The Effect of Tibial Slope on Anterior Cruciate Ligament Graft Forces and Knee Stability With and Without Concomitant Lateral Extra-Articular Tenodesis

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INTRODUCTION:

Extensive research has identified risk factors for anterior cruciate ligament reconstruction (ACLR) failure, leading to the development of new techniques aimed at enhancing knee stability and reducing anterior cruciate ligament (ACL) graft forces. Two risk factors that have gained increasing attention are excessive posterior tibial slope (PTS) and anterolateral ligament complex (ALC) injuries. However, the relationship between these two risk factors has not yet been investigated, and it remains unknown whether excess PTS exacerbates the known negative implications of concomitant ALC injury on knee stability. Additionally, concomitant procedures addressing these factors during ACLR, such as slope reducing osteotomy and lateral extra-articular tenodesis (LET), are increasingly employed. However, it remains unclear whether such procedures need to be performed simultaneously or sufficiently restore knee stability when performed in isolation. Therefore, in the present biomechanical study, we aimed to determine, first, if ALC injury amplifies the effects of excess PTS on ACL graft forces and knee stability, and second, if an LET can mitigate the detrimental effects of excess PTS on knee kinematics and ACLR graft forces, to a degree that is comparable to a slope reducing osteotomy.

METHODS: Anatomic single-bundle ACLR was performed on seven fresh-frozen cadavers. A posterior osteotomy was performed to allow for the desired adjustments of the tibial slope (PTS), which was directly measured and set at 0°, 10°, and 20° using a lateral standard x-ray (**Figure 1**). Three specimen states following ACLR were studied - intact ALC, ALC sectioned, followed by LET. The ALC sectioned state involved sectioning of the anterolateral ligament (ALL) and Kaplan fibers at their attachment sites. The LET state was achieved through the modified Lemaire technique. Biomechanical testing was executed via a six-degrees-of-freedom robot equipped with a custom load cell attached to the ACL. The robot simulated pivot shift forces (100 N compression, 10 Nm valgus torque, 5 Nm IR rotation torque) to assess anterior tibial translation (ATT), internal rotation (IR), and ACL graft forces. Statistical analyses involved mixed models with classical sandwich estimation and Holm's test for multiple comparisons. A p-value of <0.05 was deemed statistically significant.

RESULTS:

Following pivot shift loading, our analysis of ATT revealed that as tibial slope increased, ATT increased for all conditions, with statistically significant associations observed for Intact ($p=0.009$) and LET conditions ($p=0.007$)(**Figure 2**). ATT was consistently lower in LET than in Intact or Sectioned, and higher in Sectioned than in Intact, at all degrees of PTS, showing a trend but not reaching statistical significance. Furthermore, to compare the effectiveness of LET with a slope reducing osteotomy, we contrasted LET states at 10 and 20 degrees with the intact state at 0 and 10 degrees, respectively. No statistically significant differences in ATT were found between the LET state at a tibial slope of 10 degrees and the intact state at a tibial slope of 0 degrees. Similarly, no statistically significant differences were observed between the LET state at 20 degrees and the intact state at 10 degrees.

Additionally, an increase in tibial slope led to increased IR under PS loading across all three specimen conditions (**Figure 3**). This relationship was found to be statistically significant for the Intact and LET conditions ($p<0.05$). IR was lower in LET than in Intact for all tibial slope values, with statistically significant differences observed at a tibial slope of 10. When compared to the sectioned group, IR was lower in the LET group, with these comparisons being statistically significant for all three tibial slope values ($p<0.05$). No statistically significant differences were observed between the LET group at 10 and 20 degrees of slope when compared to the intact states at 0 and 10 degrees of slope, respectively.

No significant differences in ACL graft load were observed between the intact and LET group at all degrees of PTS**(Figure 4).** Furthermore, no statistically significant differences in graft load were observed between LET at a tibial slope of 10 and Intact at a tibial slope of 0, as well as between LET at a tibial slope of 20 and Intact at a tibial slope of 10.

DISCUSSION AND CONCLUSION: Our results indicate that PTS may significantly affect anterolateral knee instability in the context of ACLR under pivot shift loads. Moreover, we found that excessive PTS exacerbates the impact of ALC injury on anterolateral knee instability when present concomitantly. Importantly, implementing an LET to address this instability was shown to restore knee stability to a level comparable to that achieved with a slope-decreasing osteotomy.

Figure 2

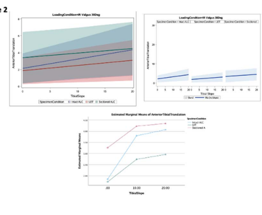

Figure 3

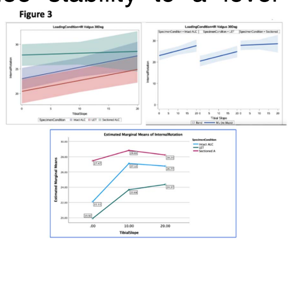

Figure 4

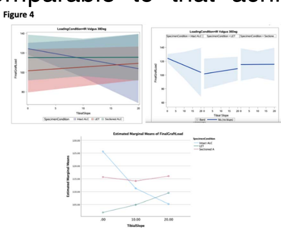

Figure 1