Ultrasonographic test for complete anterior cruciate ligament injury

Piotr Grzelak, Michał Tomasz Podgórski, Ludomir Stefańczyk, Marcin Domżalski[1]

Abstract

Background: Although ultrasound (US) has a wide range of applications in orthopedic diagnostics, sonographic evaluation of traumatic anterior cruciate ligament (ACL) insufficiency is still inadequate. There is a growing need for diagnostic tests that allow for simple and reliable assessment of ACL instability. This investigation aims to evaluate feasibility of sonographic technique for diagnosing complete ACL insufficiency.

Materials and Methods: Eighty three consecutive patients suspected of ACL injury were examined with sonographic, dynamic test of anterior instability. The translation of the intercondylar eminence against the patellar tendon was measured in the injured and opposite (injured) knee. Subsequent magnetic resonance imaging was performed on all patients. Forty-seven of them underwent a further arthroscopy. Five patients have been examined for the 2nd time to evaluate interclass and intraclass agreement and bias.

Results: Complete ACL insufficiency has been confirmed in 37 patients. In those individuals, the total anterior knee translation and the difference between two joints (side-to-side difference) were significantly increased (8.67 mm standard deviation [SD] 2.65 mm in the affected knee versus 2.88 mm SD 1.26 mm in uninjured joint; $P < 0.001$). Based on a threshold of 2.0 mm for the side-to-side difference and 5.0 mm for the absolute translation, the sonographic test was found to have a sensitivity and specificity of 91.9% and 95.6%, respectively.

Conclusions: The present technique supports the clinician with additional fast and noninvasive diagnostic procedure that can facilitate the evaluation of anterior knee instability.

Key words: Anterior cruciate ligament injury, anterior tibial translation, ultrasonography

MeSH terms: Anterior cruciate ligament, ultrasonography, arthroscopy

Introduction

Injury of the anterior cruciate ligament (ACL) is a common finding in orthopedic practice. Accurate diagnosis of this entity may be difficult, however it is essential to implement adequate treatment in order to avoid secondary damages to the knee joint.[1,2] Anterior knee instability is one of the symptoms of complete ACL rupture. A few clinical tests evaluating this parameter exist; however, the outcome of these tests depend on the subjective opinion and the experience of the examiner. Devices that allow for the measurement of translation between the femur and tibia during the examination, despite the recognized accuracy, are not widely used by clinicians. Imaging techniques play an important role in diagnosing ACL injuries. Although magnetic resonance imaging (MRI) is the gold standard modality for diagnosing knee pathologies,[1] ultrasound (US) has the advantage of combining dynamic clinical tests with visualization in real time. Together with its wide availability it is an ideal first line imaging technique when ACL insufficiency is suspected.

This study was to assess the diagnostic usefulness of this fast method for examination of complete ACL insufficiency. The test uses US to directly visualize anterior instability of the knee and is designed for physicians involved in US diagnostics as well as for orthopedics and orthopedic surgeons.

Materials and Methods

An ultrasonographically guided, dynamic test assessing anterior knee laxity and the MRI examination were

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performed in 83 consecutive patients who experienced acute knee trauma between 2008 and 2012. The inclusion criteria were suspected ACL tear on clinical examination patient has recovered from acute phase of injury, age range between 16 and 50 years. Exclusion criteria were acute injuries, no previous pathology, degenerative changes, previous surgical intervention where MRI was not possible.

The test was first performed in the uninjured knee and then in the contralateral joint in order to eliminate the influence of increased, individual specific knee laxity. In order to evaluate the intra and interobserver repeatability coefficient, 6 patients have had both their knees examined again by the same radiologist and by a second radiologist who was familiar with the examination technique.

In 47 of 83 patients after knee injury arthroscopy was performed. Information about the degree of the knee injury was obtained retrospectively from medical records. Examination protocol complied with the Declaration of Helsinki and was approved by the local research Ethics Committee.

Ultrasound examination protocol

The GE Vivid 7(General Electric Vingmed Ultrasound, Horten, Norway) US apparatus was used for the study, equipped with a 12 L linear transducer, with a frequency of 6–14 MHz.

The patient was in a supine position with legs bent. Several push-pull movements of the lower leg were performed for proper muscle relaxation, which allowed further, more precise measurements to be obtained.

Following this, the patient was placed in a seated position and an elastic roll (a diameter of about 20 cm) was placed beneath the distal, posterior aspect of the thigh, so that the lower leg of the patient hung freely from the edge of the examination couch. In this start position, the knee joint was flexed to about 70–80°. The examiner sat in front of the patient with his lower leg close to the patient's shin. The transducer was placed onto the anterior aspect of the knee, slightly above the level of the tibial tuberosity and parallel to the patellar tendon (PT). After identification of the anatomical landmarks (intercondylar eminence [IE], tibial tuberosity and PT) [Figure 1], the lower leg of the patient was pushed backwards with the examiner's foot flexing the tibia in the knee joint (a leverage mechanism) [Figure 2]. Applied force was unlimited but a direct view of its effect allowed to recognise the end point, defined as no further displacement of the tibia relative to the femur.

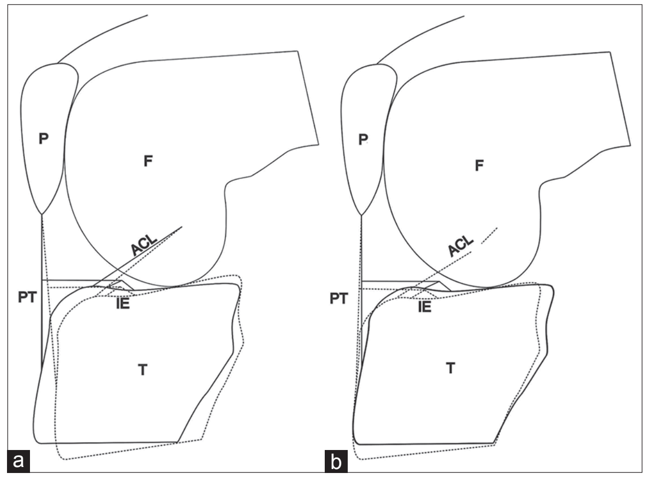

Figure 1: A line diagram showing pattern of movement of the proximal tibia in a patient with an intact anterior cruciate ligament (ACL) (a) and with an ACL deficiency (b) (F: Femur; T: Tibia; P: Patella; PT: Patellar tendon; IE: Intercondylar eminence)

Procedure was repeated 3 times and stored as a cine loop. Further analysis was performed immediately after acquisition on workstation (EchoPack, General Electric, Horten, Norway) using quantitative image analysis software. The translation of the IE with respect to the PT was measured and given in millimetres as a mean of three repetitions.

Magnetic resonance imaging examination protocol

All patients after the knee injury underwent a subsequent MRI of the knee. The examinations were performed with an Avanto 1.5T MRI system (Siemens, Germany), using the dedicated coil. The cruciate ligaments were evaluated on the basis of T1-weighted (parameters applied: TR = 600 ms, TE = 11 ms), and PD/T2-weighted (parameters applied: TR = 3000 ms, TE = 33 ms) images (FoV = 160 mm, matrix = 320 mm × 320 mm, thickness = 3 mm). All images were analyzed retrospectively on a work station (Exchibeon, Pixel Technology, Poland) using software that allowed for three-dimensional reconstructions and measurements. Examinations were evaluated by an experienced musculosceletal radiologist who was unaware of the sonographic test results. Complete ACL insufficiency was diagnosed according to the criteria described elsewhere.[1]

Statistical analysis

The values of knee joint laxity are presented as the mean and range. The normality of data distribution was checked by the Shapiro–Wilk test. Because of non homogeneity of variance the Mann–Whitney U-test was employed to evaluate the difference of the knee joint laxity between groups. To compare the side side difference of knee joint laxity in each patient, the Wilcoxon signed rank test was

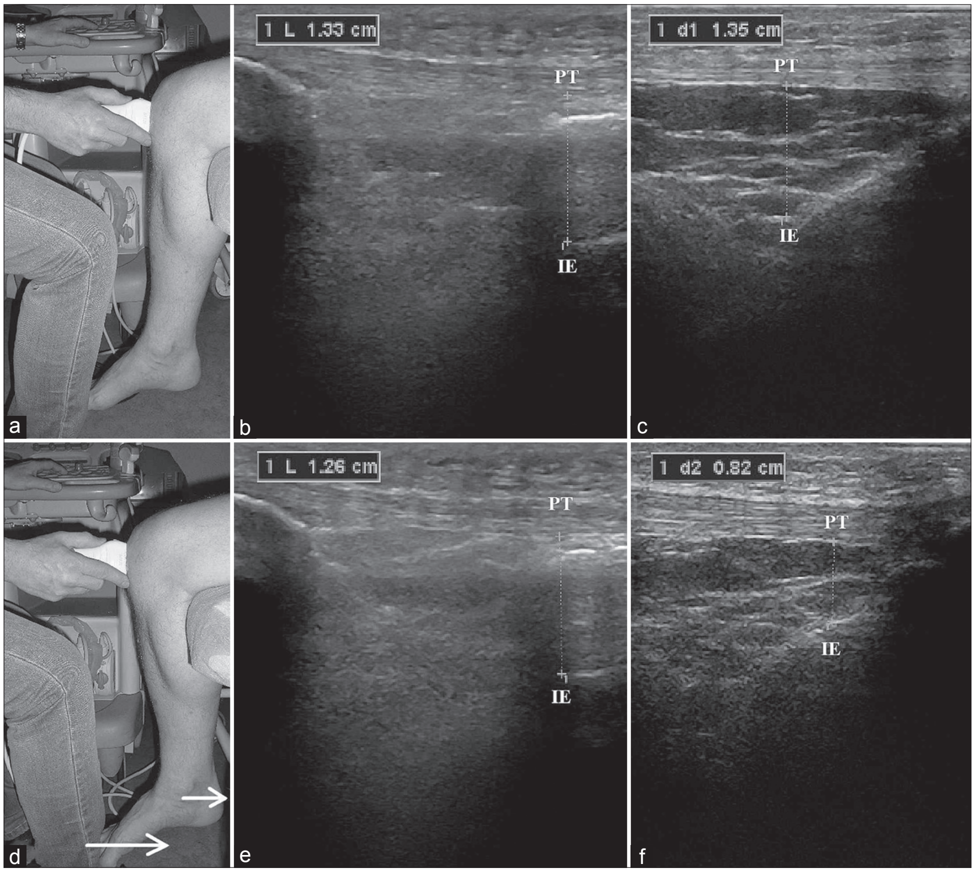

Figure 2: Ultrasonographic evaluation of anterior knee translation during the shift of the intercondylar eminence against the patellar tendon. Arrows indicate the direction of the force applied in moving the shin from a start (a) to an end (d) position. Corresponding ultrasound image in a patient with an intact anterior cruciate ligament (ACL) (b and c) and an insufficient ACL (e and f)

applied. A decision tree was used to determine the diagnostic algorithm. Sensitivity, specificity, positive and negative predictive values with a 95% confidence interval (CI) were calculated and compared to the referential test (arthroscopy or MRI). The results of interclass and intraclass agreement were analyzed with the Bland–Altman plot and by calculating the R^2 value by means of the linear regression analysis. The Bland–Altman plot depicts the percentile difference between two measurements (Y-axis) against their mean (X-axis) and is used to assess for bias. The R^2 value gives the level of agreement. Statistical analysis was performed using Statistica for Windows (version 10.0, StatSoft, Tulsa, OK, USA). A $P < 0.05$ was regarded as statistically significant.

Results

The examined group consisted of 52 Caucasian men (62.7%) and 31 Caucasian women (37.3%) with an average age of 30 years (range 16–50 years). Ultrasonographic test was performed after acute signs of injury had subsided, no sooner than 10 days from a trauma (10–365 days, average 42 days). Complete ACL injury was identified in 37 patients using MRI. Arthroscopy confirmed the ACL injury in 31 patients. In 1 patient arthroscopy revealed incomplete ACL injury instead of complete insufficiency and remaining five patients did not give their consent to arthroscopy. In 10 patients with no signs of complete ACL insufficiency in MRI, athoroscopy was performed and confirmed the negative MRI result. A total of 36 patients were not verified arthroscopically due to lack of consent to surgical treatment, insufficient indications for surgery or treatment in other clinical centre.

The results of dynamic ultrasound examination

In 37 injured knees with confirmed ACL insufficiency, the mean value of the total knee anterior translation was 8.67 mm (standard deviation [SD] 2.65 mm). In 92 knees of 46 patients without diagnosed ACL injury total translation was 2.88 mm (SD 1.26 mm). The difference was statistically significant ($P < 0.001$) [Figure 3]. The average side-to-side difference of the anterior knee translation was significantly increased in patients with complete ACL insufficiency (5.1 mm SD 2.3 mm $P < 0.001$), but not in patients without confirmed ACL injury (0.1 mm SD 1.6 mm, $P = 0.63$) [Figure 4.]

There was no difference of total anterior knee translation of uninjured knee between groups (3.05, SD 1.01 in uninjured knees of patients with ACL insufficiency of the contralateral joint versus 2.88, SD 1.26 in knees of patients without ACL injury; P = 0.5). According to the diagnostic algorithm a side side difference greater than 2.0 mm and a total anterior translation of more than 5.0 mm should be both present to identify patients with a pathological instability suggesting complete ACL insufficiency. Tables 1 and 2 present the test ability to diagnose the ACL insufficiency for each step of the diagnostic algorithm. Sensitivity, specificity, positive and negative predictive values, with a 95% CI calculated for each step of the diagnostic procedure are presented in Table 3. Interclass and intraclass agreement were 97.23% and 98.2% respectively (P = 0.0000). Information about the bias and agreement limits between measurements and between observers are presented in the Bland–Altman plots [Figures 5 and 6].

Discussion

A number of clinical examinations have been proposed to evaluate anterior knee instability, which is the indicator of the ACL injury.[3] However, all clinical tests have some limitations because they are subjective, imprecise, rarely reproducible, and pain in the swollen joint or muscle spasm can interfere with proper examination.[9,10] Pivot shift test is considered to be the most specific (98%), but its poor sensitivity (24–61%) significantly limiting its use. In addition, the complexity of movements during this test makes US guidance impossible. The anterior drawer test shows good sensitivity (68–92%) and specificity (91%), especially in chronic conditions.[4-6,8] The Lachman test is considered to be the most sensitive (85–98%) and specific (94%) in the assessment of ACL injury.[4-7] However, it might be difficult to perform it on a large person, especially by an examiner with small hands.[8] The present test combines features of the Lachman test and the anterior drawer test allowing for reliable knee assessment under sonographic control. Moreover, a leverage mechanism that was used, diminish the influence of the examiner's physical status on test accuracy.

To quantitatively evaluate anterior knee displacement, arthrometers, fluoroscopic measurements and electromagnetic systems have been introduced.[11] Although they can facilitate a diagnosis to some extent,[3,10,12,13] these methods are not free of disadvantages concerning their invasiveness, reliability, space requirements or cost,[3,8,9,12,14,15] limiting their standard use in confirming an ACL rupture.

Imaging techniques are widely used to assess the well characterised direct and indirect criteria of ACL injury.[1,9,16-19] In recent decades, MRI has gained the most acceptance in diagnosing different knee pathologies.[18] A metaanalysis carried out by Oei *et al.*[20] defined the specificity and sensitivity of MRI in detecting ACL

Table 1: The test ability to diagnose the ACL insufficiency based on side to side difference (s-t-s) of 2 mm

	Test negative (s-t-s ≤2 mm)	Test positive (s-t-s >2 mm)
ACL injury present	1	36
ACL injury absent	39	7

ACL=Anterior cruciate ligament

Table 2: The test ability to diagnose the ACL insufficiency based on side to side difference (s-t-s) of 2 mm and total translation of 5 mm

	Test negative (s-t-s ≤2 mm and TT ≤5 mm)	Test positive (s-t-s >2 mm and TT >5 mm)
ACL injury present	3	34
ACL injury absent	44	2

ACL=Anterior cruciate ligament, TT=Total translation

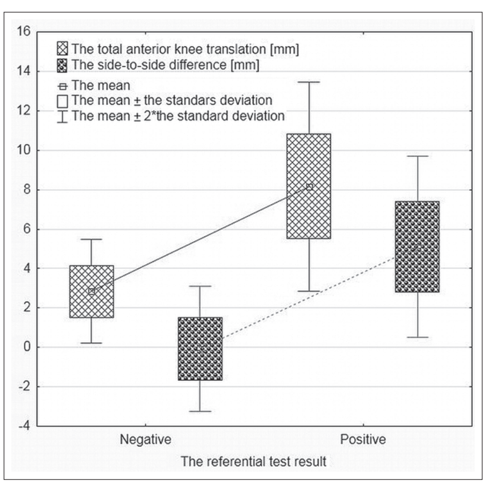

Figure 3: Bar chart showing mean difference of the total knee anterior translation and the side-to-side difference in patients with positive and negative referential test results

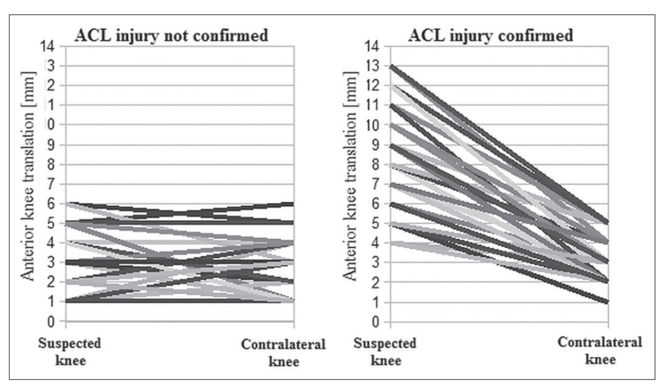

Figure 4: Line chart showing side to side difference of the anterior knee translation in each patient from the group with negative and positive reverential test results

injuries as 94.4% (95% CI: 92.3–96.6) and 94.3% (95% CI: 92.7–95.9), respectively. Nevertheless, reduced accuracy was noted in cases of partial and chronic ACL ruptures.[1] Moreover, MRI evaluates only the structure of the ligament, which does not correlate fully with knee stability. Thus, despite it being a commonly used diagnostic procedure, it will not provide a definite answer for the most important clinical question concerning mechanical and functional joint stability.[2] In addition, it is also expensive and sometimes unavailable as a routine diagnostic tool. Finally, a major limitation of MRI are the artifacts due to metallic implant placement. This can decrease the efficiency of the reconstructed cruciate ligaments evaluation.

The great advantage of US examination is its ability to assess the dynamic range of motion in a quantitative manner. For years, attempts have been made to introduce a reliable dynamic US test to assess the ACL injury. Those tests differ in probe placement (dorsal or ventral approach), applied force (gravity only or additional force) and a number of required operators.[2,8,21-23] All the above make standardization and parameterization of these tests difficult and result in varied sensitivity and specificity [Table 4].

The method presented in this paper differs from earlier studies in several regards. The ventral approach was chosen, which enables the examination of the patient staying in the supine position. This allows this technique to be applied in the operating room, as the supine position is the standard for ACL reconstruction.

In previous studies, only the side to side difference of anterior translation of the knee was evaluated. It was due to the fact that there is a great variance of absolute knee joint laxity in the population and the difference between two knees of the same patient gives more information than the absolute translation. The first step of the algorithm proposed in this study was based on the side-to-side difference of 2 mm and gave very similar sensitivity and specificity as presented by Palm *et al*.[2] (Palm *et al*. 97.3% and 84.8% vs. present study: 97% and 87.5%). Although the second step, assessing the total knee translation, decreased sensitivity from 97% to 91.9% it increased specificity from 87.5% to 95.6%. This indicates that, despite the population variability of total knee laxity, this parameter can increase the examination specificity.

The influence of the examiners posture was eliminated. The use of leverage (when the examiner pushes patients

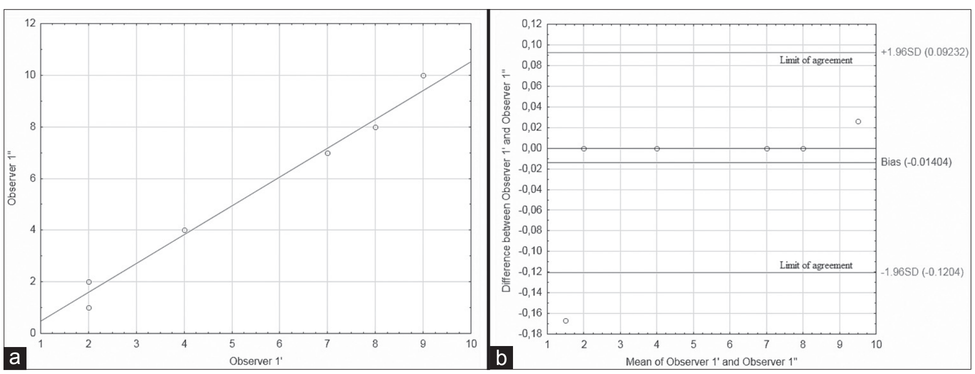

Figure 5: Intraclass correlation plot (a) and Bland–Altman plot for intra-observer agreement (b). Observer 1: The first measurement of the observer; observer 2: The second measurement of the observer

Table 3: Sensitivity, specificity, positive and negative predictive values in each step of diagnostic algorithm

Diagnostic stage	95% CI			
	Sensitivity	Specificity	Positive predictive value	Negative predictive value
s-t-s >2 mm	97.3 (84.2-99.9)	84.8 (70.5-93.2)	83.7 (68.7-92.7)	97.5 (85.3-99.9)
s-t-s >2 mm and TT >5 mm	91.9 (77-97.9)	95.6 (84-99.2)	94.4 (80-99)	93.6 (81.4-98.3)

TT=Total translation

Table 4: Results of studies concerning sonographic evaluation of the anterior cruciate ligament rupture examination

Reasearch	Approach	Diagnostic criteria	Sensitivity (%)	Specificity (%)
Friedl and Glaser[21]	Ventral	4.0 mm side-to-side difference of the tibial head ventral translation	70.00	98.00
Chylarecki *et al.*[23]	Dorsal	3.0 mm side-to-side difference of the tibial head ventral translation	95.00	98.00
Schwarz *et al.*[22]	Dorsal	3.3 mm side-to-side difference of the tibial head ventral translation	85.00	91.00
Gebhard *et al.*[8]	Dorsal	5 mm side-to-side difference of the tibial head ventral translation	96.00	98.00
Palm *et al.*[2]	Dorsal	1 mm side-to-side difference of the tibial head ventral translation	97.00	87.50
Grzelak *et al.*	Ventral	1.5 mm of side-to-side difference and 4.5 mm of absolute ventral translation of the tibial head	91.90	95.60

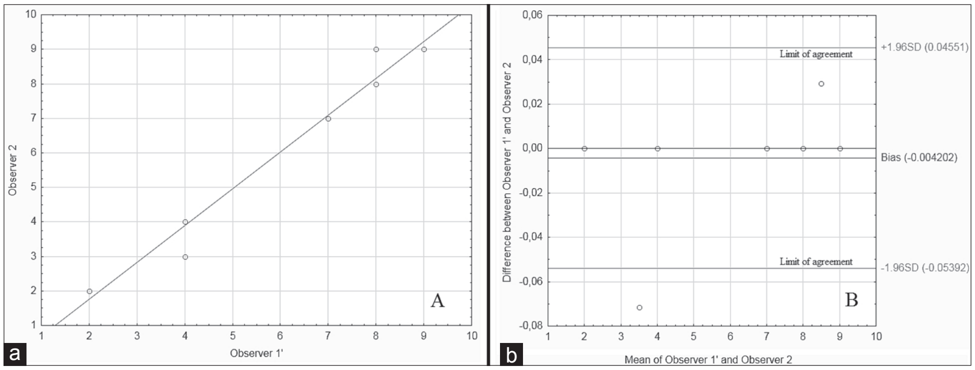

Figure 6: Intraclass correlation plot (a) and Bland–Altman plot for inter-observer agreement (b). Observer 1: The measurement of the first observer; observer 2: The measurement of the second observer.

foot with ones foot, bending patients knee) does not require much physical strength. Furthermore it enables the test to be performed by only one physician, because both hands of the physician remain free, allowing for simultaneous manipulation of the transducer and adjustment of US apparatus parameters. Moreover, the test became independent of the dynamic pull but rather on the application of constantly increased force. This reduces the displacement of the US probe during examination, enabling more precise diagnosis and improving test repeatability. On the other hand, it might be the reason for decreased absolute knee anterior translation values in comparison to the Gebhard *et al*.[8] results (present study: 8.67 mm and 2.98 mm vs Gebhard *et al*. 14.1 mm and 7.7 mm for the injured and injured knee, respectively). Contrary to this, the side-to-side differences reported in this paper were higher than in those by Palm *et al*.[2] (5.1 mm vs 3.8 mm in patients with ACL instability and 1.3 mm vs 0.1 mm in subjects without the injury). It suggests that changes of position between proposed anatomical landmarks more accurately reflects the actual movement which occurs in the knee joint.

According to the inter and intraclass agreement analysis, present test is characterised by a perfect repeatability. It indicates that the proposed examination technique is objective and very reliable. In the authors' opinion, ultrasonography is the modality that provides the physician with the widest range of clinical information. It is available, safe, inexpensive, and unlike electromagnetic devices and arthrometers, it is not dedicated just to this one type of examination.

The limitation of the present test is common for all forms of physical examinations and concerns its decreased diagnostic ability in the acute phase of trauma, when patient might not be able to move the knee joint freely. It is worth mentioning that even the MRI sensitivity is reduced in the acute phase after trauma due to the presence of hematoma and/or edema in the injured joint.[1] Nevertheless because of the application of steady force, instead of powerful, quick manoeuvres, the test may be less unpleasant. It might be confirmed by the fact that it was capable of diagnosing complete ACL insufficiency in 3 patients 10 days from the initial trauma.

Conclusion

An ultrasonographically evaluated dynamic test of anterior instability of the knee is precise, harmless and a rapid method of quantitative tibio femoral translation assessment. Because the current standard tests have not gained absolute acceptance among physicians we propose this test as an alternative that addresses their disadvantages. In our opinion US examination is a useful tool in diagnosing ACL tear.

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