anterior drawer, and pivot-shift tests are not reliable, because they vary considerably between examiners [5]. To obtain more objective evaluation methods, non-invasive arthrometers such as the KT-1000 were developed. The reproducibility of the KT-1000 has been regarded as good in some studies [2], but has been questioned by certain others [16, 22, 33]. It is often used as a complement to clinical examination to establish the diagnosis of an ACL rupture [28] and during the follow-up after an ACL reconstruction [4, 9, 15, 16, 25, 30].

The KT-1000 is widely used by knee surgeons and physiotherapists because of many advantages in the clinical setting. It is non-invasive, can be used in an ordinary examination room and is easy to handle. This method has therefore become the standard method for clinically evaluating A-P knee laxity before and after surgical treatment [1, 3, 15, 25, 27, 30]. In spite of its widespread use, the question of whether the results of KT-1000 measurements are sufficiently accurate and the extent to which they are clinically relevant still remains.

If the KT-1000 measures low side-to-side differences in A-P laxity during the follow-up after ACL reconstruction, for example, it is easy to draw the conclusion that the A-P laxity has normalised after surgery. Jonsson et al. showed that the KT-1000 recorded lower A-P laxity in injured knees after ACL rupture and after ACL reconstruction than RSA did [22]. Moreover, the KT-1000 side-to-side differences were smaller than those based on RSA measurements, both before and after ACL reconstruction [22].

According to the current standard at that time, these authors did, however, use a smaller anterior traction force (89 N) than that commonly applied today.

We aimed to compare KT-1000 and RSA measurements of A-P laxity in the intact knee joint and after ACL rupture, preoperatively and 2 years after an ACL reconstruction in a homogeneous group of patients. We also evaluated side-to-side differences in these patients. A secondary aim was to analyse the ability of these two methods to establish a diagnosis of ACL rupture.

Our hypothesis was that the KT-1000 method is as good as RSA for measuring A-P laxity in the intact and the injured knee (side-to-side difference), in patients with an ACL rupture, as well as during the follow-up after an ACL reconstruction.

Patients and methods

Twenty-two consecutive patients (14 men, 8 women) with a unilateral ACL rupture and an intact contralateral knee were included. The exclusion criteria were a history of any previous knee injury and the involvement of other ligaments. The median age at the time of ACL reconstruction was 24 (16–41) years. The time period between the injury and the ACL reconstruction was 16 (4–45) weeks. The demographics of the patient group are presented in Table 1. All the patients completed their participation in the study.

The patients were evaluated preoperatively and 2 years after the ACL reconstruction. All the patients were evaluated using RSA and KT-1000 measurements for A-P laxity. A clinical assessment was made using Lysholm, Tegner, IKDC, range of motion (ROM) and the one-leg-hop test. All the patients were examined at follow-up by independent observers who did not participate in the surgical procedure. The study was approved by the Human Ethics Committee at the University of Göteborg. All the patients gave their informed consent before they were included in the study.

Surgical procedure

The ACL reconstruction procedure was identical in all patients. All the patients were operated on by one experienced surgeon using the BTB autograft. A standard arthroscopic one-incision technique was used. The BTB autograft was harvested through a 6–7 cm long anterior skin incision. The middle third of the patellar tendon was used. The width of the graft was 8–10 mm, depending on the size of the patellar tendon. A small notchplasty was performed to avoid graft impingement. The graft was placed in approximately the 10.30 (right knee) or 1.30 (left knee) position in the posterior intercondylar notch. The fixation was performed using interference screws at both ends. Four patients had a meniscal tear, which was addressed at the time of the index operation.

Rehabilitation

All the patients were allocated to a standard postoperative rehabilitation programme. All patients were trained by one of three experienced physiotherapists, under thorough supervision by the first and third author.

Table 1 Demographics of the study group

	Patients
No. of patients	22
Age, years*	24 (16–41)
Men: women	14:8
Right: left	11:11
Time from injury to surgery, weeks*	16 (4–45)

*Median (range)

The compliance of the patients to these training sessions was judged as very good. Full weight bearing was allowed and crutches were used for approximately 10 days. After 3–4 weeks, a combination of closed- and open-chain training was started. After 3–4 months, running was permitted, followed after 4–6 months by sport-specific training. After 6 months, sports were allowed if the patients had full functional stability, in daily activities and recreational sports activities. We also used strength and jump tests to evaluate functional stability.

Anterior-posterior laxity (A-P laxity)

Anterior-posterior laxity was measured using RSA and the KT-1000. The differences in A-P laxity between the injured and the intact knee are presented (side-to-side difference). A side-to-side difference more than 3.0 mm was defined as the cut-off value for indicating ACL rupture [9, 13, 28].

Radiostereometric analysis (RSA)

Radiostereometric analysis has been used to evaluate the laxity and kinematics of ACL-injured knees for more than a decade [7, 13, 18, 20, 22–24, 26, 27, 32, 33]. It has mainly been used to quantify the effect of an ACL rupture and to measure A-P laxity during the follow-up after ACL surgery. As a tool for measuring skeletal and implant motions, RSA is accurate and precise down to 0.1 mm and 0.1–0.3° [6, 32, 39] and it has also been shown to be accurate and precise when it comes to measuring A-P laxity for repeated testing over time [11, 40]. When the effect of external forces is studied, the repeatability may decrease due to several factors, such as variations in muscular tension and inconsistencies in the application of external forces [7, 8, 21, 24, 27].

Implantation of tantalum markers

An arthroscopy was performed in all patients (injured knee) 1–3 weeks after they were recruited, confirming the diagnosis. During the same session, the tantalum markers (diameter 0.8 mm) were inserted percutaneously in both the injured and the intact knee (Fig. 1). Four to five tantalum markers were implanted into the distal femur and proximal tibia on both the injured and intact knee. For the RSA measurements at least three markers are required in each segment, and they have to be located in a 3D triangle to ensure that four to five tantalum markers were implanted into the distal femur and proximal tibia on both the injured and the intact side.

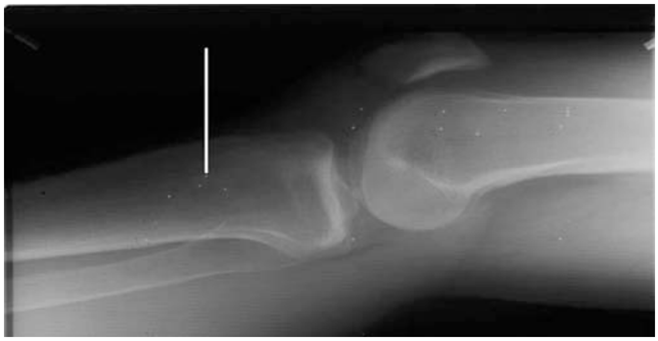

Fig. 1 The tantalum markers can be seen in an intact knee, in both the tibia and femur. The markers located outside the skeletal structure are located in the plexiglass cage

RSA examinations

All the patients were examined in a radiographic laboratory specifically designed to perform RSA examinations (Fig. 2). All the RSA measurements were made by one experienced examiner. Two ceiling-mounted radiographic tubes, one anterior-posterior and one lateral, connected to two separated generators, were used to obtain simultaneous exposures. The patients were examined in the supine position with the knee in a plexiglass calibration cage [33] (Fig. 3). The distal femur was fixed with an adjustable frame to minimise femoral movements. Anterior and posterior loads were applied approximately 7 cm distal to the joint line (Fig. 3). We used the same set-up as that previously described by Brandsson et al. [8].

The following positions were tested:

- extended knee
- 30° of flexion
- 30° of flexion with an anterior traction of 150 N [27]
- 30° of flexion with a posterior pushing force of 80 N.

Fig. 2 The RSA lab with two ceiling-mounted radiographic tubes

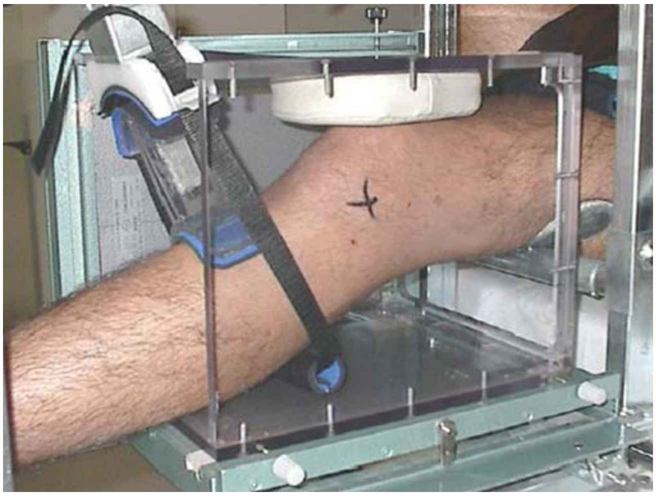

Fig. 3 The plexiglass cage with a posterior pushing force of 80 N

The mean intra-articular displacement of the two tips of the intercondylar eminence along an anterior-posterior axis of the knee represented the A-P laxity. The femoral markers were used as fixed reference segments. The median (range) mean errors and condition numbers representing marker stability and scatter were 0.047 (0.0–0.236) mm. During the preoperative examinations, both the injured and the intact side were examined. At follow-up, the postoperative side-to-side differences in displacement were based on the preoperative measurements of the intact knee, that is, the baseline examination. Measurements of digital radiographs and computations of 3D co-ordinates (34) were performed using a software package (UMRSA 5.0, RSA Biomedical, Umeå, Sweden).

KT-1000 arthrometer test

A standard KT-1000 arthrometer (MEDmetric Corp., San Diego, CA, USA) was used [3, 9, 12, 16, 30, 31, 34, 37]. One experienced observer performed all the measurements [5]. Both legs were placed on the thigh support with the knee in 30° of flexion. The arms of the patient were placed along the side of the body and the patient was instructed to relax (Fig. 4). Before each test, the instrument was calibrated to zero. The intact knee was always tested first. The median value of three measurements for each knee was registered, using a force of 134 N.

Range of motion

Range of motion was recorded on both sides preoperatively and at each follow-up. A standard hand-held goniometer was used. Values were rounded off to the nearest increment of 5°. The extension measurements were performed with the patient in the supine position and flexion was measured when the patient slid his/her heel as close to the buttocks as possible without any help from the arms.

Clinical tests

The Lysholm score, Tegner activity level [38], the international knee documentation committee (IKDC) evaluation system [17] and the one-leg-hop test were used preoperatively and at follow-up. During the one-leg-hop test, the patient jumped and landed on the same foot with his/her hands behind his/her back. The longest hop of three attempts was registered. A quotient (%) was calculated between the intact and the injured knee [14, 36].

Statistical methods

All the values are presented as the median and (range). The Mann–Whitney *U*-test was used in the independent comparison of the two groups for non-parametric data and Wilcoxon's signed-rank test was used to evaluate changes in parameters over time. A *P*-value of less than 0.05 was regarded as statistically significant.

Results

Preoperatively, we found a side-to-side difference of 4.0 (0–10.0) mm, median (range), using the KT-1000. The corresponding RSA value was 7.4 (2.2–17.4) mm

Fig. 4 KT-1000 measurements

($P < 0.0001$). An individual patient evaluation revealed that 11/22 patients (50%) had a cut-off value, for side-to-side difference, higher than 3.0 mm using the KT-1000, but using RSA, 21/22 patients (95%) had a cut-off value higher than 3.0 mm, indicating an ACL rupture.

Separate measurements for intact and injured knees revealed an A-P laxity with the KT-1000 of 8.0 (6.0–10) mm in the intact knee. The corresponding RSA value was 3.1 (0.2–8.6) mm ($P < 0.0001$). On the injured knee, the KT-1000 value was 11.0 (6.0–18.0) mm. The corresponding RSA value was 10.9 (6.2–19.6) mm (n.s).

At the 2-year follow-up, we found a side-to-side difference of 0.5 (−1.5 to 4.0) mm using the KT-1000. The corresponding RSA value was 2.8 (−1.8 to 10.7) mm ($P < 0.0001$). There was a significant reduction in A-P laxity for the KT-1000 and RSA over time between the preoperative examination and the 2-year follow-up (KT-1000; $P = 0.0001$, RSA; $P < 0.0001$) and the KT-1000 measurements were significantly lower than the RSA measurements ($P < 0.0001$).

Separate measurements for injured knees revealed an A-P laxity with a KT-1000 value of 9.5 (7.5–14.0) mm. The corresponding RSA value was 6.5 (2.4–14.1) mm ($P < 0.0001$).

There were significant improvements in the Lysholm score, Tegner activity level, the one-leg-hop quotient, and the IKDC between preoperative and the 2-year follow-up. None of the patients had any motion problems with regard to knee flexion or extension, at the 2-year follow-up. The clinical results are presented in Table 2.

Discussion

Our principal finding in the present study was that the KT-1000 recorded significantly smaller side-to-side differences in A-P laxity, both before and after the ACL reconstruction, larger A-P laxity in the intact knee and larger A-P laxity in the ACL-reconstructed knee than the RSA did. Our hypothesis that the KT-1000 is as good as RSA for measuring A-P laxity in the intact and the injured knee (side-to-side difference), in patients with an ACL rupture, as well as during the follow-up after an ACL reconstruction, was not verified.

Table 2 Tegner activity level[a], Lysholm score[a], one-leg-hop quotient, IKDC, ROM[ab], Preoperative and 2-year follow-up, $n = 22$

	Preoperative	2-year
Tegner	3 (2–9)	7 (4–10)
Lysholm	75 (25–99)	95 (79–100)
One-leg-hop	82 (0–96)	97 (85–100)
IKDC A	0	8
B	0	12
C	10	2
D	12	0
ROM: Intact knee, extension	−5 (−15 to 0)	
ROM: Injured knee, extension	0 (−10 to 15)	0 (−10 to 5)
ROM: Intact knee, flexion	150 (125–160)	
ROM: Injured knee, flexion	140 (85–160)	150 (135–160)

[a]Median(range)
[b]ROM (°)

The most important purpose of the KT-1000 is to evaluate A-P laxity in the knee. One of the reasons why the KT-1000 is one of the most widely used non-invasive arthrometers might be that it can be used in an ordinary examination room and is easy to handle. However, to be clinically relevant, the results from its measurements must be sufficiently accurate. Using a 3 mm cut-off value for the side-to-side difference of A-P laxity, implies that the KT-1000, correctly diagnoses an old ACL rupture in fewer cases. This method also overestimates the effect of ACL reconstruction on the A-P laxity in the knee.

Numerous studies have evaluated the reproducibility and possible sources of errors when using external transducer or skeletal markers to measure skeletal motions. RSA has firm documentation in terms of its accuracy and precision in the evaluation of small motions [6, 29, 40]. Fleming et al. [11] showed that this method is also an accurate and precise way to measure A-P laxity in the knee when repeated over time. It therefore seems reasonable to support the claim that RSA more correctly mirrors the 'true' laxity. Our findings have clinical relevance when it comes to the choice of evaluation method for A-P laxity before and after an ACL reconstruction.

On the other hand, RSA can never be used as an evaluation instrument in clinical practice. It is invasive and associated with a more complicated evaluation procedure than the KT-1000. It is therefore more suitable for use as a research or reference tool [6–8, 11, 13, 18–23, 25–27, 29, 33, 40].

In 1995, Ballantyne et al. [5] studied KT-1000 reliability between two different examiners in patients with a unilateral ACL rupture. The anterior knee laxity, that is, the side-to-side difference, was measured. These researchers concluded that the experience of the examiner was an important factor, which influenced the results. The interclass correlation coefficient (ICC) was 0.84 for the experienced examiners. Sernert et al. [34] studied the KT-1000 and found a low correlation with an ICC of 0.60 between two examiners when they studied anterior knee laxity in intact knees.

Shino et al. [35] found that the soft tissues around the knee influenced the non-invasive arthrometers when trying to measure skeletal displacements of the knee, between the tibia and femur. Kärrholm et al. [27] and Jonsson and Kärrholm [19] found that the tibial starting position in relation to the femur, before loads are applied, may vary depending on several factors, such as position of the knee, degree of flexion, presence of known and unknown associated injuries, fixation devices, soft tissue tension and degree of muscle relaxation.

Table 3 A-P laxity* in injured and intact knees, KT-1000 and RSA

	KT-1000			RSA			Two-year
	Injured knee	Intact knee	Side-to-side difference	Injured knee	Intact knee	Side-to-side difference	KT-1000/RSA side-to-side diff
Preoperative	11.0 (6.0–18.0)	8.0 (6.0–10.0)	4.0 (0–10)	10.9 (6.2–19.6)	3.1 (0.2 to 8.6)	7.4 (2.2 to 17.4)	$P<0.0001$
2-year	9.5 (7.5–14.0)	9.0 (7.0–10.5)	0.5 (−1.5 to 4.0)	6.5 (2.4–14.1)	3.0 (0.2 to 7.8)	2.8 (−1.8 to 10.7)	$P<0.0001$
P = pre/2-year		n.s	$P=0.0001$		n.s	$P<0.0001$	

Preoperative and 2-year follow-up values, $n=22$*mm median (range)

Jonsson et al. [22] compared the KT-1000 with RSA to determine A-P laxity in intact knees, after ACL injury and after reconstruction. A total of 86 patients were allocated to two groups. The RSA measurements were performed in 30° of flexion, with an anterior traction of 150 N, and in 30° of flexion, with a posterior pushing force of 80 N. The KT-1000 measurements were performed using 89 N. The first group consisted of 39 patients who had chronic ACL insufficiency. The second group consisted of 47 patients, 34 of whom had undergone ACL reconstruction using the Kennedy-ligament augmented device (LAD). The patients were examined only once and were not followed longitudinally over time. Jonsson et al. found that the KT-1000 arthrometer recorded significantly smaller A-P laxity values than RSA in both the injured and the ACL-reconstructed knees. On the intact side, the data were more scattered, but the median values for A-P laxity did not differ between the two methods. Fleming et al. [10] compared the KT-1000, RSA and planar stress radiography with the A-P laxity of knees operated on with reconstruction of the ACL. They found that the KT-1000 and planar stress radiography overestimated the laxity values compared with the RSA recordings.

Our study produced results similar to those in the literature, except that we also found a significantly higher A-P laxity in the intact knee using the KT-1000. The power of our study is that, as different from other studies, we evaluated the patients both preoperatively and up to 2 years postoperatively in a homogeneous group of patients, using the BTB autograft in all patients.

Our conclusion from the present study was that the KT-1000 recorded significantly smaller side-to-side differences in A-P laxity, both before and after the ACL reconstruction, larger A-P laxity in the intact knee and larger A-P laxity in the ACL-reconstructed knee than the RSA did. One factor that could explain our findings is that the KT-1000 overestimates A-P laxity in a ligament/graft with high stiffness, as in the intact knee and after an ACL reconstruction. Our findings have clinical relevance when it comes to the choice of method for evaluating A-P laxity before and after an ACL reconstruction and underline the need to evaluate and further develop non-invasive arthrometers.

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