Mechanical Properties of Quadriceps Tendon Allograft Compared to Bone-Patellar Tendon-Bone Allograft as an Alternative Graft for ACL Reconstruction

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Disclosures:
R. Shani: None. J. Xerogeanes: 2; Linvatech. 6; linvatech, arthrex, smith and nephew, DJO global,. M. Nasert: 3A; Paid Employee of Musculoskeletal Transplant Foundation 125 May Street, Edison, New Jersey, USA.

Introduction: Over 200,000 anterior cruciate ligament reconstructions (ACLR) are performed in the United States yearly, making it one of the most common orthopedic procedures. Graft choices for ACLR include both autograft and allograft tendons. The most popular autograft choices are the bone-patellar tendon-bone (BPTB) and hamstring (HS) tendons. While the BPTB has long been considered “the gold standard” of autograft choices, the operative time for harvest and harvest site morbidity present significant problems. The HS graft also presents issues with post operative numbness, weakness and the inability to reliably predict the size of the graft pre-operatively. The BPTB is also a popular allograft choice, but its availability and intraoperative length restrictions again make its use problematic. Thus, alternative autografts and allografts grafts are being considered. Recent improvements in both graft harvest and operative fixation have renewed interest in the quadriceps tendon as both an autograft and allograft choice. Thus, biomechanical comparisons of the patella tendon and quadriceps tendon grafts (QTG) are important as a means to select the best ACL replacement graft. Previous studies1-3 evaluating the graft biomechanical characteristics have yielded conflicting results and failed to consider both structural and material properties when testing the quadriceps tendon. Our hypothesis is that the quadriceps tendon will have biomechanical properties equivalent or better than the bone-patellar tendon-bone graft thus providing a suitable alternative graft choice for ACL reconstruction. In this study, in-vivo mechanical testing was performed to quantify both the structural and material properties of 10 mm sections of the quadriceps and patellar tendon.

Methods: Harvest Technique
We used a similar preparation technique as described by Staubli.4 For the quadriceps tendon (N = 12), we created 10 mm width strips with a corresponding 25 - 28 mm distal patella bone block and for the patellar tendon (N = 11) a 10 mm width specimens was created from the central tendon portion with a corresponding 25 - 28 mm proximal patellar bone block and a 25 - 28 mm distal tibial tubercle bone block. In both specimens, full thickness grafts were obtained. These measurements were selected to replicate those of the grafts used in ACL reconstructions.

Specimen Preparation and Mechanical Testing
Quadriceps Tendon
The distal bone block end was potted in bone cement (PMMA), drilled, and pinned in preparation for mechanical testing. The tendon portion was cut such that there was between 8 cm and 10 cm protruding from the potted bone block so that 5 cm was the active length and the remaining 3 cm to 5 cm proximal end was secured into the cryo-grips that were attached to the linear actuator of the MTS servo-hydraulic test machine (MTS Corp., Eden Prairie, MN). The distal potted bone-block end of the tendon was secured to the plate of the test machine (Figure 1).

Bone Patellar Tendon
For the BPTB, the distal and proximal bone block ends were potted in bone cement (PMMA), drilled, and pinned in preparation for mechanical testing. The proximal potted bone-block end of the BPTB (Patella end) was attached to the linear actuator and the distal potted bone-block was secured to the platen of the MTS servo-hydraulic test machine (Figure 2.). Cross Sectional Area (CSA) was measured using calipers to measure the thickness of the graft and a ruler to measure the width for both the QTG and the BPTB. The CSA was determined by multiplying the thickness and the width. The CSA was measured at 3 different locations and averaged. All specimens were preconditioned (10 cycles between 50 N and 250 N in tension at 1 Hz in force control), then relaxed to 0 N and tensioned to failure at 5mm/second in displacement control using the MTS m

Statistical Analysis:
The results were analyzed using an unpaired t-test to compare statistical differences. Any differences that were found with a probability less than 5% (p < 0.05) will be considered statistically significant. All data is reported as average ± std. deviation.

Results: Failure Mode
In the quadriceps group, 6 of the 12 specimens failed at midsubstance and 6 of 12 specimens failed at the distal patellar...
insertion site. In the patellar tendon group, 7 of the 11 specimens failed at the midsubstance, 3 tore at the distal insertion site, and 1 tore at the proximal insertion site.

**Mechanical Properties**

The CSA of the quad tendon was significantly greater than patellar tendon. The structural properties (ultimate load, stiffness) and the material properties (ultimate stress, young’s modulus) of the quad tendons are significantly different from the patellar tendon with the exception of ultimate strain (Table 1).

**Discussion:** The structural properties of the quadriceps tendon graft are significantly higher than those of the BPTB. While the ultimate load of the QTG is almost identical to the native “anatomic” ACL (2160 N) as reported by Woo et al\(^5\)\(^6\), it is 25% greater than that of the BPTB indicating that the QTG is sufficiently strong to bear the in situ loads observed upon implantation for ACLR. Much of this difference can be attributed to the increased thickness or cross sectional area of the QTG. The material properties of the QTG are again significantly different than the BPTB. However, the Young’s modulus of the QTG is almost identical to that of the native ACL, and a reflection of the mechanical similarities of the two tissues. While it is controversial as to which biomechanical properties are the most important when selecting a graft, we feel that the ultimate load and modulus are clinically very important as they predict the in situ load bearing capacity and knee stability (through resistance to deformation), respectively.

The purpose of this study was to demonstrate that the quadriceps tendon is a suitable alternative to the patellar tendon for ACL reconstruction from an in-vitro biomechanical standpoint. Our hypothesis that the quadriceps tendon has equivalent or better biomechanical properties than the bone-patellar tendon-bone graft is supported by the data by demonstrating that the QTG is superior in strength to the BPTB and has similar mechanical properties to that of the native ACL.

**Significance:** The QTG has the appropriate structural and material properties for consideration as both an autograft and allograft for ACL reconstruction. The significantly greater ultimate load and a modulus similar to the native ACL make it an equal if not superior graft choice than the BPTB.

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**References:**

### Table 1. Mechanical Properties of Quadriceps Tendon and Patellar Tendon

<table>
<thead>
<tr>
<th>Property</th>
<th>Quadriceps Tendon</th>
<th>Patellar Tendon</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Sectional Area (mm²)</td>
<td>312.2</td>
<td>48.4</td>
<td>&lt;0.003</td>
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<tr>
<td>Ultimate Load (N)</td>
<td>2185.9</td>
<td>1622.9</td>
<td>0.045</td>
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<td>Stiffness (N/mm)</td>
<td>466.2</td>
<td>297.3</td>
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<td>Ultimate Stress (MPa)</td>
<td>33.9</td>
<td>33.8</td>
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<td>Young’s Modulus (MPa)</td>
<td>353.3</td>
<td>342.5</td>
<td>0.005</td>
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<td>Ultimate Strain (%)</td>
<td>10.7</td>
<td>11.3</td>
<td>0.484</td>
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