ORIGINAL ARTICLE

A comparison of Telos™ stress radiography versus Rolimeter™ in the diagnosis of different patterns of anterior cruciate ligament tears

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KEYWORDS
Anterior Cruciate Ligament; Complete tear; Partial tear; Laximetry; Rolimeter™; Telos™; Stress x-rays; Pivot-shift test; Knee laxity measurements

Summary
Introduction: Our knowledge on anterior cruciate ligament (ACL) pathomechanics has increased. The diagnosis of partial ACL tears must be accurate in order to adjust the operative planning to anatomic status and injury severity. Instrumented measurement of knee laxity is a useful preoperative tool to quantify anterior tibial translation and several laximetry tests are available. Yet, their accuracy remains to be established.

Hypothesis: Clinical examination combined to instrumented laximetry with Telos™ 15 kg and/or Rolimeter™ would increase their sensitivity and specificity in the diagnosis of various ACL injury patterns.

Materials and methods: One hundred and seventy-seven patients were prospectively included. The ACL status was validated by arthroscopy. Around 69.5% had a complete ACL tear and 30.5% had a partial ACL tear.

Results: Gross laxity with positive clinical tests was associated with complete ACL tears. Mean side-to-side difference was significantly greater with both laximetry methods in complete versus partial ACL tears. Laximetry results among different types of partial tears were not significantly different. Telos™ results were consistent with gross laxity confirmed by pivot-shift test, while this was not recorded with Rolimeter™. Gross laxity with clinical tests and anterior tibial translation more than 5 mm with Telos™ were substantially associated with complete ACL tears.

Discussion: The combination of standard clinical examination with Telos™ was more accurate than with Rolimeter™ in the preoperative identification of the ACL injury pattern. Applying additional diagnostic tools can help the surgeon to preoperatively diagnose partial or complete ACL ruptures and propose an injury-specific surgical treatment.

Level of evidence: Level III (case-control study).

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### Introduction

Instrumented measurement of knee laxity is a useful additional tool in both preoperative and postoperative evaluation of anterior cruciate ligament (ACL) reconstruction [1]. Many studies have shown their potential benefits and drawbacks from the use of arthrometry devices in the diagnosis of rupture and the evaluation of ACL reconstruction [1,2]. The objective quantification and the numerical measurement of knee laxity can discriminate the injured from the non-injured knee and can help identify the deficient structures [3]. Additionally, laxometry can be used as an objective tool for quantification purposes or for the validation of new reconstruction procedures [2]. Drawbacks of their use include the need for careful interpretation of their results, the potential over-estimation of laxity [4], and that most of them are examiner-dependent [1,2].

Since the rise of the double bundle concept in anatomy [5] and biomechanics [6] of ACL reconstruction, there has been an interest in the literature on complete and partial ACL ruptures [7–9]. Many surgeons apply different treatment based on injury pattern, that includes single or double bundle ACL reconstruction in complete tears, augmentation of the remaining bundle in partial tears, or even conservative treatment of incomplete ACL ruptures [8–13]. This raises the need for accurate evaluation and measurement of ACL laxity in order to potentially identify the injury pattern before arthroscopy and chose the correct treatment [12]. The need to discover tools to precisely diagnose the ACL injury pattern is even greater when standard clinical examination [1,14–16] or imaging methods [17] fail to produce consistent results.

Currently, there are many devices that help measure knee laxity, and the most popular are the KT-1000" and KT-2000" Knee Ligament Arthrometer (KT-1000™, KT-2000™; MEDmetric Corp, San Diego, California), the easy-to-use Rolimeter™ (Aircast Europa, Neubeuern, Germany), and the stress radiography Telos™ device (Telos GmbH, Lauscher, Holstein, Switzerland). Numerous studies compare different instrumented methods mostly to KT-1000™ [1,2], some data on laxometry and partial ACL tears [18–22], and no studies comparing Rolimeter™ to Telos™ in ACL tears [1,2,18,23–29].

### Hypothesis

Combination of standard clinical tests and two different instrumented laxometry methods would increase their sensitivity and specificity in the preoperative diagnosis of the ACL injury pattern.

### Materials and methods

The study involved the prospective evaluation of all patients who were surgically treated for ACL rupture in two orthopaedic departments during the period of September 2009 to February 2010. Inclusion criteria were:

- adolescent and adult patients that were to be surgically treated for primary ACL reconstruction;

- no concomitant ligamentous injury;

- no contralateral knee injury or any other previous ipsilateral or contralateral knee operation.

### Clinical examination

Patients were preoperatively examined with the Lachman and the pivot-shift tests. Lachman test were divided in “delayed Lachman” for side-to-side difference (SSD) of less than 5 mm, and “soft Lachman” for more than 5 mm. Pivot-shift was graded by the examiner according to IKDC criteria as “equal” (grade 0), “glide” (grade +1), “clunk” (grade +2), or “gross” (grade +3) [14]. Two surgeons performed both tests with the same technique at office consultations and before surgery under anaesthesia and the maximum value was selected.

### Instrumented laxometry

Preoperative evaluation included bilateral Telos™ stress radiography (15 kg on the tibia at 20° of knee flexion) (Fig. 1) [4,30,31]. One day before surgery and Rolimeter™ at office consultations and under anaesthesia (maximum force; 20° of flexion) (Fig. 2). Maximum value was selected. Anterior tibial translation of the injured knee and SSD were calculated. Two senior surgeons calculated the anterior tibial translation from the radiographs by measuring the distance from the posterior margin of the medial tibial condyle to the femoral condyles (Medial Anterior Tibial Translation; MATT) (Fig. 1). In cases of a non-compatible x-ray, the procedure was repeated.
tear was classified as "PL intact". In the case of an isolated PL bundle rupture and the visual confirmation of the presence and the integrity of the AM bundle, the tear was "AM intact" (Fig. 3). Finally, when the ligamentous stump of the ACL was found "scaring" on the PCL, the tear was classified as "PCL healing" [12,34,35].

Statistical analysis

Chi-squared test was used for comparison of two qualitative variables. Spearman correlation test and Pearson test were used for comparison of two quantitative variables. Results from qualitative versus quantitative variables were compared using Mann-Whitney and Kruskal-Wallis tests.

Results

One hundred seventy-seven patients were included (female to male ratio 0.36). Mean age was 30.2 ± 11.0 years (15–64). Patients from the two participating hospitals had similar demographics and characteristics concerning type of ACL tear and laxity results in both clinical tests and instrumented methods. Group A from the first hospital had 100 patients (age 32.1 ± 11.7 years, female to male ratio 0.4, time from injury to operation 22.8 ± 7.5 weeks) and group B from the second hospital had 77 patients (age 27.0 ± 10.2 years, female to male ratio 0.31, time from injury to operation 19.9 ± 9.3 weeks).

Arthroscopic evaluation

ACL injury pattern was complete in 123 knees (69.5%) and partial in 54 knees (30.5%). Among partial tears, 25 (14.1%) presented with a "PL intact", seven (4.0%) "AM intact" and 22 (12.4%) "PCL healing".

Clinical examination

Considering the whole series, 18% had "delayed Lachman" and 82% had "soft Lachman"; 6% had "no pivot" (equal), 35% "pivot +1", 45% "pivot +2" and 14% with "pivot +3". Correlation of Lachman and pivot-shift test with the ACL

Figure 3 Examples of an anteromedial (AM) intact type of injury.
injury pattern is presented in Table 1. Gross laxity values of Lachman and pivot-shift tests (grade +2 and +3) were observed significantly more often in complete ACL cases (98% and 79%, respectively). Negative (equal) and grade +1 pivot were more accurate in the diagnosis of an incomplete tear, but without any difference between the subgroups (Table 1). "Pivot +2" or "+3" had 82.2% sensitivity and 87% specificity in the diagnosis of complete ACL tears.

Instrumented laximetry

Considering the whole series, mean SSD was 6.4 ± 4.3 mm with the Telos™ and 4.5 ± 2.9 mm with the Rolimeter™ device (Spearman test r = 0.30, P < .000028). According to ACL injury pattern (Table 2), SSD of anterior tibial translation between complete and all types of partial ACL tears was significantly greater with Telos™ (mean 7.4 ± 4.4 mm vs. 5.3 ± 2.6 mm) and Rolimeter™ (mean 4.0 ± 3.3 mm vs. 2.6 ± 2.6 mm, respectively). The difference of laximetry results among different types of partial tears was not significant (Table 2). SSD > 5 mm with Telos had an 80.9% sensitivity and an 81.8% specificity for complete ACL tears. SSD > 5 mm with Rolimeter™ had a 67.5% sensitivity (P < 0.01 when compared to stress x-rays) and an 84.3% specificity (P: NS).

Correlation of preoperative Lachman and pivot-shift tests with the two instrumented methods is shown in Tables 3 and 4, respectively. There was a strong correlation between gross laxity results of both clinical tests with the Telos™ device (P < 0.01 for Lachman and P < 0.0001 for pivot-shift), which was not observed with the Rolimeter™. The combination of SSD > 5 mm with Telos and positive pivot-shift with the diagnosis had an 88% sensitivity and a 94.6% specificity for complete tears (P < 0.01 when compared to Telos or pivot-shift alone). SSD > 5 mm with Rolimeter™ and positive pivot-shift with the diagnosis of complete ACL tears had a 72.7% sensitivity (P < 0.01 when compared to Telos™ and clinical examination) and a 92.4% specificity (P: NS) (Table 5).

Discussion

Clinical examination is the cornerstone in the first approach on patients with ACL-deficient knee. The clinical tests are predominantly dependent on the skills, training and experience of the surgeon and there have been reports of a variety of results and intra-observer errors even for the most common examinations [1,14–16]. Further drawbacks include the inability to accurately quantify and compare the results and the production of inexact measurements [1,2,14,15]. On the other hand, the instrumented measurement of knee laxity assesses mostly anteroposterior (AP)

Table 1 Comparison between the clinical examination results and the anterior cruciate ligament (ACL)-injury pattern.

<table>
<thead>
<tr>
<th>ACL injury pattern</th>
<th>Clinical examination of knee laxity</th>
<th>Pivot-shift test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lachman test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delayed&lt;sup&gt;a&lt;/sup&gt; (%)</td>
<td>Soft&lt;sup&gt;b&lt;/sup&gt; (%)</td>
</tr>
<tr>
<td>Complete tear</td>
<td>2</td>
<td>98&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>AM intact</td>
<td>71</td>
<td>29&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>PL intact</td>
<td>37</td>
<td>63&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>&quot;PCL nurse&quot;</td>
<td>50</td>
<td>50&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

AM: anteromedial; PL: posterolateral; NS: not significant when compared to "delayed".

<sup>a</sup> < 5 mm side-to-side difference (SSD).

<sup>b</sup> > 5 mm SSD.

<sup>c</sup> P < .00001 when compared to "delayed".

<sup>d</sup> P < .00001 when compared to grade 0 and 1.

Table 2 Correlation between the arthroscopic anterior cruciate ligament (ACL) injury pattern and the preoperative results of side-to-side difference (SSD) with Telos™ stress radiography & Rolimeter™.

<table>
<thead>
<tr>
<th>ACL injury pattern</th>
<th>SSD of anterior tibial translation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Telos™ (mm)</td>
</tr>
<tr>
<td>Complete tear</td>
<td>7.4 ± 4.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>All partial tears</td>
<td>4.0 ± 3.3&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>AM intact</td>
<td>8.0 ± 3.8&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>PL intact</td>
<td>3.3 ± 3.1&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>&quot;PCL nurse&quot;</td>
<td>2.9 ± 2.8&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

ACL: anterior cruciate ligament; AM: anteromedial; PL: posterolateral; NS: not significant when compared to "delayed".

<sup>a</sup> P < .00001 when compared to partial tears.

<sup>b</sup> Interquartile range 25–75% (IQR): 4.2–10.0 mm, interquartile mean (IQM): 5.9 mm.

<sup>c</sup> IQR: 5.3–2.6 mm, IQM: 3.5 mm.

<sup>d</sup> IQR: 2.1–4.9 mm, IQM: 2.6 mm.

<sup>e</sup> IQR: 1–4 mm, IQM: 3 mm.

Table 3 Instrumented measurement of side-to-side difference (SSD) in correlation with the preoperative results of the positive Lachman test for the whole study population.

<table>
<thead>
<tr>
<th>SSD of anterior tibial translation</th>
<th>Lachman test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delayed (mm)</td>
</tr>
<tr>
<td>Telos™</td>
<td>3.5</td>
</tr>
<tr>
<td>Rolimeter™</td>
<td>3.0</td>
</tr>
</tbody>
</table>

NS: not significant.
Table 4  Correlation between the side-to-side difference (SSD) of anterior tibial translation with Telos™ & Rolimeter™ and the pivot-shift test.

<table>
<thead>
<tr>
<th>SSD of anterior tibial translation</th>
<th>Pivot-shift test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (equal) (mm)</td>
<td>+1 (glide) (mm)</td>
</tr>
<tr>
<td>Telos™</td>
<td>1.2</td>
</tr>
<tr>
<td>Rolimeter™</td>
<td>2.8</td>
</tr>
</tbody>
</table>

NS: Not significant when compared to 0 (equal) and +1 (glide).
<sup>a</sup> P < .00001 when compared to 0 (equal) and +1 (glide).

Table 5  Sensitivity and specificity of the different preoperative methods for the diagnosis of complete anterior cruciate ligament (ACL) tears.

<table>
<thead>
<tr>
<th>Preoperative diagnosis of complete ACL tears</th>
<th>Pivot-shift&lt;sup&gt;a&lt;/sup&gt; (%)</th>
<th>Rolimeter&lt;sup&gt;b&lt;/sup&gt; (%)</th>
<th>Pivot-shift with Rolimeter&lt;sup&gt;c&lt;/sup&gt; (%)</th>
<th>Stress x-rays&lt;sup&gt;d&lt;/sup&gt; (%)</th>
<th>Pivot-shift with stress x-rays&lt;sup&gt;e&lt;/sup&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>82.2</td>
<td>67.5</td>
<td>72.7&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>80.9</td>
<td>88&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Specificity</td>
<td>87</td>
<td>84.3</td>
<td>92.4&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>81.8</td>
<td>94.6&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Positive +2 or +3 value.
<sup>b</sup> Side-to-side difference (SSD) of anterior tibial translation more than 5 mm.
<sup>c</sup> Positive +2 or +3 values and SSD more than 5 mm.
<sup>d</sup> P < 0.01 when compared to Rolimeter™ alone.
<sup>e</sup> P < 0.001 when compared to stress x-rays alone.

translation, requires additional equipment, produces only static results and involves possible error due to muscle guarding and insufficient patient cooperation [1,2]. When employed separately, both methods suffer from the same lack of reliability and intratester error [1]. But probably, the combination of both methods can serve as a useful diagnostic tool to preoperatively measure knee laxity with accuracy. This combination may help the surgeons to diagnose specific injury patterns that require particular treatment (reconstruction versus augmentation). In cases of partial ACL tears, many authors suggest to preserve the ligament remnants because they provide anatomic landmarks for tunnel positioning and they offer both vascular and mechanical properties to the graft, and recommend to perform a more advantageous graft augmentation of the remaining bundle [8,12,13,36]. Therefore, it is important to have accurate diagnostic tools in the ACL-deficient knee and to adapt the therapy according to the injury pattern.

In a recent review of partial ACL tears literature, DeFranco and Bach [31] emphasized the importance of a positive pivot-shift test as a diagnostic tool for complete ACL tears and the need for operative treatment. They also reported a threshold group of patients with positive pivot-shift test under anaesthesia and gross laxity in instrumented methods that require surgical reconstruction, versus negative pivot-shift with marginal laxity results that require conservative treatment [31]. Noyes et al. [37] have also related poor outcome in patients with partial tears and laximetry results greater than 5 mm and Garces et al. [38] recorded more than 5 mm SSD in stress x-rays in patients with total ACL tears. Rijke et al. studied anterior tibial translation after the application of 67N and 89N forces with KT-1000™ and stress x-rays and recorded that anterior drawer up to 5 mm was considered normal and that complete tears had anterior drawer more than 7 mm [22,39]. Accordingly, our laximetry results were also consistent with the complete tear group for both the Telos™ and the Rolimeter™ device. Mean SSD was 7.4 mm for Telos™ and 5.3 mm for Rolimeter™ in cases of complete ACL tears versus 4.0 mm and 2.6 mm, respectively, for any type of partial tear. A review of the literature revealed threshold values from 3 to 5 mm of SSD with the use of different laxity measuring devices in cases of partial tears [12,31,37,38] (Table 6).

Telos™ results showed higher mean laxity values than Rolimeter and a threshold value of 5 mm was strongly associated with the differential diagnosis of complete versus partial tears (sensitivity 80.9%, specificity 81.8%). SSD less than 5 mm with Telos™ was observed in the majority of partial ACL tears (interquartile range 2.1—4.9 mm), except for the rare cases of AM intact bundle whose small number (n = 7) prevents safe conclusions and also raises a suspicion for the careful examination of the mechanical integrity of a remaining AM bundle. The efficacy of stress x-rays has been questioned with conflicting results. Beldame et al. [18] compared Telos™ with Franklin stress x-rays and found that Telos™ had more reproducible results in the diagnosis of knee laxity. Jardin et al. [40] recorded that stress x-rays are more accurate than KT-1000™ in the diagnosis of AP laxity, while Boyer et al. [29] showed that KT-1000™ had sensitivity 92% in the diagnosis of ACL insufficiency versus 72% for Telos™.

The data from the correlation of laximetry with clinical tests showed that Lachman test exhibited same repartition...
Table 6 Studies on the results of stress x-rays in the diagnosis of anterior cruciate ligament (ACL) tears.

<table>
<thead>
<tr>
<th>Study</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garces CL, 1995</td>
<td>47 patients with ACL deficiency out of a population of 116 were tested with Telos™ stress x-rays: 100% specificity and 76% sensitivity of ACL deficiency with &gt; 5 mm difference, &lt; 3 mm difference recorded in control group</td>
</tr>
<tr>
<td>DeFranco MJ, 2009</td>
<td>Senior author states that side-to-side difference greater than 3 mm in arthrometric testing combined with positive pivot-shift, is suggestive of complete ACL tear</td>
</tr>
<tr>
<td>Litner DM, 1995</td>
<td>Cadaveric study where partial tears of the anterior cruciate ligament were associated with a mean increase in sagittal laxity of 1.3 mm. This difference (3.0–1.3 mm) was acknowledged to be difficult to distinguish in clinical practice</td>
</tr>
<tr>
<td>Noyes FR, 1980</td>
<td>Side-to-side difference in laxity of &gt; 5 mm was a poor prognostic sign. Difference for knees classified with a functional anterior cruciate ligament was 0.9 ± 1.8 mm</td>
</tr>
<tr>
<td>Colombet P, 2010</td>
<td>Radiological examination with stress x-rays was able to make the difference between a complete tear and a partial tear, without determining the exact nature of the tear. Telos™ measurements and arthrometric assessments give the same information about partial tears</td>
</tr>
<tr>
<td>Rijke AM, 1994</td>
<td>Mechanical anterior drawer of 0 to 5 mm was considered as a normal distribution curve, and a drawer of 7 mm represented abnormal ACL function</td>
</tr>
<tr>
<td>Jardin C, 1999</td>
<td>Comparison of Telos™ and KT-1000™ in the diagnosis of AP laxity. Telos™ was more accurate in quantifying AP laxity (P &lt; .001) compared to KT-1000™</td>
</tr>
<tr>
<td>Boyer P, 2004</td>
<td>Comparison of KT-1000™ with Telos™ in 147 knees: sensitivity in testing AP laxity was 72% for Telos™ and 92% for KT-1000™. KT-1000™ was more reliable than Telos™ for the measurement of anterior knee laxity</td>
</tr>
<tr>
<td>Beldame J, 2011</td>
<td>Comparison in 112 patients for AP laxity of Telos™ vs. Franklin stress x-rays. Telos™ stress x-rays had more reproducible results in the diagnosis of ''ruptured ACL'' vs. ''healthy ACL''</td>
</tr>
</tbody>
</table>

AP: anteroposterior.

when compared to Telos™ and Rolimeter™ results. A better correlation was observed with the comparison of pivot-shift and Telos™ results (P < .00001), which was not seen with the Rolimeter™. This confirmed that gross clinical laxity with the pivot-shift was also reproduced with the instrumented measured laxity measurements of Telos™. The sensitivity and specificity of both instrumented laximetry methods increased with the addition of positive clinical examination. SSD more than 5 mm in stress x-rays with +2/+3 positive pivot-shift test had a specificity of 94.6% in the diagnosis of complete ACL tears. In the case of incomplete ACL tears, clinical examination and instrumented methods had significantly smaller laxity measurements than complete tears, but neither could differentially diagnose between the integrity of AM or PL bundle.

Both instrumented methods provide predominantly a static measurement of AP knee laxity. Although there are a number of devices for measuring AP knee laxity, there is very rare evidence on the ability of any device to quantify rotational instability of the ACL-deficient knee [1,2]. On the other hand, clinical examination provides a more dynamic assessment of AP and rotatory stability, expressed mainly by the pivot-shift test [7,15,31,41]. In the present study, great values of pivot-shift test were observed in complete ACL ruptures and were strongly correlated with increased laximetry results. Negative or +1 values provided not significantly different results for AM and PL bundle tears. Probably, this is evident of the complex way the two bundles function and the synergistic effect on both rotational and AP stability of the knee [15,41].

In the present study, two methods for the measurement of AP knee laxity were compared that are popular in some hospital settings. The number of surgeons involved in the study design was purposefully small in order to minimize an intratester disagreement that would possibly appear with a larger group of surgeons in the interpretation of the clinical examination results or the arthroscopic findings.

In conclusion, the combination of clinical examination and instrumented measurement of knee laxity increased the sensitivity and specificity of the latter in the diagnosis of arthroscopically-confirmed complete ACL tears. Both instrumented methods had similar specificity when combined with clinical tests, but stress x-rays had greater sensitivity in the diagnosis of complete ACL tears than Rolimeter™ which ease of use is a strong advantage in screening knee laxity. SSD more than 5 mm with Telos™ and positive pivot-shift confirmed complete ACL tears, and SSD lower than 5 mm raised a strong suspicion for the presence of a remaining ACL bundle when they were combined with a negative pivot-shift. Laximetry methods are a useful tool to quantify laxity and a potential, yet not a prerequisite, addition to clinical tests to confirm partial tears. The application of a strict diagnostic protocol can help the surgeon to preoperatively diagnose complete from partial ACL tears and to tailor an injury-specific surgical treatment.
Disclosure of interest

D.D. royalties: SBM S.A.
J.C.P. royalties: SBM S.A.
P.G.N. and P.R.S.: no conflict of interest.

References


