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Rotational Stability of the Knee in ACL Deficiency: What is the Evidence?

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Objectives: Understand the importance of rotational stability in ACL deficiency and reconstructed knees, as well as describe the methodologies, based on current evidence.

Hypothesis: The anterior cruciate ligament (ACL) plays an important role in providing anterior and rotational stability to the knee, acting as primary constrain of anterior displacement of tibia with respect to the femur and secondary restrain of internal and valgus rotations¹⁻³. A gender specific anatomy and the presence of possible tears affecting joint peripheral structures could affect joint stability, and a pure ACL reconstruction, basically introducing a new constraint in sagittal plane, could however not be able to restore the knee stability to normality, leaving some rotational instability. For this reason much attention is being paid to residual rotational instability and to the possible corresponding treatments. Lachman and drawer are clinically used to highlight joint antero/posterior laxity, whereas pivot-shift (PS) test has been demonstrated to be extremely specific for dynamic rotational instability^{4,5}, even the maneuver is quite complex to perform.

Knee Instrumented Laxity Evaluation: Several devices have been developed to standardize and quantify the severity of knee ligament injuries. Specifically, for what concerns static laxity in sagittal plane, the most common instrumented systems are KT-1000 and KT-2000 (MEDmetric Corporation, San Diego, CA)⁶. In order to assess instead pure rotational laxity, different devices have been proposed⁷: in Pittsburgh, the researchers developed an ambulatory devices which allows to measure knee rotational laxity and the corresponding applied torques⁸, whereas Lorbach et al. proposed an instrumented boot able to measure tibial rotations under stress⁹.

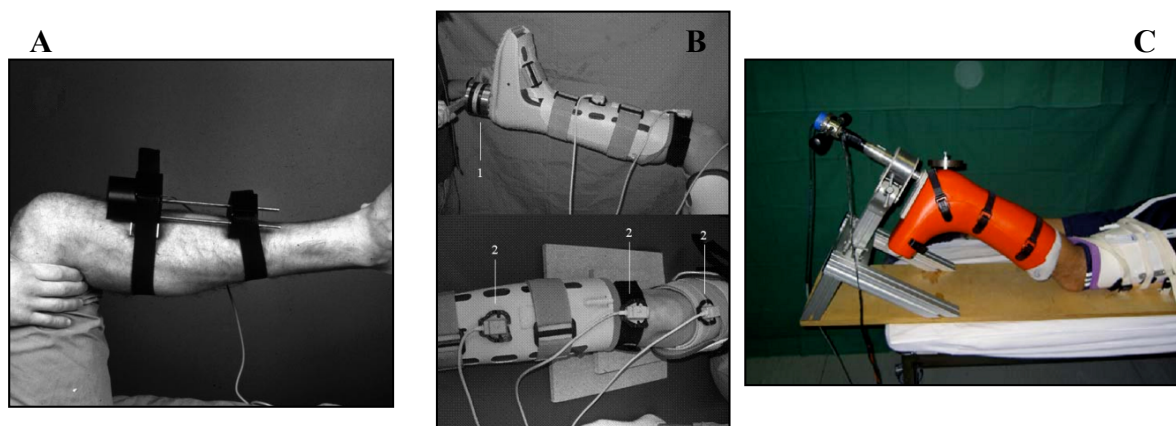


Figure 1. A) Lars Rotational Laximeter⁷; B) Rotational Laxity Tester⁸; C) Instrumented boot able to measure tibial rotations under stress⁹.

Parallely in order to quantify PS test, quite complex systems which need markers¹⁰, footplates¹¹, robotic technology¹², MRI¹³ have been proposed.

Intraoperative Assessment: In the last decade the intra-operative quantification of knee laxity has been fundamentally based on the use of a navigation systems (fig 2.A). Navigation systems allow to directly compare the ACL reconstruction techniques from the point of view of passive stability and laxity measurement: antero/posterior displacement, varus/valgus and internal/external rotations¹⁴. This technology allows in fact a better understanding of the biomechanical behavior given by a specific reconstruction, allowing to analyze not only the global static laxity of the joint but also the behaviour of each joint compartment (fig 2.B)¹⁵ or reconstructed bundles elongations.

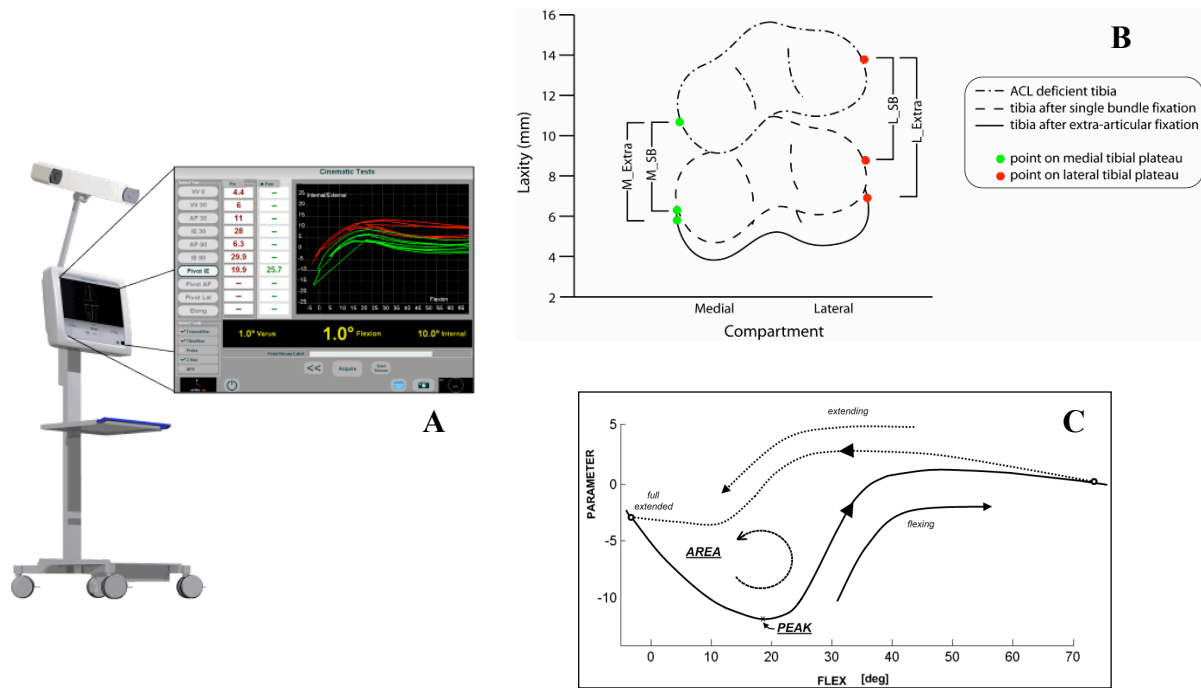


Figure 2. A) Commercial intraoperative navigation system; B) Medial/lateral compartment displacement during antero/posterior stress test: differences due to the introduction of an extraarticular tenodesis¹⁵; C) Pivot-shift analysis performed with the use of navigation system: peak and areas underlined by the curves are highlighted¹⁶.

Kinematic navigation systems additionally allowed to perform a quantitative analysis also of PS test (fig 2.C), highlighting the dynamic instability of the joint¹⁶. A navigated PS test has been therefore confirmed to be essential in order to demonstrate the real efficacy of a specific surgical technique and to highlight the joint rotational behavior.

Rotational Laxity Problem: The use of navigation systems highlighted also a problem related to the pure rotational laxity found after ACL reconstruction. In fact, even if the variability in executing rotational stress test could be related on how the tester performs the test itself (fig 3.A), also in the same test condition rotational laxity could not be able to highlight differences neither in ACL reconstructions nor in specific knee joint conditions (fig 3.B).

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Kinematics and knee laxity, before and after Anterior Cruciate Ligament reconstruction

Evaluation using dynamic and static Radiostereometric analysis

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Introduction: Whether full active and passive extension training, started immediately after an Anterior Cruciate Ligament (ACL) reconstruction, will increase the post-operative A-P laxity of the knee has been the subject of discussion. For many years, many protocols have included full extension with full weight bearing after an ACL reconstruction. This is, however, based on empirical facts and has not been studied well in randomised studies. The A-P laxity of the knee joint is an important parameter when evaluating ACL-injured knees. For instance, it is difficult to find a study dealing with ACL insufficiency or post-operative follow-up after an ACL reconstruction, which does not use the KT-1000 as an evaluation instrument to assess objective outcome. The question of whether the results of KT-1000 measurements are sufficiently accurate and the extent to which they are clinically relevant still remains. Previous studies have shown abnormal kinematics in knees with chronic ACL insufficiency and reconstruction of the ligament using bone-patellar tendon-bone (BPTB) or hamstring autograft has not normalised the kinematics.

The primary aim of this study was to evaluate whether a post-operative rehabilitation protocol, including active and passive extension without any restrictions in extension immediately after an ACL reconstruction, would increase the post-operative A-P laxity. The second aim was to compare the KT-1000 arthrometer with RSA, a highly accurate method, to measure A-P laxity in patients with ACL ruptures, before and after reconstruction. The third aim was to evaluate whether an early ACL reconstruction would protect the knee joint from developing increased external tibial rotation.

Materials and methods: Twenty-two consecutive patients (14 men, 8 women, median age: 24 years, range: 16-41) were included and randomly allocated to two groups in the first part of the studies. Twenty-six consecutive patients (18 men, 8 women; median age 26, range 18-43) were included in the second part. All the patients had a unilateral ACL rupture and no other ligament injuries or any other history of previous knee injuries. One experienced surgeon operated on all the patients, using the BPTB or hamstring autograft. We used RSA with skeletal (tantalum) markers to study A-P laxity and knee kinematics. Dynamic RSA was performed to evaluate the pattern of knee motion during active and weight-bearing knee extension. For A-P laxity, we used static RSA and the KT-1000. Clinical tests were conducted using the Lysholm score, Tegner activity level, IKDC, one-leg-hop test and ROM. The patients were evaluated pre-operatively and up to two years after the ACL reconstruction.

Results: The KT-1000 recorded significantly smaller side-to-side differences than RSA, both before and after the reconstruction of the ACL using a BPTB autograft. There were no significant differences in A-P laxity between early and delayed extension training after ACL reconstruction, up to two years post-operatively. Neither ROM, Lysholm score, Tegner activity level, IKDC nor the one-leg-hop test differed.

Before surgical repair of the ACL and at the two-year follow-up, there were no significant differences between the injured and intact knees in internal/external tibial rotation or abduction/adduction, when the ACL reconstruction was performed in the early phase after ACL injury.

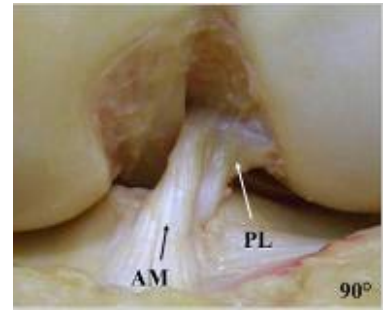
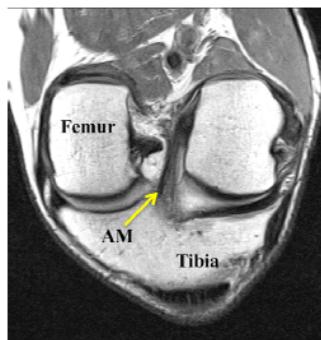
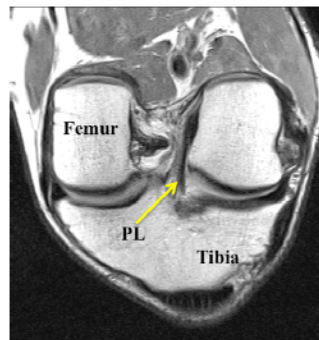
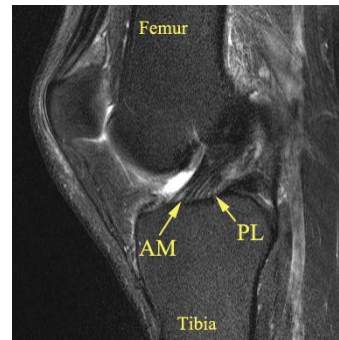
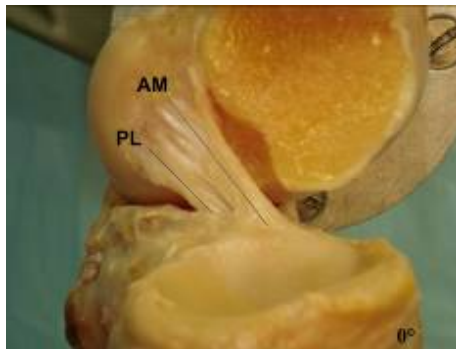
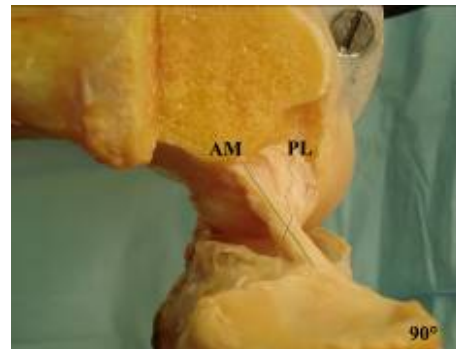
Conclusion: Early active and passive extension training, immediately after an ACL reconstruction using BPTB autografts, did not increase post-operative knee laxity up to two years after the operation. The KT-1000 recorded significantly smaller side-to-side differences than the RSA, both before and after the reconstruction of the ACL. Before surgical repair of the ACL, the knee kinematics remained similar on the injured and normal sides. Two years after the reconstruction, the kinematics of the operated knee still remained normal, after using either BPTB or hamstring autografts.

In Vivo Evaluation of Rotational Stability with Dynamic Stereo X-ray

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■ ACL Anatomy

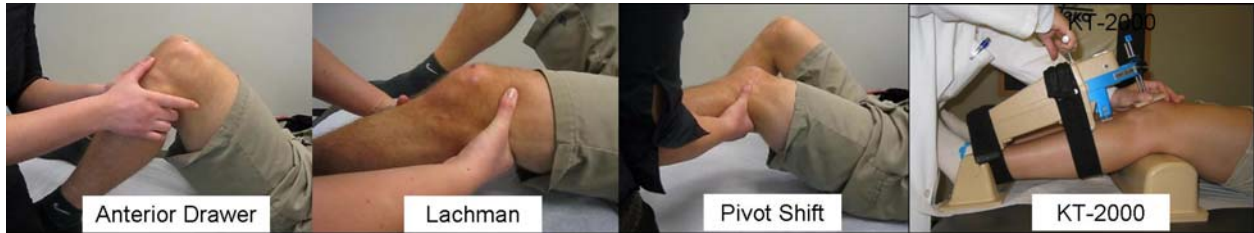
- The ACL is composed of two functional bundles, the anteromedial (AM) bundle and the posterolateral (PL) bundle.¹ Cadaveric studies have demonstrated that the AM bundle is approximately twice as long as the PL bundle, and that the two bundles have a similar cross-sectional diameter.
- The AM bundle has its highest tension at 45 degrees of knee flexion, and is taut throughout the range of motion. The PL bundle has its highest tension at full extension, and becomes loose as the knee flexes.



- Femoral insertion site orientation changes with knee flexion: The femoral AM and PL insertion sites are horizontally oriented when the knee is close to 90 degrees of flexion, while they are vertically oriented in full knee extension. This tensioning pattern of the native ACL allows the two bundles to work together to provide anterior and rotational stability of the knee throughout the entire range of motion.²

Outcome Evaluation after ACL Reconstruction

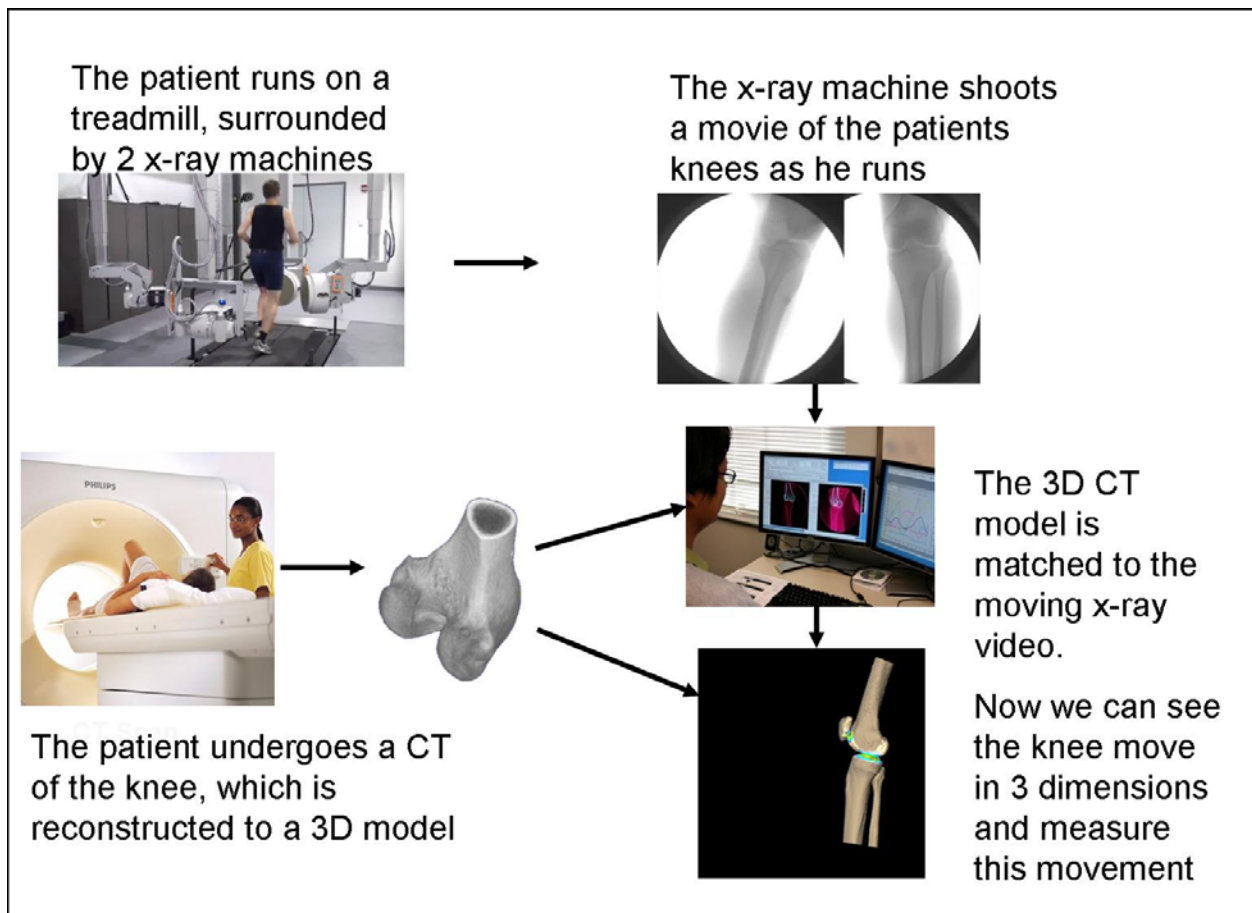
- Outcome evaluation after ACL reconstruction can be performed in a variety of ways, including patient reported outcome measures, physical examination and diagnostic instruments.



- Recent randomized controlled trials and meta-analyses have tried to compare different ACL reconstruction techniques using the aforementioned outcome measures.³⁻⁵ Many of these studies show no difference between the compared groups. Therefore some have called into question the effectiveness of our current outcome measures for identifying differences.
- One explanation for the inability to demonstrate differences in outcome could be due to way of reporting of the results. For example, a recent meta-analysis by Lubowitz et al. compared single- and double-bundle ACL reconstruction. When they reported the result of the pivot shift exam, they grouped the “normal” and “nearly normal” results together. This led to SB and DB achieving 94.6% and 97.5% good pivot shift results respectively with no difference between the two groups. However, if we want to review the data more critically by only comparing the “normal” category, DB provided significantly better results (83.1% DB vs. 67.9% SB).⁵⁻⁶
- Another problem is how to accurately assess rotational stability. The pivot shift test is largely dependent on the person performing the exam. In addition, quantifying the pivot shift is difficult. Also, the loads applied by the examiner during the pivot shift test are not representative of the actual forces placed on the knee during activities of daily living and sports.
- To fully assess the outcome of ACL reconstruction, we need to improve our outcome measures. New outcome measures should be accurate, precise and reliable. Only when we have good outcome measurements can we improve our surgical technique in order to optimize care for our patients.
- At the University of Pittsburgh Orthopaedic BioDynamics Laboratory, we employ Dynamic Stereo X-ray (DSX) to evaluate rotational stability and in vivo knee kinematics during activities of daily living. This system was designed to look at in vivo joint kinematics with a 0.1 mm accuracy. Below is a schematic explanation about DSX. A 3D CT scan of the knee is made. Then the subjects undergo dynamic stereo x-ray, using biplane imaging of their knee while performing tasks on a treadmill. Fluoroscopic images are collected at 100 frames per second. The fluoroscopic images that are generated with this system are then lined up the 3D CT scan. This will allow the bones to be visualized in a 3D fashion during the performed activities. From this data joint kinematic can be calculated including joint

contact area, joint motion paths, velocities and more. Using this system, we were able to show that non-anatomic ACL reconstruction does not restore normal knee motion.⁷⁻⁸

- These abnormalities in joint kinematics after non-anatomic ACL reconstructions may be the reason for the high rate of osteoarthritis.⁹⁻¹⁰ Being able to quantify the rotational and anterior stability after different ACL reconstruction techniques may help us improve our reconstruction techniques and reduce the risk of OA in order to provide the best long term outcome for our patients.



Conclusion

- Finding no difference does not mean there is no difference in ACL reconstruction. We have to look meticulously to find differences and be critical of our current outcome evaluations.
- Therefore we need more objective outcome measurements including biology, kinematics and imaging.
- Dynamic Stereo X-ray is an accurate tool to assess in vivo knee kinematics and rotational stability during real life activities.
- The personality of anatomic ACL reconstruction needs to be discovered.

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ICL #15

Rotational Stability of the Knee in ACL Deficiency - What is the evidence

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Background

Anterior cruciate ligament (ACL) disruption is a common cause of anterior knee instability, particularly as a result of sports activities. On the basis of several biomechanical studies, double-bundle ACL reconstruction, which is designed to reproduce both the anteromedial bundle (AMB) and the posterolateral bundle (PLB), has become increasingly popular over the past decade, because this procedure has been able to more closely restore the rotational stability compared with the conventional single-bundle technique . Zantop et al. reported that the AMB and the PLB stabilise the knee joint in response to anterior tibial loads and combined rotatory loads in a synergistic way . Yagi et al. and Araki et al. reported that anatomic double-bundle ACL reconstruction guaranteed similar results to the physiologically intact knee and provided a better control of rotational stability compared with AM single-bundle and PL single-bundle reconstruction. A newly developed noninvasive in vivo measurement system using an electromagnetic sensor can be used to measure the 6 degrees of freedom of the knee during the pivot-shift test with a high sampling rate (60 Hz). It enables monitoring of instantaneous 3D position displacement and calculates a 3D acceleration of the motion.

Measurement of the tibial anterior translation and the acceleration of its subsequent posterior translation during the pivot-shift test using this measurement system in both ACL-intact and -deficient knees were reported. It was hypothesized that the ACL-deficient knee will have a significantly increased tibial anterior translation and acceleration of its subsequent posterior translation and that this will correlate with the clinical grading of the pivot-shift test.

Double bundle Anatomic ACL reconstruction vs Single AM and PL bundle reconstruction

Double-bundle anterior cruciate ligament (ACL) reconstruction reproduces

anteromedial and posterolateral bundles, and thus has theoretical advantages over conventional single-bundle reconstruction in controlling rotational torque in vitro. However, its superiority in clinical practice has not been fully proven. We analyzed rotational stability with three reconstruction techniques in 60 consecutive patients who were randomly divided into three groups (double-bundle, anteromedial single-bundle, posterolateral single-bundle). In the reconstructive procedure, the hamstring tendon was harvested and used as a free tendon graft. Followup examinations were performed 1 year after surgery. Anteroposterior laxity of the knee was examined with a KT-1000 arthrometer, whereas rotatory instability, as elicited by the pivot shift test, was assessed using a new measurement system incorporating three-dimensional electromagnetic sensors. Routine clinical evaluations, including KT examination, demonstrated no differences among the three groups. However, using the new measurement system, patients with double-bundle ACL reconstruction showed better pivot shift control of complex instability than patients with anteromedial and posterolateral single-bundle reconstruction.

Double bundle vs Single bundle Anatomic ACL reconstruction

We additionally conducted a prospective randomized study of anatomical single-bundle (A-SB group) versus double-bundle (A-DB group) anterior cruciate ligament (ACL) reconstruction using the hamstrings tendons. Twenty patients with unilateral ACL deficiency were randomized into two groups. We created the bone tunnels at the position of the original insertion of the anteromedial bundle footprint and posterolateral bundle footprint in the A-DB group and at the central position between these two bundles in the A-SB group. All of the patients were tested before ACL reconstruction and one year after surgery. The KT1000 measurements, isokinetic muscle peak torque and heel-height difference were evaluated and the general knee condition was assessed by Lysholm score. For pre-and postoperative stability assessment, we used the six-degrees-of-freedom of knee kinematic measurement system using an electromagnetic device (the EMS) for quantitative assessment during the Lachman test and the pivot shift test. There were no significant differences in the KT-1000 measurements, isokinetic muscle peak torque, heel-height difference, and Lysholm score at one-year follow-up between these two groups. The EMS data showed there were significant differences in the acceleration of the pivot shift test between the operated knee and the contralateral normal knees in the A-SB

group. In conclusion, clinical outcomes were equally good in both groups. However, the EMS data showed the anatomical double-bundle ACL reconstruction tended to be biomechanically superior to the single-bundle reconstruction.

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ISAKOS 2011

Rotational Stability of the Knee in ACL Deficiency – Review of the literature

Moises Cohen – UNIFESP/EPM

Rotational Stability of the Knee in ACL Deficiency – Review of the literature

Anterior cruciate ligament (ACL) injury accounts for 40% of sports injury. ACL injury is more common in young and active individuals and leads to knee instability and poor function.

This ligament resists anterior instability and internal rotation of the tibia.

Functionally, the ACL is divided into two parts, the anteromedial bundle (AMB) and the posterolateral bundle (PLB).

In extension, the AMB appears as a flat band, and the posterolateral bulk of the ligament is taut. As the flexion begins, the anteromedial band tightens, and the posterolateral bulk loosens.

Understanding knee rotational stability assessments and the involved structures would be useful for diagnosis of ACL injury and comparison between operation treatments.

The role of ACL bundles in anterior tibial translation is well understood, but the function in rotational stability is controversy.

Previous studies supported that AM bundle was responsible for AP stability and PL bundle mainly contribute in rotational stability. However, other authors advocate that both bundles similarly control anterior translation and tibial internal rotation during pivot-shift testing.

Some authors reported that injury of ACL increases the internal tibial rotation. In contrast, other papers showed decreased tibial rotation after transection of the ACL.

Another study showed that ACL rupture may be associated to the primary restraints of tibial rotation like Lateral Colateral Ligament (LCL). And these additional injury to the LCL might be a factor, which explains the differences in pivot shift between patients. Importance of a complete physical examination.

Reconstruction surgery aims to restore the kinematics and stability of the injured knee.

Nowadays there are several techniques using a single or a double bundle for ACL reconstruction. However, there is no consensus on which is the best technique in restoration of rotational stability.

Some authors reported that SB reconstructions alone were insufficient in controlling the combined rotatory load and valgus torque.

So other authors suggest that DB reconstruction may be more appropriate to restore normal anterior translation and combined rotation.

However, Meredick et al (AJSM 2008) in a systematic review showed no statistically significant differences in pivot-shift results between SB versus DB.

Some other studies reported a better control of rotational instability using a more horizontal position of the graft in a SB reconstruction.

Pivot shift (PS) test is a rotational stability test that is better correlated with subjective satisfaction, overall knee function and sports participation.

PS is a subjective assessment because it is influenced by several factors.

As a result, attempts to perform instrumented knee laxity measurements to quantify the rotational instability arise all over the world.

Authors reported that computer assisted measurement techniques are accurate, reliable and a non-invasive method.

Currently orthopedic surgeons have used standard static measures of anterior-posterior tibial translation, questionnaires of patient functional mobility and satisfaction to evaluate knee stability and success level of an ACL reconstruction.

However, these measures do not necessarily suggest that knee joint function is fully restored. Furthermore, such measures do not provide with information of the level of dynamic rotational control achieved after an ACL reconstruction.

So, we emphasize the need for development of an objective system to assess tibial rotation after surgery and to improve clinical practice and evaluation of patients.

New quality papers on this subject are recommended in order to clarify the role of ACL in rotational stability of the knee and test new measurement systems to assess tibial rotation before and after reconstruction surgery.