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Anterior Cruciate Ligament Reconstruction With a Quadrupled Hamstring Autograft Does Not Restore Tibial Rotation

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Summary: As a result of the morbidity associated with anterior cruciate ligament (ACL) reconstruction with a bone–patellar–tendon–bone graft, many orthopaedic surgeons prefer hamstrings as the graft for ACL reconstruction. However, this selection is not based on solid scientific evidence. In vitro research shows that this graft cannot restore control of tibial rotation. Our recent in vivo research work has also demonstrated the same result. In particular, patients undergoing ACL repair who were reconstructed with a quadrupled hamstring tendon graft showed excessive tibial rotation during a dynamic activity when compared with healthy control subjects. Although the hamstring tendon graft has a more advantageous biomechanical profile than other grafts, it seems that it could not replicate the normal ACL regarding its actual anatomy and functional rotational abilities. The improvement and development of new surgical procedures and grafts seems to be the only way to address this problem of excessive tibial rotation. We also propose that the inability of current operative techniques to restore tibial rotation to normal preinjury levels can be the cause of future pathology and osteoarthritis found in ACL-reconstructed patients in the long-term. Abnormal rotational movements could result in loading of the knee cartilage in areas that are not commonly loaded in a healthy knee. These areas resulting from insufficient cartilage thickness may not be able to withstand the newly introduced loading and, over time, knee osteoarthritis is developed. Key Words: Tibial rotation—Anterior cruciate ligament reconstruction—Osteoarthritis—Pivoting—Hamstring tendon graft.

The bone–patellar–tendon–bone (BPTB) and the quadrupled hamstring tendon (semimembranosus/gracilis [ST/G]) graft are the most commonly used autogenous grafts for anterior cruciate ligament (ACL) reconstruction. Generally, the literature shows only small differences between these 2 grafts regarding postoperative pain, muscle strength, knee range of motion and static stability, complication rate, and final outcome.5,14,29,30 Some recent studies5,34 have shown that the use of the BPTB graft leads to higher postoperative activity levels in comparison with the ST/G graft. On the other hand, the ST/G graft appears to be stronger than the BPTB. In addition, the ST/G graft has stiffness that is closer to the normal ACL.4,13,26 Furthermore, the BPTB graft leads to increased anterior knee pain and inability to assume a kneeling position.4,5,17,18,29 For all these reasons, the popularity of the ST/G graft has increased among orthopaedic surgeons. In a recent multicenter clinical review, it has been reported that 77.6% of the ACL reconstructions performed have used ST/G as the graft.21

The ideal graft material should reproduce the complex anatomy of the native ACL, provide the same biomechanical properties as the native ACL, and minimize the donor site morbidity. Although both of the 2 grafts have allowed athletes to return to their sport activities, without any clinical implication, none of them seem to meet all of these criteria.6,9,27 The orthopaedic surgeon must choose a graft source and fixation technique in an effort to restore knee stability, both anterior and rotational.
Cadaveric studies have reported that the current reconstruction procedures using BPTB or ST/G grafts are successful in limiting anterior tibial translation but fail to restore rotational stability.\textsuperscript{16,19,32} Previous studies from our laboratory have also shown that tibial rotation remains excessive, 1 and 2 years after ACL reconstruction with a BPTB graft, during high demanding activities that involve a pivoting movement.\textsuperscript{8,24,25} In these studies, we collected 3-dimensional kinematics at a sampling frequency of 50 Hz using a 6-camera optoelectronic system (Peak Performance Technologies, Inc., Englewood, CO). Our subjects performed 2 different experimental protocols: 1) descending from a stair and subsequent pivoting (Fig. 1) and 2) landing from a platform and subsequent pivoting (Fig. 2). Such activities placed combined rotational and translational loads on the knee. As mentioned here, our findings revealed that the increased tibial rotation found in the ACL-deficient knees was not restored with a reconstruction using a BPTB graft. This was the case even after a long period, 2 years postoperatively. We concluded that an ACL reconstruction using a BPTB graft fails to restore tibial rotation to previous physiological levels during highly stressful activities, although anterior tibial translation is completely restored. However, our previous work has not addressed if this is also the case with the ST/G graft.

**IN VIVO FINDINGS WITH THE SEMITENDINOUS/GRACILIS GRAFT**

Thus, our current work has focused in expanding our past work by investigating if tibial rotation remains excessive in patients undergoing ACL repair reconstructed with an ST/G graft.\textsuperscript{10} Similarly, with our past work, we evaluated the maximum range of motion of tibial rotation during descending from a stairway and subsequent pivoting. Thus, we were able to evaluate the function of the replacement graft in response to combined anterior translational and rotational tibial loads. The application of such loads on the knee can provide us with additional insights into functional recovery after an ACL reconstruction.

We evaluated 11 patients, all ACL-reconstructed with the same arthroscopic technique using an ST/G graft, 9 months on average, after the surgery. Like in our previous experiments, we incorporated a “double” control group, because we used as controls both the intact leg of the ACL-reconstructed group and a completely healthy group of 10 subjects. All clinical tests (Lachman test, pivot shift test, and KT-1000 measurements) revealed that knee joint stability was regained in all of our patients. The patients were asked to descend 3 steps, pivot (externally rotate) on the landing leg at 90°, and walk away from the stairway. Our dependent variable was the maximum range of motion of tibial rotation during the pivoting period. Our results showed that this variable was found significantly higher in the ACL-reconstructed leg with an ST/G graft when compared with the contralateral intact leg and the healthy control. No significant differences were found between the healthy control leg and the intact leg of the ACL-reconstructed group. Therefore, our results demonstrated that tibial rotation remained abnormal and significantly increased 9 months after an ACL reconstruction with an ST/G graft during the activity performed in our investigation.

To our knowledge, this is the first in vivo study that evaluated tibial rotation in patients undergoing ACL repair reconstructed with an ST/G graft. Thus, additional studies are needed to verify these findings from both ours and other laboratories. However, it is certainly worth discussing what we believe are the reasons for these results.

**CURRENT OPERATIVE TECHNIQUES AND TIBIAL ROTATION**

We believe that there are several reasons for the lack of restoration of tibial rotation to normal preinjury levels using the ST/G graft. As recent in vitro studies\textsuperscript{19,28,32} have shown, current practice of ACL reconstruction with hamstrings, that places the graft in the 11 o’clock of the femur and the tibial tunnel in the center of the ACL footprint,\textsuperscript{15} results in inadequate resistive ability to rotational forces. Scopp et al\textsuperscript{28} and Loh et al\textsuperscript{19} have shown in vitro that a more oblique tunnel placement in the femur is better than the standard femoral tunnel placement regarding tibial rotation. In these studies, the more oblique femoral tunnel placement (at 10 o’clock) resulted in less internal tibial rotation in comparison with the standard femoral tunnel placement. In our patients, we placed the femoral tunnel between the 10 and 11 o’clock position (Fig. 3) as the postsurgery radiographic examination also indicated. Currently, we are performing ACL reconstructions with an ST/G graft with the femoral tunnel placed in a more oblique position. So, it would be of great interest in the future to examine if this way will affect the in vivo kinematics of the ACL-reconstructed knee.

An additional explanation for the lack of restoration of tibial rotation to normal levels using the ST/G graft is the absence of complete reinstatement of the actual anatomy of the ACL. The most fundamental aim of ACL reconstruction is to restore the normal ACL anatomy as closely as possible. However, there is general agreement
that current ACL reconstruction techniques using autologous tendon grafts anchored in one femoral and one tibial tunnel achieve this goal only to some degree. It has long been realized that the ACL does not function as a uniform band of fibers with constant tension as the knee moves, but it seems to differentiate into 2 bundles, the anteromedial (AM) and posterolateral (PL) bundle.\textsuperscript{2,11} Although there is still disagreement about the actual anatomic division of the ACL, the general consensus appears to be that the ACL has these 2 distinct functional bands. When the knee is extended, the PL bundle is tight and the AM bundle is moderately lax.\textsuperscript{12,20} As the knee is flexed, the femoral attachment of the ACL is taking a more horizontal orientation, causing in this way the AM bundle to tighten and the PL bundle to loosen.\textsuperscript{1}

The role of the AM bundle has been widely demonstrated for resisting anterior translational loads. The PL bundle, however, has not received sufficient attention. A recent in vivo study by Woo et al\textsuperscript{7} has shown that the in situ forces of the PL bundle in response to a 134-N anterior load are the highest in full extension and decreased with increasing flexion. They also demonstrated that the PL bundle plays a significant role in the stabilization of the knee against a combined rotatory load, which suggests the need for a more anatomic reconstruction designed to replicate the 2 ACL bundles.

In theory, a 2-bundle reconstruction is advantageous because we can regain a structure that can better resemble a normal ACL both morphologically and functionally. Studies in both human and animals have demonstrated similar results on the 2-bundle reconstruction technique. Radford et al\textsuperscript{12,23} used an in vitro sheep model and reported that the knee function after a reconstruction with a double-bundle prosthetic ligament was closer to that of the intact knee than after the single bundle. Human clinical trials also reported similar results.\textsuperscript{20,35} Muneta et al\textsuperscript{30} reported the clinical results after a 2-year follow up with a 2-bundle procedure in 54 patients and demonstrated good anterior stability with no serious complications. This technique, however, has not been investigated dynamically, and future research work using external loading conditions similar to ones used in the current study should be performed to determine the advantages of the 2-bundle anatomic reconstruction.

\textbf{FIG. 1.} A stick figure describing the descending and pivoting task. The subjects descend the 3 steps with their own pace. The descending period is concluded on initial foot contact with the ground. After foot contact, the subjects pivot (externally rotate) on the landing leg at 90° and walk away from the stairway. While pivoting, the contralateral leg is swinging around the body and the trunk is oriented perpendicularly to the stairway.
FIG. 2. A stick figure describing the landing and pivoting task. The subjects jump from a 40-cm height platform and land as naturally as possible with both feet on the ground. After foot contact, the subjects pivot (externally rotate) on the right or left (ipsilateral) leg at 90° and walk away from the platform. While pivoting, the contralateral leg is swinging around the body and the trunk is oriented perpendicularly to the platform.

FIG. 3. A figure describing our femoral tunnel placement between 10 and 11 o’clock position.

TIBIAL ROTATION AND OSTEOARTHRITIS: AN INTRIGUING HYPOTHESIS

The results of the current study may also provide with an intriguing explanation regarding the development of future pathology and deterioration at the ACL-reconstructed knee. We propose that the excessive tibial rotation found in an ACL-reconstructed knee with current graft techniques could degenerate soft tissues (ie, cartilage) resulting in osteoarthritis. Because current ACL reconstruction procedures cannot replicate exactly normal ACL anatomic complexity, they cannot restore normal tibiofemoral kinematics at the knee joint, leading this way to pathologic moving patterns. These abnormal rotational movements of the articulating bones at the knee could result in the applications of loads at areas of the cartilage and are not commonly loaded in a healthy knee. These areas are the result of lack of sufficient cartilage thickness and may not be able to withstand the newly introduced loading, and over time, the end result could be knee osteoarthritis.

Several studies have shown\textsuperscript{3,31} that variations in cartilage morphology, and its mechanical properties are clearly related to regions of functional load-bearing, in which highly loaded regions show increased thickness and enhanced mechanical properties. In contrast, infrequently loaded regions show cartilage with degraded properties.\textsuperscript{3,31} A shift in the load-bearing area, as a result of the abnormal kinematics, as occurs in the ACL-
reconstructed knee, may lead an infrequently loaded area to sustain severe loads and therefore subsequently impair with further damage of the articular surface and increased fibrillation of the collagen network. However, it is important that our theoretical proposition needs to be explored through both in vivo and in vitro studies.

CONCLUSIONS

In conclusion, current ACL reconstruction technique with an ST/G graft, although succeeding in limiting anterior tibial rotation during dynamic activities. Although the ST/G graft has a more advantageous biomechanical profile than other grafts, it could not replicate the normal ACL regarding its actual anatomy and functional rotational abilities. The improvement and development of new surgical procedures and grafts seems to be the only way to address this problem of excessive tibial rotation. Thus, future studies should focus on the advantages and disadvantages of different surgical procedures, whether it is the graft material or the tunnel positioning, keeping always in mind the importance of reproducing the actual ACL anatomy during the reconstruction.

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