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REVIEW ARTICLE

Current concept in rotational laxity control and evaluation in ACL reconstruction

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Accepted: 25 September 2012

KEYWORDS

Knee injuries;
Anterior cruciate
ligament;
Rotational knee
laxity;
Laximetry;
Arthroscopy;
Computer assisted
surgery

Summary Rotation combined with translation; compose the three-dimensional motion of the knee subluxation in anterior cruciate ligament deficient knee. The worldwide scientists were focused initially on the translation part of this complex 3D motion, but since the beginning of the century there was a large interest on knee rotational laxity study. Lot of paper reported new devices and results with an explosion since the beginning of the decade. The purpose of this review is to provide an extensive critical analysis of the literature and clarify the knowledge on this topic. We will start with a dismemberment of different rotational laxities reported: the rotation coupled with translation in 2D tests such as Lachman test and anterior drawer test; the rotational envelope considering the maximum internal external rotation; and the "active rotation" occurring in 3D Pivot-shift (PS) test. Then we will analyze the knee kinematics and the role of different anterior cruciate ligament (ACL) bundle on rotation. A review of different mechanical and radiological devices used to assess the different rotations on ACL deficient knees will be presented. Two groups will be analyzed, dynamic and static conditions of tests. Navigation will be described precisely; it was the starter of this recent interest in rotation studies. Opto electronic and electromagnetic navigation systems will be presented and analyzed. We will conclude with the last generation of rotational laxity assessment devices, using accelerometers, which are very promising.
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Introduction

Pathologic knee laxity resulting from anterior cruciate ligament (ACL) injury is a complex and 3D motion [1]. This abnormal motion is assessed by the pivot-shift (PS) test, it reproduces the dysfunction resulting from the giving way during sports activities in ACL deficient patients [2,3]. This phenomenon is composed of translation and rotation along a helical axis [1]. The translation was the main displacement measured by scientists, in static conditions, especially during an anterior drawer test and a Lachman test. The residual rotational laxity after an ACL reconstruction is an emerging problem in the evaluation of successful surgery [4]. Uncontrolled rotational laxity is one of the many reasons for ACL reconstruction failure [5]. A quantitative and precise evaluation is valuable feedback on the outcome of the procedure. Over the last 10 years, the use of new technologies to measure rotation and 3D motions [6] has contributed to promote researches on knee rotational laxity [7–12]. The quest for knee rotational laxity control represents a new challenge for surgeons and stimulated the appearance of anatomic double bundle ACL reconstruction in which the postero-lateral (PL) bundle is supposed to control the rotation better than the traditional single bundle reconstruction [6]. The purpose of this review is to provide an extensive critical analysis of the literature regarding rotational knee laxity, the biomechanical aspects, which rotational control is needed for the different parts of the ACL, mechanical and radiological evaluation of the rotation, and the different generations of 3D tools for rotational assessment.

The different components of rotation in the knee kinematics

Rotation and translation are combined in the knee subluxation which occurs during the giving way symptom. The knee rotation can be assessed in different conditions. In two dimensions plan, it is analyzed as an isolated tibial motion. The maximum internal and external tibial rotation under a controlled load was described initially by Nielsen [13] and called axial rotation laxity envelope. This rotational envelope is assessed by static knee laxity tests and compared with contralateral side. Some tests are instrumented, therefore quantifiable [9,14,15]. However, these tests must be done in strict conditions with controlled torque (8Nm) and some cadaver studies reported larger measurement with foot splint device, compared with the real tibial rotation [16]. In three dimensions conditions, the rotation is linked with the translation, thus two different rotations should be considered. First of all, the coupled rotation, it occurs automatically during the Lachman test and the anterior drawer test, both are static tests. When an antero-posterior load is applied to the tibia, an anterior translation occurs and an automatic internal rotation happens (Fig. 1) [17]. This assessment requires precise tools such as an opto-electronic (OE) camera [18] or electromagnetic (EM) devices [19–22]. The third type of rotation, which can be measured in rotational knee laxity, is the tibial rotation that occurs during the giving way symptom. This is assessed by the PS test, which is a dynamic test. We refer to it as “the active rotation” because it contributes to the knee subluxation,

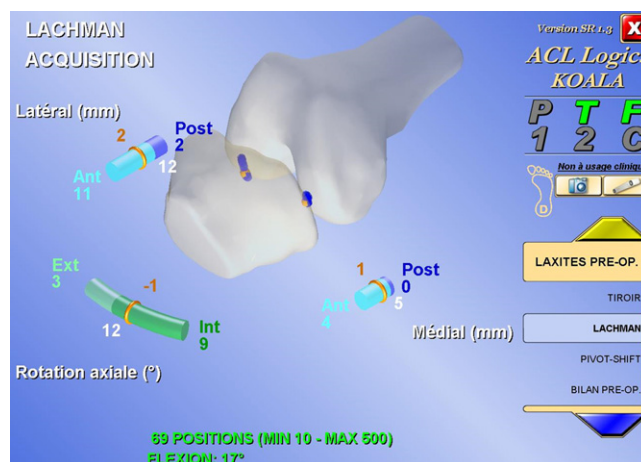


Figure 1 Coupled rotation measured with opto-electronic navigation.

therefore to knee dysfunction. It is the principal type of rotation, and probably the most difficult to assess. During the last decade many authors have studied and measured the maximum rotation during the PS test [7,23–27]. The main difficulty with instrumental measurement of the PS test is its standardization and the control of the different loads for translation and rotation. Hoshino [23] reported a study with EM assessment of the PS test. Twelve acknowledged experts performed their own preferred technique of a PS test and a standardized technique based on the Galway and MacIntosh procedure [28]. He concluded that “standardizing the PS test maneuver provides a more consistent quantitative evaluation”. However the load control remains a challenge and robotic solutions have been proposed. A biomechanical study has been reported by Engebretsen [29] using an EM device. He showed that the coupled internal rotation and valgus torques best recreated the anterolateral subluxation that occurs in the PS. Musahl and Pearle [30] designed an optoelectronic navigated mechanized PS test. The mechanized PS test consisted of a modified continuous passive motion (CPM) machine and a custom-made foot holder to allow the application of internal rotation moments at the knee. Valgus moments were achieved by a 45° tilt of the CPM machine with respect to the supine position and a Velcro strap secured across the proximal tibia. They demonstrated that such a technique provided a more repeatable measurement, compared with a manual PS test. The great interest of all these standardized and load control PS tests is to provide an objective graduation of the test. Kopf and Becker used an accelerometer and measured the difference of the acceleration peak value. They showed that quantification of the PS test is feasible when inertial sensors are used. Lopomo et al. [31] used accelerometers and OE traditional navigation simultaneously to quantify the PS test intra-operatively on 15 consecutive patients. They analyzed the speed of rotation, which is another variable for assessing and classifying the subluxation. They concluded that the accelerometer is a valid method for assessing dynamic joint laxity.

In summary, the knee rotational laxity is an extensive field, which needs to be precisely defined before we can discuss, compare, or assess. The rotational envelope is completely different from coupled rotation and the maximum

active rotation during the PS test. The PS test is the only dynamic test and the most representative of knee dysfunction. An objective quantification and classification of this test could be very helpful for patient's outcome and the comparison of different surgical techniques.

Which rotational control for which part of the anterior cruciate ligament

The ACL is the primary restraint against anterior translation and external rotation of the tibia under the femur. This function is determined by the anatomy of the ligament and its insertion sites. ACL was basically considered as a cable attached to the distal femur and the proximal tibia inside the intercondylar femoral notch. Numerous papers have described the normal anatomy of the ACL, and there is a general agreement about the attachment areas, with some insignificant differences between different authors. The center of the femoral attachment is located at 25 to 30% of the postero-anterior dimension of the Blumensaat line [32–34]. The center of the tibial attachment area is located approximately at 44 to 50% of the antero-posterior tibia dimension and at 44 to 50% of the medio-lateral tibia dimension [32,33,35]. However, it is important to consider not only the center of the attachment site, but also the total area. It is generally accepted that both femoral and tibial attachments have a length of approximately 10 to 20 mm and a width of 10 mm [36], with a wide inter-individual variability.

Double bundle anterior cruciate ligament anatomy

More detailed anatomical preparations have shown that the ACL is actually divided into two separate bundles, with separate attachments, and subsequently separate functions [18,37]. The antero-medial (AM) bundle is fixed to the medial part of the tibial attachment and in the antero-superior part of the femoral attachment, and is located more anterior in the extended knee. The PL bundle is fixed to the lateral part of the tibial attachment and in the postero-inferior part of the femoral attachment, and is located more posterior in the extended knee. Due to this anatomical design, the AM bundle is longer than the PL bundle, but the strain in the PL bundle is potentially higher. However, the respective position of the two bundles changes with the knee flexion angle: at full flexion, the femoral attachment of the PL bundle is located just anterior to the AM bundle [12]. Due to these modifications, both bundles experience different kinematic behavior: the AM bundle remains relatively isometric during the whole range of motion, with a tendency to tighten with flexion, while the PM bundle is tightened in full extension, slackened beyond 20° of flexion and tightened again in full flexion [38].

Double bundle stability

Classically, the role of the ACL in knee stability has been assessed by *in vitro* studies with laxity measurements before and after section of the native ACL (and eventually after ACL reconstruction). Transection of the ACL induces an

augmentation of the anterior translation of the tibia both in slight flexion and at 90° of flexion. It also induces an augmentation of the internal rotation of the tibia, again both in slight flexion and at 90° of flexion [39].

The respective role of each bundle has been mainly assessed by selective reconstruction after total ACL transection. An extensive literature review would exceed the scope of this paper, but some significant examples of experimental and clinical studies, whose results remain controversial merit citation.

Yagi et al. [40] reported the results after robotic measurement of anterior tibial load and rotatory load on 10 gross specimens. They compared the native knee, the knee after ACL resection, after single-bundle (SB) reconstruction and eventually double-bundle (DB) surgery. DB reconstruction corrected the anterior tibial translation closer to that of the intact knee. The *in situ* force in the reconstructed ACL was also closer to that of the normal ACL after DB reconstruction.

Sbihi et al. [41] reported a similar study with the Rolimeter measurement of anterior laxity at 20, 60 and 90° of knee flexion on 16 gross specimens. Reconstruction of the ACL with a two-bundle graft technique provided control of anterior laxity at 20, 60, and 90° flexion similar to that observed in knees with an intact ACL while the single construct technique re-established physiological laxity at 60 and 90° only. This improved control of anterior laxity with the two-bundle reconstruction was small regarding anterior laxity, but potentially more relevant for rotational stability.

Robinson et al. [18] reported 21 cases of DB ACL reconstruction. They performed an intra-operative navigated measurement of the anterior drawer at 90° of flexion, of the Lachman test and of the PS test after either reconstruction of the PL or AM bundle, and eventually after DB reconstruction. There was no significant change in the anterior tibial translation between the three techniques of reconstruction. But there was a significantly better control of the rotational laxity after SB PL and DB reconstruction in comparison to isolated AM SB reconstruction.

Hussein et al. [42] reported 320 cases of ACL reconstruction after random assignment to conventional SB, anatomic SB and anatomic DB. They observed a significant improvement in the control of anterior tibial translation and PS after DB reconstruction.

Ferretti et al. [43] measured anterior translation and internal/external rotation with a navigation system in 10 cases of ACL reconstruction with AM SB first, and eventually an additional PM bundle reconstruction. Fixation of the AM bundle significantly reduced the antero-posterior displacement and the tibial rotation throughout the range of motion. The addition of the PL bundle to the AM bundle did not significantly reduce internal and external rotation of the tibia at any degree of flexion measured.

Claes et al. [44] reported a kinematic 3D gait analysis of tibia rotation in 20 cases of ACL reconstruction divided into five groups: healthy volunteers, contralateral knee, injured knee before reconstruction, anatomic SB and anatomic DB reconstruction. Both techniques adequately restored tibial rotational excursion. The results of this dynamic study did not support the theoretical advantage of a DB ACL reconstruction over an "anatomical" SB ACL reconstruction.

In conclusion, there is a general agreement in the literature to the following statements about laxity control: Both

AM and PL bundles can control the anterior translation of the tibia at any degree of knee flexion. The AM bundle is more efficient than the PL bundle for the control of anterior translation of the tibia at 90° of knee flexion. The PL bundle is more efficient than the AM bundle for the control of anterior translation of the tibia at 20° of knee flexion. Both AM and PL bundles can control the internal rotation of the tibia at any degree of knee flexion. The PL bundle may be more efficient than the AM bundle for the control of internal rotation of the tibia at any degree of knee flexion.

Mechanical and radiological evaluation of the rotation

Rotational stability is an important variable in restoring normal physiological kinematics after ligamentous injuries of the knee. However, rotation of the knee generates a 3D motion that complicates its measurement. Therefore, to measure rotation properly one needs to define the angle and the plan in which the measurement is performed. In case of a dynamic and static measurement, one must define the constraints applied and the exact conditions of the measurement. Ideally, the method should be simple, reproducible, discriminative, and convenient. Since the determination of the neutral point is always difficult, measurement of the entire rotation is more reliable.

Rotational laxity in the knee can be assessed with dynamic radiographs, dynamic MRI (Porto-Knee Testing device), static measurement (Rotameter), navigation, dynamic radio-stereometry, stereo dynamic fluoroscopy, accelerometers and OE systems.

Dynamic radiographs and MRI

Dynamic radiographs have been shown to have a limited contribution in the evaluation of the rotational laxity. In 2007, the French society of arthroscopy conducted a study



Figure 2 Porto dynamic MRI using a nonmetallic device.

on cadavers looking at measurements of rotational laxity with navigation and radiographs using the Telos system in ACL intact and deficient knees. No significant differences in rotational laxity were found with dynamic radiographs under these study conditions.

Rotational laxity can also be measured with a dynamic MRI using a special device applying an anterior load and an internal rotation torque (Porto-Knee Testing Device) to the knee (Fig. 2). On MRI pictures, the anterior translation between the lateral (LTP) and medial tibial plateau (MTP) is measured and compared. Thereby, a differential cut-off value of 3.5 mm between the MTP and LTP has been shown to correlate with abnormal rotational laxity and positive PS [10].

Static rotational laxity measurement

Several static rotational knee laxity systems of measurement have been developed and validated over the last

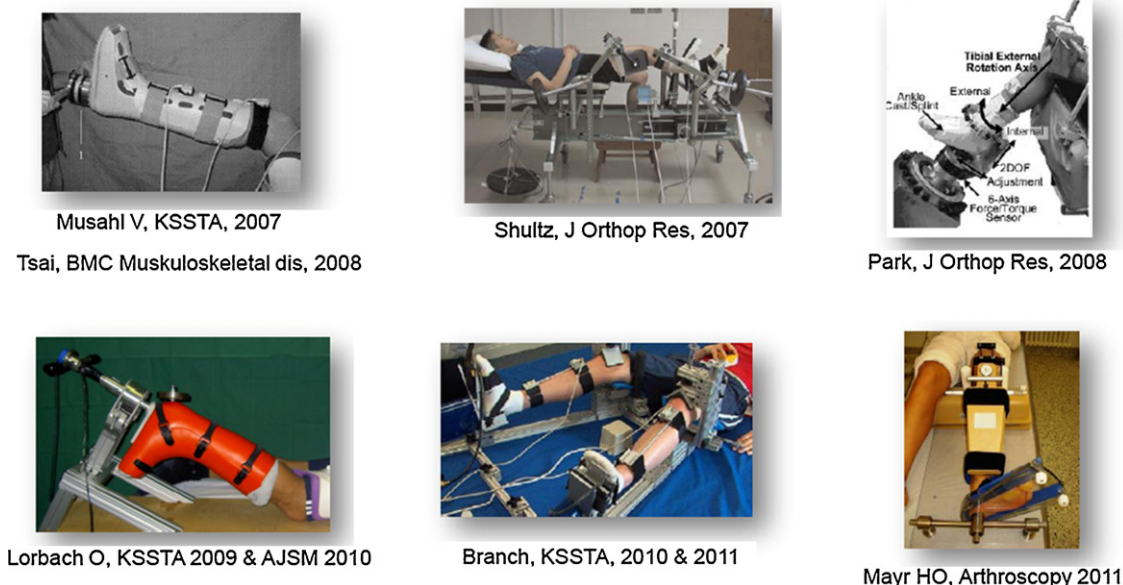


Figure 3 Different types of mechanical devices to assess rotation in static conditions.

decade (Fig. 3) [14,20,45–48]. A customized device applies a rotational torque to the lower part of the leg and the angle of rotation is recorded. This method allows for pre- and postoperative measurements, is simple to use and has been well validated. The limitations include possible motion between the leg and the device, the passive nature of the constraints and require the measurement of the complete range of rotation. Indeed, the neutral rotation point remains difficult to determine and reproduce in a reliable manner [14,45–49]. As demonstrated by Lorbach et al., internal rotation increases with knee flexion, external rotation is increased in women whereas the internal rotation is similar in both sexes [50]. The force applied on the knee is another source of error as the global rotation range increases from a torque of 5 to 15 Nm [50]. Once again the condition in which the measurement will be performed has to be precisely adjusted and steadily repeated. Future development may look at the application of a rotational torque piloted by a computer integrating the measurement of rotation changes in real time.

Should we preferentially use static and passive measurements instead of dynamic measurements (PS)? This is still a matter of debate today. Bigozzi et al. and Hoshino et al. stated that static internal/external rotation were not sufficient for describing the complete picture of a knee laxity, and that instrumented PS was better at depicting rotational laxity in the ACL deficient knee [51,52]. However, static measurements are much simpler to perform and give valuable information on rotational laxity. Further studies are required to provide a definitive answer to this question.

Dynamic rotational laxity measurement

Navigation systems allow precise measurements to be made in different plans intraoperatively. Global rotational laxity can be determined precisely with just one limitation due to the variability seen in the application of rotational torque. As with most methods, this torque is applied manually, which generates inter- and intra-personal variability? The same is true of the PS maneuver. However, the PS can be elegantly quantified in term of translation and rotation with a navigation system.

Dynamic radio-stereometry consists of an active study of knee kinematics. By a superimposition technique and computerized mathematical treatment, kinematics in different plans can be calculated. Rotational laxity can thus be measured pre- and postoperatively in loading, functional and dynamic conditions [53,54]. Since the goal of any surgery on the knee is to restore normal kinematics, this type of approach is of great interest. However, this method is technically complicated and requires expensive equipment [53]. It is currently a powerful tool for research.

To evaluate the global laxity of a knee joint, one may rely upon the measurement of a dynamic anterior drawer and upon the measurement of rotational laxity. These measurements should be performed pre- and postoperatively with a good repeatability, a well-controlled load-response curve, and with a simple and easily implementable method. Concerning the PS, measurements should include the anterior translation and the degree of rotation, as mentioned for navigation. Now, as pertinently pointed out by Bedi et al.

[55], it may be more interesting to measure the anterior translation of the lateral tibial plateau rather than the global rotation.

In summary, non-invasive and objective methods of measurement are required for quality control in knee ligament injuries and their treatment. Over the last decade, we have made great progress in the measurement of rotations in the knee. Numerous and different techniques have been developed and validated, but there is still large variation in measurements. Although already complex and demanding, these methods still necessitate improvement and refinement especially in the way we apply any constraints around the knee.

In the future, one objective will be to develop an instrumented PS piloted by a robot thus enhancing the precision and the repeatability of the maneuver. The future system of measurement will have also to specifically include the anterior translation of the lateral tibial plateau.

Opto-electronic and electromagnetic systems for rotation assessment

Computer aided surgery (CAS) was used initially in neurosurgery in the beginning of the 90th. The first author who reported CAS ACL reconstruction was Julliard in 1992 with a first prototype and performed the first patients in 1994 [56]. The technique he used was very innovative based on infrared rays, and did not required pre-imaging data. This image-free system referenced on points acquisition and surface digitalization with “bone morphing” technology [57]. It is a wireless and passive system using an infra optical camera tracking reference arrays called “Rigid Bodies” equipped with retro-reflective markers. It was mostly addressed initially to improve tunnel placement. But quickly this system was used to measure in 3D conditions the knee laxity [18,26,58]. In 1997 Pearle demonstrated the reliability and the precision of navigation [59]. He compared robotic/UFS testing system with an image-free navigation system in cadaveric knees and showed that an image-free navigation system can reliably register and collect multiplanar knee kinematics during knee stability examination. The accuracy is in the range of ± 0.1 mm for linear measurements and $\pm 0.1^\circ$ for angular measurements. In 2001, S. Martelli [27] tested a navigation protocol to assess the graft biomechanical behavior and the knee kinematics on double-bundle reconstruction, using two femoral tunnels and one tibial tunnel in cadaver knees. He evaluated graft position, elongation and orientation as well as knee stability. He concluded that navigated analysis is a means to improve the evaluation of ACL reconstruction and objectively measure residual laxity.

In the same time other technology was developed using EMs principle (Fig. 4). It is based on an EM field around the patient’s target anatomy that can be tracked to triangulate the positioning of instruments and patient-tracking devices during surgical navigation procedures. PS test was measured intraoperatively in 2002 using an EM device (the “Flock-of-birds”) by Bull et al. [60]. The advantage of this system is to be not impaired by a camera’s line of sight to the tracked instruments. Instruments and staff can come in and out of the EM field with no disruption to the surgical navigation information. Patented algorithms constantly monitor

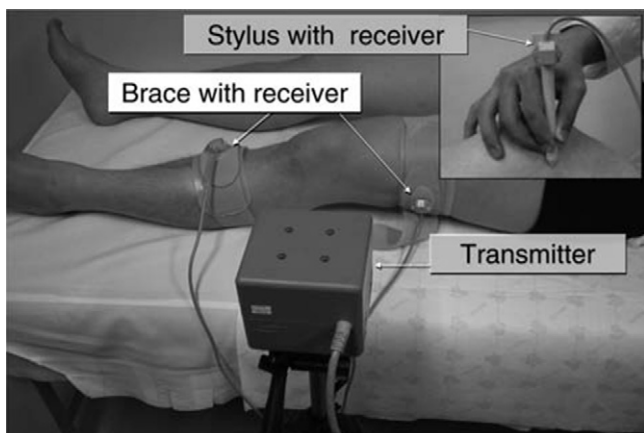


Figure 4 Principal of electromagnetic system for knee laxity measurement.

the EM field, including metal disturbance, to ensure surgical navigation precision.

CAS and knee laxity assessment: different kinds of measurement can be performed. Two dimensions measure as well as translation during anterior drawer test and Lachman test or rotation during maxim internal and external rotation in different degrees of flexion (rotational envelop). The main advantage of the technology is to allow 3D measurement such as the rotation coupled with the translation in the previous 2D tests, but also the maximum of translation and rotation during the PS test (Fig. 5) [17]. We can also measure the speed of knee subluxation reduction.

This tool was a fundamental step in advancing the knowledge of ACL reconstruction. The most important finding of current navigated ACL reconstruction studies was to compare DB ACL reconstruction to SB. Navigation was also used by some authors to evaluate the benefits of lateral plasty procedure [61–63]. One limitation of this technology is the bony implantation of rigid bodies and thus cannot be used outside the operating room. It cannot be used to assess the laxity at the office before the surgery or at the long term

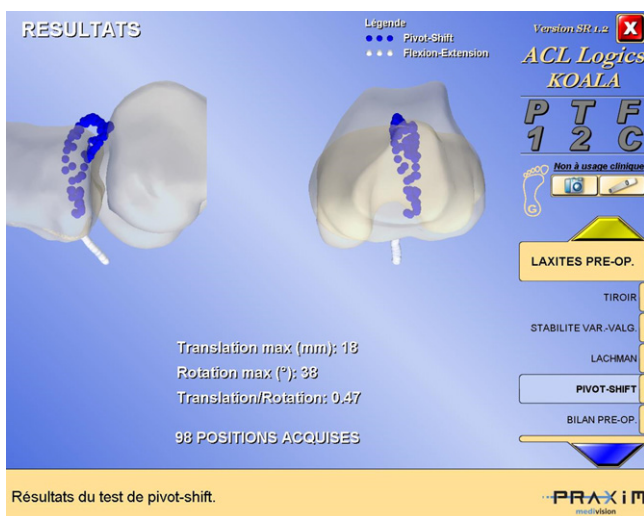


Figure 5 3D measurements of translation and rotation during the Pivot Shift test.

after ACL reconstruction. New devices are coming with non-invasive systems [64]. Another limitation comes from that the navigated laxity testing is not instrumented and it is necessary to try to apply similar forces during pre- and post-operative testing to obtain comparable data. It is possible to use a sterilized KT 1000/S® or Rolimeter® (Aircast) for anterior laxity testing but these bulky instruments may interfere with the placement of the navigation rigid bodies. Noyes et al. [65] demonstrated the inter-operator variability of the PS test and the search for a method to instrument this test remains. Currently many authors developed devices to assess and standardized the PS test [12,23,30,64,66–70]. Rotation is the center of researcher's preoccupations; a standardization of the PS test will lead to a new classification and probably better comparison and indication of different techniques of ACL reconstruction. This surgical adaptation to a personalized objective laxity assessment is the new concept of "a la carte surgery" defined as the statistical highest grade of clinical outcome for one technique to one patient. Navigation will be the key point of this new concept.

So what is the future for the navigation system for ACL reconstruction? Construct non-invasive tools for laxity assessment of both knees in the same patient and compare the ACL deficiency to healthy contralateral knee. Establish a kind of digitalized rotational envelope library. Develop a standardization and objective classification of laxity. Precisely assess the secondary restraint structures and not only the ACL. Develop predictive tools to deduce from virtual per-operative data the best positioning of the graft(s) and allow the best strategy. A combination of different systems could be considered especially a combination of OE or EM system with accelerometer.

Accelerometer systems for rotation assessment

The PS phenomenon is commonly reported to be the anterior subluxation of the lateral tibial plateau followed by its sudden reduction during the application of combined stresses [71]. While performing the PS test the speed of the procedure, the abduction angle of the hip and the magnitude of the applied force are not exactly the same in each test and among the examiners, making it extremely complex in both execution and interpretation. This issue provokes a great variability among both testers and patients, thus the PS test results a highly surgeon–subjective clinical examination [23,51,72]. Again, the presence of other soft-tissue lesions in the knee, coexisting with an injured ACL makes the interpretation of the PS grade more complicated [73]. Acceleration has been recently identified as a good quantitative variable that provides information about the dynamic condition of the knee joint during the PS maneuver. Acceleration can be directly measured by specific sensors, called accelerometers.

In the recent years, different in vivo and in vitro studies reported the use of triaxial accelerometer in the evaluation of dynamic knee laxity during PS maneuver. Specifically Lopomo et al. [74], Maeyama et al. [44] and Debandi et al. [75] reported the use of one single acceleration sensor able to detect both ACL injury and specific reconstructions. Lopomo et al. [74] used a single triaxial acceleration

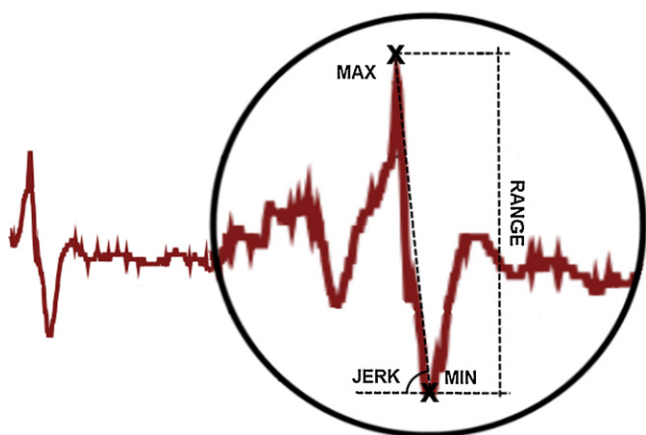


Figure 6 Acceleration parameters highlighted on a typical acquisition signal.

sensor system (KiRA, Orthokey LLC, Lewes, DE, USA) skin-mounted on the lateral side of the tibia, between the lateral aspect of the anterior tuberosity and Gerdy's tubercle. Their findings underlined that the measured tridimensional acceleration was able to highlight the presence of the PS phenomenon. In particular, they were able to automatically detect the PS event by the sample-by-sample calculation of Pearson's correlation coefficient between a specific window-template – previously defined on a set of trial patients – and the corresponding part of the analyzed signal. After identification, a few parameters identified in the acceleration signal were able to discriminate the lesion (Fig. 6).

Reliability

In a preliminary in vivo intraoperative study, Lopomo et al. [31] compared the results measured with a single acceleration sensor with the kinematic parameters simultaneously measured by a navigation system used as reference. They reported an average displacement of the sensor due to soft tissue artifacts of 4.9 ± 2.6 mm, good repeatability of measurements, an optimal inter-patient similarity in acceleration curves (Fig. 7) and a good positive correlation with the antero-posterior acceleration measured by the navigation system.

Recently several in vitro studies analyzed the reliability of the setup based on a single acceleration sensor in discriminating the grade of the PS, using an EM system as a gold standard and involving twelve expert surgeons. In particular Ahlden et al. [24] reported a good correlation between the maximum value of acceleration measured reached during the PS maneuver, as well as between the jerk and the average PS grade. On the same setup, Araujo et al. [67] reported that the assessment based on the single accelerometer demonstrated from moderate to good correlation with the gold standard, depending on the use of a standardized or a preferred technique, respectively.

Clinical validation

From the clinical point of view, Lopomo et al. [31] reported in an in vivo study the supporting clinical rationale on the

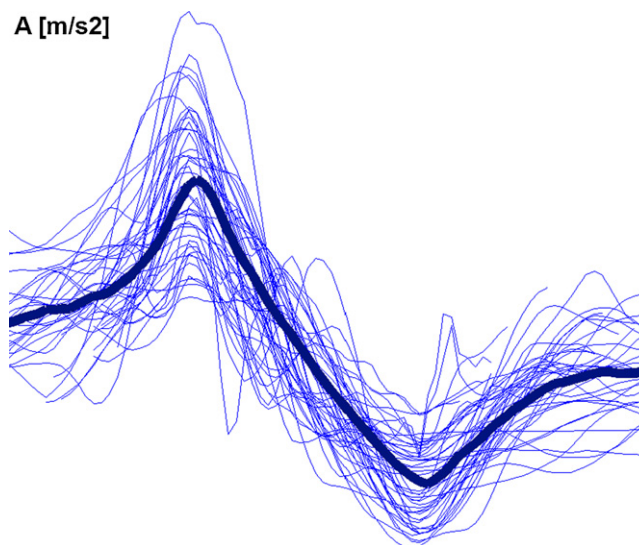


Figure 7 Inter-tester similarities of acceleration curves for the in vivo acquisitions.

use of a single accelerometer in the quantification of PS test. Specifically they analyzed 66 consecutive patients after anesthesia, reporting a fair/good intra-tester reliability and, above all, reporting a probability ranging from about 70 to 80% of judging whether or not a knee is in the injured group, just by analyzing the acceleration measurements [74]. The percentages are in agreement with the low sensitivity and high specificity of the PS test reported by the literature [76,77].

Current limitations

Since during ambulatory examinations the PS test is performed when the patients are awake, their voluntary or involuntary muscular resistance could suppress the PS phenomenon [78]. It is because of this issue that several studies were performed under anesthesia. This contrasts with the condition under which the PS test is normally used and eases external rotation of the hip [79]. Obviously, without the possibility of correctly eliciting the PS phenomenon, no quantitative measurement would work.

Even manual performance of the test represents a limitation by failing to control the amount and the direction of the applied force. Indeed, the angle of hip abduction and the force applied to the knee could negatively affect test outcome, i.e. the variability among examiners remains an important issue [66,72,78,80,81]. Therefore it is possible to accomplish better consistency among testers by standardizing the procedure [23] eventually considering the more appropriate configuration for optimizing muscle relaxation [78].

The accelerometer, directly measuring the acceleration reached during the PS test, is able to perform a quantitative evaluation of dynamic knee laxity, while the conventional devices do not. This is highlighted by all the articles reported in this short review.

Moreover the proposed device would be the optimal measurement method to discriminate an ACL injury in the clinical setting. Despite all the previous limitations, a

fair/good repeatability was in fact obtained. In particular the study device being non-invasive and requiring a short time for the execution of the test allows the quantification of the PS test even on the contralateral knee making the comparison between injured and non-injured joint, which is highly specific, possible.

The reliability of the proposed PS quantitative analysis was comparable with the reliability results for static laxity tests reported in the literature [82] as well with the navigation system used as gold standard [83], reinforcing the evidence of the potentiality of the method itself.

Overview

When we talk about knee rotation studies it is needed to precise which type of rotation we are talking about: coupled rotation, rotational envelope or the active rotation occurring during the PS test. Throughout the numerous studies on different mechanical effects of the two ACL bundles, we can state that both bundles AM and PL are active on internal rotation of the tibia at any degree of knee flexion. However, it seems that PL bundle could be more effective than the AM bundle on tibia rotation control, especially close to the extension. Mechanical and radiological devices are split in two groups: static and dynamic groups. Mechanical systems are mostly addressed to rotational envelope. Dynamic radio-stereometry is interesting because it allows rotational analysis in weight bearing conditions and uses non-invasive devices. Dynamic radiographs and MRI have got limited conditions and special devices are mandatory. However, dynamic MRI provides very interesting data such as a separate analysis of each medial and lateral tibial plateau. Navigation still remains the reference, mostly because it's precision, validated by powerful and accurate robots. However, till now it needs invasive bonny markers, which cannot be used outside the operating room. A new generation is coming using accelerometers but required complicated calculation to provide millimeters and degrees data. The analysis of the speed reduction of the tibia subluxation could be used to grade and classify the PS test, leading to a personalization of surgery in an "a la carte surgery concept" for ACL reconstruction.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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