Regional Mechanical Properties of the Long Head of the Biceps Tendon

Christopher W. Kolz, BS, Thomas Suter, MD, Heath B. Henninger, PhD.
University of Utah, Salt Lake City, UT, USA.


Introduction: A common method for treating pathologies of the long head of the biceps tendon (LBT) is tenodesis. Tenodesis is performed to restore elbow flexion and supination strength by attaching the LBT to the humerus while alleviating pain of the underlying pathology. Common methods for LBT tenodesis include interference screw and suture anchor fixation [1-3]. Current surgical techniques place the tenodesis fixation points above or below the pectoralis major insertion on the humerus, where the location is based on hardware choice and surgeon preference. McGough et al. investigated the uniaxial tensile properties of the complete LBT [4], but to date there are no data examining if regional differences in LBT tendon properties exist. The presence of graded material properties along the length of the LBT may guide placement and selection of tenodesis hardware to incorporate the strongest or most resilient segment of the tendon.

Methods: The LBT was harvested from 12 pairs of fresh-frozen cadaveric shoulders (Age: 59±6 yrs; 10M, 2F). Tendons were tested using a quasi-static uniaxial tensile testing protocol on a servo-hydraulic materials testing machine (Instron 1331 Load Frame, Model 8800 controller, Instron Corp., Norwood, MA) equipped with a 250 N tension-compression load cell (Dynacell, Instron Corp., Norwood, MA). Each tendon was divided into an intra-articular, supra-pectoral and sub-pectoral zone (30%, 40%, and 30% of the LBT’s total length, respectively). In one tendon of each pair a dog-bone shaped specimen was punched from the tendon segment and used to quantify the LBT material properties. Segments from the other tendon were tested intact to simulate the boundary conditions of interference screw fixation into bone. The samples were mounted to the Instron using custom soft tissue clamps, and a pre-stress of 0.05 MPa (based on cross sectional area) was applied to each specimen for one minute prior to testing, followed by a five minute rest period. The specimens underwent preconditioning with ten cycles of 8% clamp-to-clamp strain at a rate of 1%/s, followed by a ramp to failure at 1 mm/s [5]. The dog-bone trials were recorded using a Prosilica GC1350 Gigabit Ethernet camera (Allied Vision Technologies, Vancouver, BC, Canada) and three fiducial tissue markers were tracked using high-resolution video tracking software (DMAS v6.5, Spica Technology Corporation, Maui, HI) to determine tissue strain. Peak stress, tissue strain, elastic modulus (defined as the slope of the stress-strain data for the last 1% of tissue strain), and hysteresis (area between the loading and unloading curves as a percent of the loading curve) were quantified from the 10th cycle. Ultimate stress and strain (maximum stress and corresponding strain prior to abrupt loss of tissue integrity) were quantified from the failure test. In intact specimens, structural properties including the peak force and stiffness were quantified from the 10th cycle, whereas ultimate load and stiffness were determined from failure tests. Statistical comparisons were made between anatomic functional zones using paired t-tests where p≤0.05 was considered significant. P-values were adjusted for multiple comparisons using the Bonferroni-Holm’s step-down method.

Results: Stress/load-strain curves for dog-bone/intact specimens were consistent with typical tendon and ligament mechanical behavior exhibiting a nonlinear toe followed by a linear region (Fig. 1). The material properties of the regions of the LBT are consistent with the literature for the complete LBT
No statistical differences were found between any of the material properties with exception to peak cyclic stress and elastic modulus (Table 1). Metrics for intact specimens also showed few statistical differences with the exception of peak cyclic stress and failure load for the supra-pectoral region (Table 2). Cross sectional area was greater for intra-articular regions (p≤0.01) (Table 1, 2). No other differences arose in the preparation measurements.

**Discussion:** The supra-pectoral region of the LBT showed trends towards greater strength in intact specimens, including higher peak stress and failure load than the other two regions. A similar trend was noted in the material properties of the dog-bone punched LBT where elastic modulus were higher in the supra-pectoral region. When normalized to cross sectional area, intact structural properties were generally inferior to the corresponding dog-bone specimens, likely due to the clamp boundary effects and expected strain inhomogeneity present in the intact specimens. The intact data are useful as they simulate the boundary conditions present in interference screw fixation of LBT tenodesis, and are supported in that the structural properties are similar to those for interference screws [1, 7]. It is important to note that the intra-articular region is wide and flat to resist the compressive forces it experiences during superior humeral head migration, and the sub-pectoral zone fans out on the distal end to integrate into the muscle belly and is compressed beneath the pectoralis major tendon. Given the nature of the in-vivo loading (pure tension), cylindrical shape, and the relative accessibility of the supra-pectoral LBT, the present results suggest the supra-pectoral LBT may be the best candidate site for LBT tenodesis. Secondary considerations include the potential for inferior cortical bone quality and consequent need for robust fixation in the proximal bicipital groove [8, 9], further limiting preference to the distal supra-pectoral region.

**Significance:** These data provide evidence that the supra-pectoral LBT may provide the highest quality tendon for tenodesis fixation when considering the relative strength of the tissue and accessibility in the clinical setting. Sub-pectoral tenodesis requires take-down and repair of the pectoralis major tendon. Prior studies show that revision rates are lower when the supra-pectoral zone is used, but care must be taken to preference the location towards the distal end of the supra-pectoral zone to mitigate bicipital groove pain and patient discomfort [2, 3]. Future studies should examine the extent to which tendon pathology alters the LBT material and structural properties, which may differ from the findings from the present study of non-pathologic LBT.

**Table 1:** Material properties for the three anatomic functional zones.

![Graphs](image-url)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-articular</td>
<td>5.4 ± 1.5†</td>
<td>2.5 ± 1.9</td>
<td>4.2 ± 1.5</td>
<td>132.9 ± 100.6</td>
<td>15.3 ± 3.2</td>
<td></td>
<td>22.3 ± 9.3</td>
<td>12.5 ± 5.1</td>
<td>293.5 ± 185.9</td>
</tr>
<tr>
<td>Supra-pectoral</td>
<td>4.9 ± 0.4^</td>
<td>6.0 ± 5.6*</td>
<td>4.1 ± 1.2</td>
<td>321.5 ± 309.1*</td>
<td>17.6 ± 4.3</td>
<td></td>
<td>31.7 ± 15.4</td>
<td>11.6 ± 6.6</td>
<td>387.2 ± 297.4</td>
</tr>
<tr>
<td>Sub-pectoral</td>
<td>4.4 ± 0.6</td>
<td>6.2 ± 4.8**</td>
<td>3.9 ± 1.4</td>
<td>275.3 ± 175.4</td>
<td>17.3 ± 4.4</td>
<td></td>
<td>25.5 ± 10.5</td>
<td>11.6 ± 6.3</td>
<td>372.8 ± 250.5</td>
</tr>
</tbody>
</table>

†Significantly greater than both other regions (p≤0.05)
‡Marginally significant versus both other regions (p≤0.05)
^Significantly greater than intra-articular specimens (p=0.058)
**Marginally significant versus intra-articular specimens (p≤0.05)