Editorial Commentary: Increased Tibial Slope and Decreased Medial Proximal Tibial Angle Negatively Affect Anterior Cruciate Ligament Graft Maturation: Objective Evidence on When to Add a Lateral Extra-Articular Augmentation Procedure to a Soft-Tissue Anterior Cruciate Ligament Reconstruction

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Abstract: Recent anterior cruciate ligament (ACL) research focuses on risk factors for ACL graft failure and techniques and augmentations to limit failure. One of the most recognized risk factors is sagittal malalignment in the form of high posterior tibial slope (PTS), especially PTS $\geq 12^{\circ}$, which leads to increased force through the ACL and ACL graft. To reduce the risk associated with increased PTS, lateral augmentation techniques, typically either a lateral extra-articular tenodesis or an anterolateral ligament reconstruction, improve clinical outcomes, and the authors preferred graft choice, particularly in such cases, is bone−patellar tendon−bone autograft. Furthermore, in revision cases, there exists a strong argument to perform a slope reducing osteotomy to correct bony malalignment which, if left untreated, could lead to ACL graft failure. Slope-reducing osteotomies are reported to significantly decrease anterior tibial translation and forces on the ACL graft. Coronal malalignment is also a risk factor for ACL failure (although not as extensively studied as sagittal alignment). Both varus and valgus alignment of the knee can lead to increased forces through the ACL or ACL graft compared with knees in neutral alignment, and workup requires proper lateral and long-leg anteroposterior radiographs to determine sagittal and coronal alignment and guide treatment algorithms. Recent research shows that decreased medial proximal tibial angle of the knee (increasing varus alignment of the tibia) may delay graft maturation. However, there is yet to be a consensus about what exactly contributes to ACL graft failure in the coronal plane and what is the best treatment option, especially in the primary setting when an osteotomy is not indicated. Again, we recommend bone−patellar tendon−bone autograft as our preferred graft choice unless contraindicated by skeletal immaturity.

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The recently published article titled "Higher Posterior Tibial Slope and Lower Medial Proximal Tibial Angle of the Knee Are Associated With Delayed Graft Maturation After Anterior Cruciate Ligament Reconstruction Surgery With Hamstring Autograft" by Sato, Han, Feeley, Ma, Majumdar, and Lansdown provides important insights into the correlation of posterior tibial slope (PTS) and medial proximal tibial angle (MPTA) and their effect on anterior cruciate ligament (ACL) graft maturation at 2 years postoperatively.[1] The authors should be congratulated on their innovative use of magnetic resonance imaging (MRI) techniques and the correlation to common preoperative radiographic measures.

This retrospective study consisted of 28 patients who underwent anterior cruciate ligament reconstruction (ACLR) using a doubled semitendinosus and gracilis hamstring autograft and had a 2-year postoperative follow-up that consisted of an MRI and patient-reported outcomes (PROs). The study aimed to determine how osseous morphology and PROs correlate with graft maturation via T1p, T2, and UTE T2* on MRI. The main findings from this study were 2-fold: (1) increased PTS had a significant correlation with inferior outcomes of hamstring graft maturation and (2) decreased MPTA (increasing varus alignment of

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the tibia) had a significant correlation with inferior outcomes of graft maturation. The PROs had no correlation with graft maturation in this cohort. However, limitations of this study, including a small cohort with no power analysis, the use of hamstring autografts, and selection bias for those who underwent MRI (no failures were included), could result in bias in the results.

The finding related to PTS having a significant positive correlation with inferior hamstring graft maturation is especially important for all our practices and how we treat patients with primary ACL tears or ACL graft tears, especially when using soft-tissue grafts such as a hamstring or quadriceps autografts. Many previous clinical and biomechanical studies have indicated high PTS as a risk factor for ACL or ACL graft failure.[2-5] For example, in a 20-year follow-up study, Salmon et al.[3] specifically mentioned PTS $\geq 12^\circ$ as a risk factor for ACLR using hamstring autograft, and a biomechanical study by Bernhardson et al.[2] reported increased ACL graft forces as PTS increases. The present study adds a unique new finding to this previous literature and highlights the revascularization, proteoglycan concentration, and collagen restructuring of the ACL hamstring autograft that can be visualized with specialized MRI. Inferior graft maturation is evident by low proteoglycan concentrations and disorganized collagen restructuring, which may increase the risk of graft failure. With these findings put together, it can be reasonably assumed that inferior hamstring graft maturation is caused by the increased forces experienced by the ACL graft in patients with a greater PTS. This then begs the question: what should we be doing to improve graft maturation when an osteotomy is not indicated in the primary phase? In our practice, we commonly add a lateral extra-articular tenodesis (LET) or anterolateral ligament reconstruction (ALLR) in patients with PTS $\geq 12^\circ$, and these findings may reinforce this indication. Of note, the senior author typically uses a bone–patellar tendon–bone (BPTB) ACLR for patients who undergo primary ACLR and rarely uses hamstring for primary ACLR.[6] Previous biomechanical studies have reported decreased ACL graft forces, even with increased PTS, when an ACLR is augmented with an LET or ALLR.[5,7,8] In addition, an LET or ALLR is reported both biomechanically and clinically to help reduce rotational instability, which could also decrease the forces experienced by the ACL graft.[9-13] The combination of these previous findings and the findings from this study suggest that the addition of an LET or ALLR, especially in cases of increased PTS, may lead to decreased graft failure by improving graft maturation.

The finding of a correlation between decreased MPTA (increasing varus alignment of the tibia) and graft maturation is another very interesting finding for this study. Previous biomechanical studies have both highlighted how varus and valgus alignment lead to increased forces through the ACL; however, to our knowledge, no studies have reported on how MPTA affects the forces on an ACL graft.[14-16] In addition, since this study found no correlation between tibiofemoral angle (varus or valgus alignment) or joint line convergency angle and graft maturation, is it just increasing varus of the tibia causing this inferior graft maturation or could other measures like joint line obliquity or lateral distal femoral angle also play a role? Also, is there more to this issue that may be answered with a larger cohort and a prospective power analysis? The addition of an LET or ALLR has proven to help decrease ACL graft forces in cases with increased PTS, but no similar findings for augmentation techniques are present in the literature for coronal malalignment. In addition, there is not sufficient evidence to suggest that adding in a coronal realignment osteotomy procedure in the primary phase could help reduce ACLR failure rates, especially when there is no correlation between PROs and graft maturation, given the additional morbidity of an osteotomy.

With the findings from this study, there is additional evidence that a lateral extra-articular augmentation procedure like an LET or ALLR should be added in the primary phase for those undergoing a soft-tissue ACLR with increased PTS, especially $\geq 12^\circ$.[3,11,17-19] Furthermore, in revision cases, there exists a strong argument to perform a slope-reducing osteotomy to correct bony malalignment which, if left untreated, could lead to ACL graft failure.[2,20,21] Slope-reducing osteotomies are reported to significantly decrease anterior tibial translation and forces on the ACL graft.[22-24] However, in our minds, there is yet to be a consensus about what exactly contributes to ACL graft failure in the coronal plane and what the best treatment option for this is, especially in the primary setting when an osteotomy is not indicated.

Future studies should explore how different ACLR graft choices, such as quadriceps tendon autograft and BPTB, or if the addition of a lateral extra-articular augmentation procedure, such as an LET or ALLR, can affect ACL graft maturation in patients with a PTS $\geq 12^\circ$ or with a decreased MPTA. It is possible that each graft may have a different response to increased PTS, and these results may not be generalizable to other grafts, such as a BPTB.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: C.M.L. reports speaking

and lecture fees from Foundation Medical and Evolution Surgical and has a family member that reports relationships with Ossur Americas, Smith & Nephew, Linvatec Europe, and Responsive Arthroscopy that include consulting or advisory; a family member that reports relationships with Ossur Americas, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine that include funding grants. R.F.L. reports consulting or advisory for Ossur Americas, Smith & Nephew, Linvatec Europe, and Responsive Arthroscopy; and funding grants from Ossur Americas, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine. All other authors (L.V.T.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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