Effects of Biceps Tension on the Torn Superior Glenoid Labrum

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ABSTRACT: The purpose of this study was to evaluate the role of the tension on the long head of the biceps tendon in the propagation of SLAP tears by studying the mechanical behavior of the torn superior glenoid labrum. A previously validated finite element model was extended to include a glenoid labrum with type II SLAP tears of three different sizes. The strain distribution within the torn labral tissue with loading applied to the biceps tendon was investigated and compared to the inact and unloaded conditions. The anterior and posterior edges of each SLAP tear experienced the highest strain in the labrum. Labral strain increased with increasing biceps tension. This effect was stronger in the labrum when the size of the tear exceeded the width of the biceps anchor on the superior labrum. Thus, this study indicates that biceps tension influences the propagation of a SLAP tear more than it does the initiation of a tear. Additionally, it also suggests that the tear size greater than the biceps anchor site as a criterion in determining optimal treatment of a type II SLAP tear. © 2015 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res 33:1545–1551, 2015.

Keywords: FE; labrum; SLAP; biceps; propagation

A tear of the superior labrum anterior posterior (SLAP tear) is a traumatic lesion in the superior glenoid labrum, which may include the attachment of the long head of the biceps tendon. This tear can contribute to significant pain and disability in the shoulder.[1] SLAP tears are classified according to four or more subtypes.[1,2] Among them, the type II tear involving detachment of both the superior labrum and the biceps tendon from the glenoid has been reported as the most common lesion.[1,2]

Both the motion of the humeral head and the traction on the biceps tendon have historically been implicated as predominant factors contributing to SLAP tears in numerous biomechanical studies of the tear mechanism. When SLAP tears were first described, it was hypothesized that they resulted from the traction imposed on the biceps tendon during repeated throwing movements.[3] Later, several causal mechanisms were suggested for the SLAP tear, including the combination of humeral head compression and biceps tension[4] and the pulled and twisted biceps tendon.[5]

However, there is still a knowledge gap concerning how biceps tension relates to SLAP tear pathology and thus the optimal treatment of the SLAP tear. By testing labral strain at a specific phase during certain motions, specific activities at high risk for initiating a SLAP tear have been identified.[6–9] However, those studies neither observed the strain inside the labral tissue nor investigated the behavior of the labrum with an existing SLAP tear. Moreover, Costa et al.[10] reported that simple traction of the biceps tendon did not play a role in the initiation of the SLAP tear. The lack of clear understanding concerning the role of biceps tension in both the initiation and propagation of a SLAP tear leads to debates among surgeons on the proper treatment for the biceps tendon, which may include arthroscopic repair, debridement, tenodesis, tenotomy, or solely observation.[11,12]

The purpose of this study was to evaluate the role of tension on the long head of the biceps tendon on the propagation of SLAP tears by studying the mechanical behavior of the torn superior glenoid labrum. We hypothesized that: (1) the regions of high strain in the torn labrum occur at the edge of the given tear; (2) increasing load on the long head of the biceps tendon causes increased strain in the torn labrum regardless of the tear size; and (3) the effect of biceps tension on the increasing strain in the torn labrum is greater than that in the intact labrum. These hypotheses were tested by extending a validated finite element model[13] to investigate the strain distribution within the labral tissue. The extended model includes a glenoid labrum with SLAP tears of different sizes.

METHODS

Development of an Intact Model

Detailed information about the development, verification, and validation of an intact finite element model was provided in a previous study.[13] The scapula, humerus, labrum, long head of the biceps tendon, and articular cartilages from a fresh frozen cadaveric shoulder (male, 84 years old) were scanned to develop a three-dimensional finite element model of the glenohumeral joint having an intact glenoid labrum. Scanned micro CT images by GE eXplore Locus (GE Healthcare–Pre-Clinical Imaging, London, Canada) were segmented and smoothed into each tissue component using commercial software (Amira 5.3, Visage Imaging, Inc., San Diego, CA). Based on surface information for each tissue, the finite element mesh was generated by a preprocessing tool (Hypermesh 10, Altair Engineering, Inc., Troy, MI). Mesh density and material properties were defined according to previously validated settings.[13] Shell elements were used for the bony components and hexahedral elements for the soft tissues. At the

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lateral end of the biceps anchor-labrum complex, hexahedral elements were added to extend the tendon over the humeral head and through the bicipital groove (Fig. 1). Bones were assumed to be rigid materials[13] and cartilages were modeled as isotropic elastic material (0.66 and 1.7 MPa for the humerus and glenoid, respectively).[13,14] The glenoid labrum was sectioned into superior, anterior, inferior, and posterior labrum having four different elastic moduli (21.3, 15.4, 19.3, and 20.9 MPa, respectively),[13,15] and different local coordinate systems following the local fiber orientation. The labrum was assumed to be a transversely isotropic, hyperelastic material.[13] The behavior of the biceps tendon was expressed by an isotropic, hyperelastic material with an elastic modulus of 629 MPa.[16] All sliding interfaces were modeled using frictionless, surface-to-surface contacts due to the low coefficient of friction in synovial joints.[13] The displacements predicted by the finite element model were compared with the observed experimental displacements.[13]

Type II SLAP Tear Models

Small, medium, and large type II tears, the most common type of SLAP tears, were introduced into the intact model at the interface with the glenoid rim along an arc (Fig. 2). The small tear was introduced between -10° to $+10^\circ$ with respect to the inferior–superior vector.[17] The medium tear ran from -30° to $+30^\circ$,[18] and the large tear ran between -60° to $+30^\circ$.[18] Tears were simulated by separating the desired portion of the superior labrum and the corresponding portion of the glenoid bone and cartilage. The shared nodes among the superior labrum and the glenoid rim in the intact model were duplicated to permit sliding surface-to-surface contact at the plane of separation. The other portions of the model, including mesh density, boundary conditions, material properties, and contact definitions, were not changed from the intact finite element model.

Loading Conditions

The humerus was positioned in 30° of glenohumeral abduction in the scapular plane with neutral humeral rotation.[19] The humerus and the glenoid had their own local coordinate systems. The center of the humeral head was assigned as the origin of the humerus coordinate system. Similarly, the origin of the glenoid coordinate system was placed at the midpoints of the long and short axes of the glenoid. The local coordinate system for the humerus was defined as the following: Z-axis was inferiorly parallel to the humeral shaft, Y-axis was laterally perpendicular to the Z-axis, and X-axis was the cross-product of the other two axes directed anteriorly. The local coordinate system for the glenoid was also defined: Y-axis was superiorly parallel to the posterior and anterior glenoid axis, X-axis was anteriorly perpendicular to the Y-axis, and Z-axis was the lateral common line perpendicular to the Z- and Y-axes. Fifty newtons of compressive force[13,20] was applied in the medial direction by force-control to seat the humerus in the glenoid cavity. At the same time, the desired tension was applied to the lateral end of the biceps tendon and directed along the force vector of the biceps muscle. The tensile vector was parallel to the line between the midpoint of the greater and lesser tubercles of the humerus and the midpoint of the crest of the greater and lesser tubercles of the humerus. Four tensile forces to the long head of the biceps tendon were modeled—0 N, 22 N, 55 N, and 88 N.[19] A tension of 22 N was chosen because it was shown to affect the range of motion and kinematics of the glenohumeral joint.[21] A tension of 55 N was chosen to represent the force of maximum isometric contraction calculated from the physiologic cross-sectional area of the long head of the biceps muscle.[22] A tensile loading of 88 N[6] was chosen to simulate the maximum force during stretch of an activated muscle, or a lengthening contraction.[23]

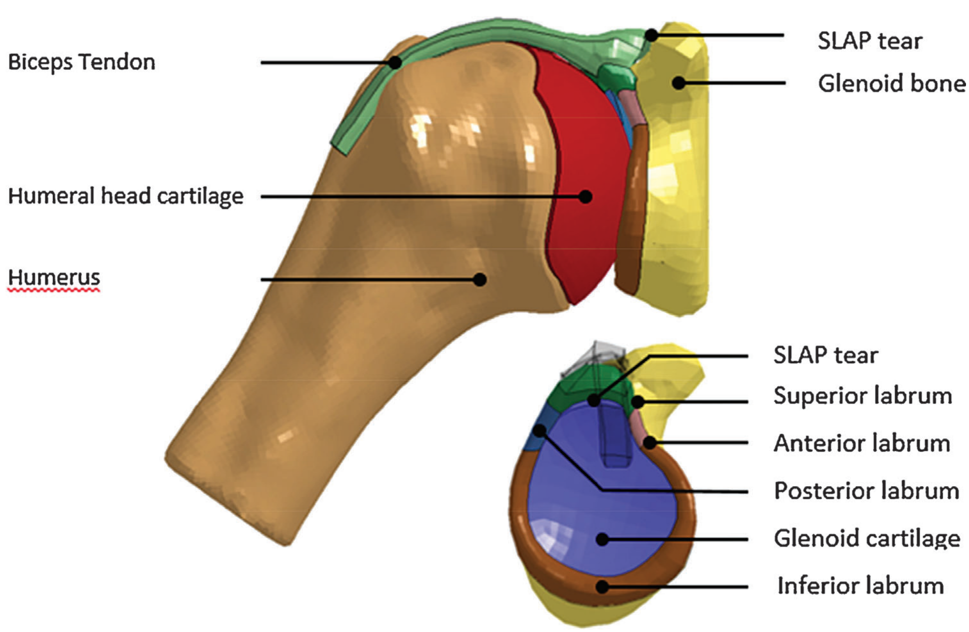

Figure 1. A validated finite element model of the glenohumeral joint with a SLAP tear introduced at the interface between the glenoid and the superior labrum. The humerus is shown in the coronal view and is hidden in the lateral view. The biceps tendon is transparent in the lateral view to show an example of a SLAP tear.

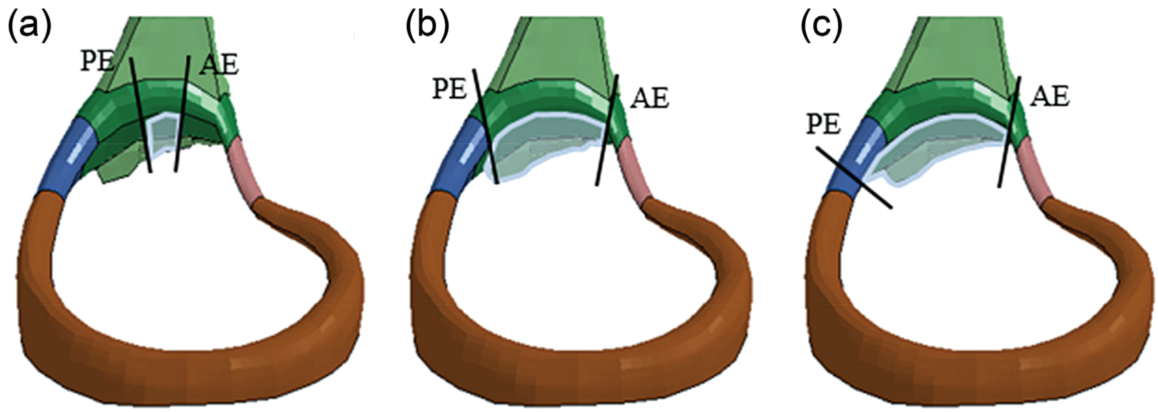

Figure 2. The labral component in the models of the glenohumeral joint, showing (a) small, (b) medium, and (c) large SLAP tear models. The light green represents biceps tendon and the light transparent blue indicates a given SLAP tear. In this and following figure, the labrum is shown in a lateral view from a slightly inferior perspective. PE, posterior edge; AE, anterior edge of the SLAP tear.

Data Analysis

Analyses were performed using the FE solver, LS-DYNA/ Explicit version (Livermore Software Technology Corporation, Livermore, CA). The distributions of both the effective von Mises strain and maximum-principal strain were observed. The von Mises strain is indicative of the energy required to distort a material[11] and the maximum-principal strain has a direct positive relationship with tear size.[24] All nodal strains in the contact surface were averaged within the specific interaction region. The posterior edge of the SLAP tear was selected for observation, because the SLAP tear has been known to extend in a posterior direction. For comparison, the strain map for the intact labrum at each location was also studied. The effect of biceps tension on the labral strain in each SLAP tear model was assessed.

RESULTS

Predicted Strain Distribution in the Torn Labrum

The highest strain in the torn labrum was observed at the edge of the given SLAP tear regardless of the size of the tear (Fig. 3). The location experiencing the highest strain was matched with the edge of the given tear in Figure 2. With a larger SLAP tear, the superior labrum also had a larger peak strain value. The peak strains with 22 N of biceps force were 0.049, 0.057, 0.078, and 0.108 for no tear and small, medium, and large tears, respectively. The strain distributions in other biceps loading conditions were similar to the strain contour shown in Figure 3.

Effect of Biceps Tension on the Labral Strain

The highest labral strains were predicted for the highest biceps tensions in all conditions (Fig. 4). Under 0 N of biceps tensile load, the difference between the strains in the intact labrum and the strains in all torn labra was less than 1% (Fig. 4). The effect of the biceps tension on the maximum-principal strain of the labrum with a medium or large SLAP tear is greater than the effect of biceps tension on the strain of the labrum with a small tear (Fig. 5).

Effect of Tear Size on the Labral Strain

The behavior of labral tissue with a medium or large SLAP tear differed from that of the small tear condition (Figs. 5 and 6). The predicted von Mises strain distribution at the cross section of the small SLAP tear model was similar to the intact model (Fig. 6). The region of high strain with small tears expanded from the attached surface to the free surface (from inferolateral

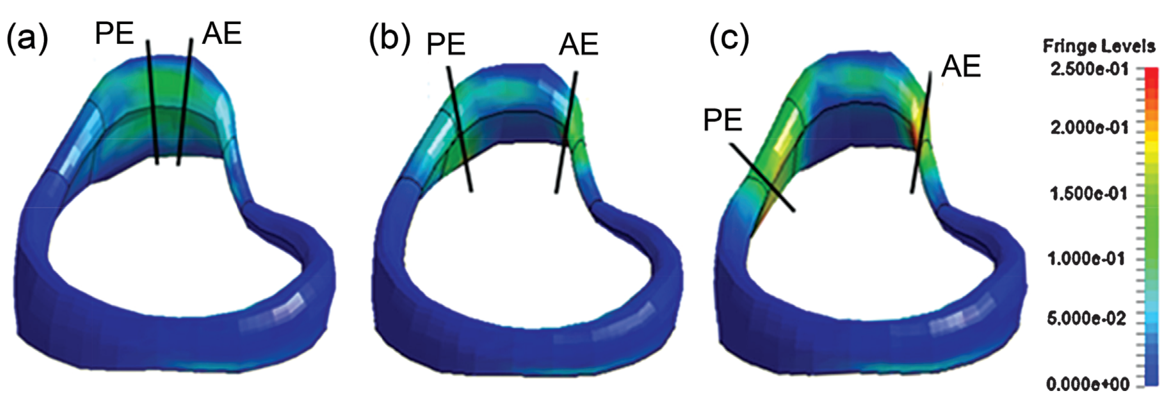

Figure 3. The predicted maximum-principal strain distribution in the labrum with (a) small, (b) medium, and (c) large SLAP tear finite element models under 22 N of biceps tension.

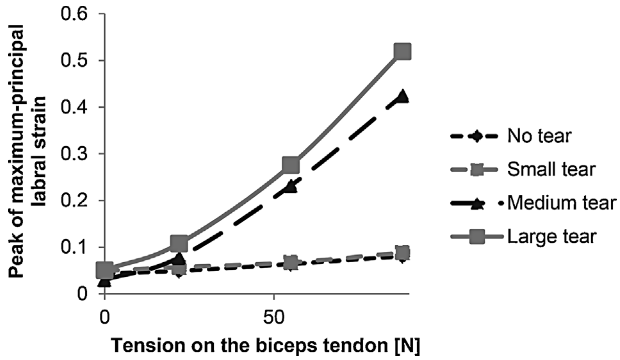

Figure 4. The effect of the biceps tension on the peak of the maximum-principal strain measured at the posterior edge (PE) for the torn labrum.

to superomedial tissues) and widely distributed. However, the strain pattern in the labrum with a medium or large tear was different from the intact model (Fig. 6). The area of high strain in the labrum with a medium or large tear was located at the interface with the glenoid rim. With biceps tension increasing from 0 N to 88 N, strain increased 6%, 7.5%, 26.7%, and 29.2% for no tear and small, medium, and large tear conditions, respectively. The sensitivity of the maximum strain with small tears to the biceps tension was smaller than that with medium or large tears (Fig. 5).

DISCUSSION

The purpose of this study was to understand the impact of biceps tension on the propagation of SLAP tears by observing the mechanical behavior of the torn superior glenoid labrum with biceps loading. The area of high strain in the torn labrum was found at the edge of each tear (Fig. 3). The strain on the labrum increased with increased biceps tension regardless of tear size, but these associations were stronger in the labrum with a medium or large SLAP tear (Figs. 4–6). Therefore, this work demonstrates that a SLAP tear is likely to propagate as a result of increased tension on the long head of the biceps tendon. However, there is a threshold effect where tears smaller than a specific size act similar to the intact labrum state, whereas tears larger than that size have a dramatic increase in strain, suggesting a risk for propagation. In this study, the exact size of the threshold tear was not investigated.

The current study suggests that tension on the long head of the biceps tendon is a risk factor associated with the propagation of a SLAP tear as well as the tear's initiation. Based on mechanical testing,[23] traction on the biceps tendon could reproducibly create type II SLAP lesions. Previous researches[13,19] also demonstrate that biceps tension increases the risk of SLAP tear initiation. Biceps tension increases strain in the intact labrum[19] and shifts the location of the peak displacement from an anterior attachment to a posterior attachment of the biceps tendon on the superior labrum.[13] Similarly, the current study found that increasing tensile force of the biceps tendon resulted in increased strain in the torn labrum (Figs. 4 and 5) and an enlarged peak of the maximum-principal strain at the edge of the tear (Fig. 3). Since the local high strain adjacent to a tear has been accepted as an indicator of risk of tear propagation,[24] results suggest that increasing biceps tension increases the risk of tear progression.

The impact of biceps tension on the risk of tear propagation is much more pronounced in the larger tear group (medium and large tears), even though the positive relationship is observed in all torn labrum

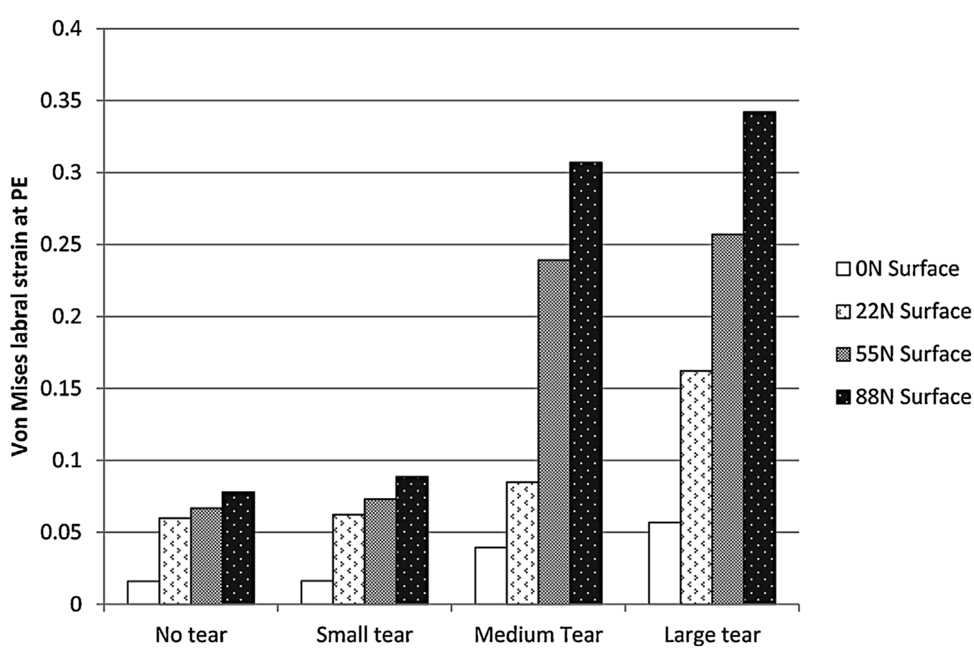

Figure 5. The averaged von Mises strain in the intact labrum and the strain in each tear model as a function of biceps tension at the cross section of the posterior edge for the torn labrum.

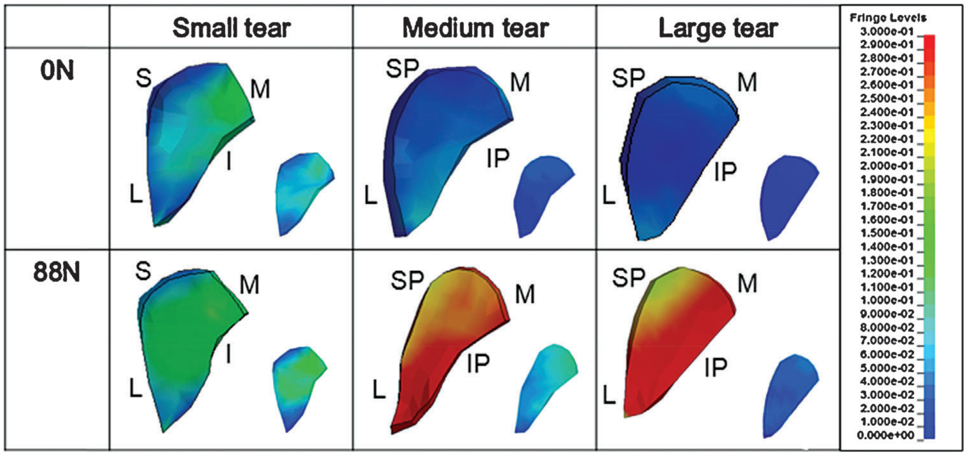

Figure 6. The predicted von Mises strain distribution at the cross section of the posterior edge for the torn labrum under 0 N and 88 N of biceps tension. Each labrum tissue is distorted as a result of loading conditions. The subset image is the strain at each relative location for the intact labrum. Blue corresponds to low strain and red corresponds to high strain. S, M, I, L, SP, IP stand for superior, medial, inferior, lateral, superoposterior, inferoposterior, respectively.

models (Figs. 4 and 5). In the larger tear group, the increasing strain distinctly responded to the increasing biceps tension (Fig. 5). High strain is also concentrated where the labral tissue surface interacts with the glenoid rim (Fig. 6), instead of being more uniformly distributed throughout the labrum. This interface-focusing strain pattern means that biceps tension is not successfully dissipated in the larger tear models. The reason may be found in the distance between the posterior edge of the SLAP tear and the biceps anchor. Farther from the biceps anchor, the volume of labral tissue around the posterior edge of the SLAP tear is smaller. Thus, under the same loading conditions, the labral tissue around the edge could experience higher strain. In addition, the primary vector of biceps tension within the labrum in the larger tear group is practically parallel to the circumferential direction, so tension cannot be efficiently transferred and dissipated to the labral tissues in the radial direction. Thus, with medium or large tears, a large amount of biceps tension remains within the labrum, increasing the labral strain. Moreover, the highest maximum principal strain value predicted by the model was up to 50% in the Figure 4. The reported mean strain at failure for the human shoulder labrum was approximately 40%,[15] and for the human hip labrum was approximately 50%.[25] With considering the higher maximum principal strains than the von Mises strain, this strain could be observed in the glenoid labrum before failure.

Interestingly, the effect of biceps tension on the torn labrum with a small detachment area was more similar to the intact labrum than to the labrum in the larger tear group. The area of high strain in the small tear model was predicted to be at the edge of the specific tear (Fig. 3), and the magnitude of the maximum-principal strain at that area was slightly increased with increasing biceps tension (Fig. 4) similar to the medium and larger tears. However, the magnitude of strain (Figs. 4 and 5) and the strain pattern (Fig. 6) in the labrum with a small tear are remarkably different from those in the larger labral tears. For example, the area of high strain was found along the circumferential direction in Figure 3 and expanded in the radial direction in Figure 6. In a previous study,[19] biceps tension was also dissipated in the radial and circumferential directions through an intact labrum. The mechanism for transferring biceps tension may be similar because more labral tissue in the small tear model is attached to the glenoid rim, and the radial and circumferential pathways for load transfer remain mostly intact. The small differences in the pattern and the magnitude of strain from the intact labrum (Figs. 5 and 6) provide evidence of the successful dissipation of tensile force through the entire labrum in the small tear model.

Therefore, this study suggests tear size as a criterion for determining optimal treatment of the biceps tendon following a SLAP tear. To date, age and physical activity have been the general criteria for determining the optimal treatment.[11,12] However, this study shows that when other factors are equal, tear size determines the sensitivity of labral strain to the biceps tension (Figs. 4–6). Thus, knowledge of tear size can be important to determine whether the biceps tendon should be tenotomized. When labrum detachment involves only a small area, suturing the superior labrum to the glenoid rim may reduce the risk of tear progression. In contrast, biceps tendon tenotomy or tenodesis could be the optimal treatment for the larger SLAP tears described in this study. Thus, SLAP tear sizes for which release of the biceps tendon can be recommended remain a topic for future study. However, the results of this study correspond well with clinical findings. According to Boileau and colleagues,[11] tenotomy of the biceps tendon can be considered an effective alternative to the repair of the type II SLAP tear. Moreover, the long head of the biceps tendon is known as a pain generator in the setting of a SLAP tear, and release of the biceps tendon has been recommended by many clinical reports on the basis of favorable patient satisfaction and recovery of shoulder kinematics.[11,26]

The current study was based on the predicted strain using a subject-specific finite element model, which has limitations. The geometry was acquired from a single cadaveric shoulder. The applicability of this analysis is affected by how representative this specimen is to the general population, so anatomic variation must be considered. The glenoid labrum especially has wide anatomic variations,[27] so the dimensions of the specimen used in this study were compared with those reported in the literature.[13] The anterosuperior labrum is smaller in volume than both the posterosuperior labrum of the same specimen and the anterosuperior labrums reported in the literature.[13,15] Thus, the forces passing through the anterosuperior labral tissue likely resulted in overestimated strains. However, we investigated strain pattern with a focus on the posterosuperior labrum, so that strain analyses in the region of interest are not likely to be affected by this anatomic difference. Moreover, a finite element model requires material properties for each component. However, on the basis of a sensitivity analysis, the variation in material properties has minimal effect on the stain patterns and only a small effect on the strain magnitudes.[13] Finally, this study was performed for one arm position on a subject-specific model. Thus, results might differ for other arm positions or in other shoulders, especially shoulders having different insertion sites of the biceps tendon. With a change in the biceps tendon attachment on the superior labrum, the primary loading vector of the biceps tendon would differ and the area of high strain may shift depending on the anchor location of the biceps tendon. In addition, arm posture alters the primary vector and amount of biceps tension, morphology of the biceps tendon, and compression of the glenohumeral joint. Thus, the strain pattern is likely to be sensitive to arm posture. Changing arm position in the current model was relatively easy, so another arm posture, 120° of glenohumeral abduction, was tested. However, even after increasing the angle of arm abduction, the greatest strain at the edge of each tear was similar to the distribution of strain shown in Figure 3, and the magnitude of strain in medium and large tear conditions decreased by 10–17%. With 120° abduction, 22 N of biceps tension increased strain by 6.8% in a medium tear and 13% in a large tear. Since this study focused on the impact of biceps tension on the propagation of a SLAP tear, the role of arm position on the behavior of intact and torn labrums is beyond its scope. However, it is worth noting that the behavior of torn labrum tissue needs to be investigated in multiple arm positions.

In summary, the tension on the long head of the biceps tendon may create a risk for propagation of a superior labral (SLAP) tear, especially when the size of the tear exceeds the width of the biceps anchor on the glenoid. The edges of a given tear on the labrum are suggested as the regions into which the tear is most likely to propagate. This study suggests the possibility that optimal treatment (tenotomy or tenodesis) may depend on tear size. Additional in vitro and in vivo research is needed to confirm this conjecture before widespread adoption of such a clinical recommendation.

AUTHORS' CONTRIBUTIONS

EH collected, analyzed, and interpreted data and performed writing. REH offered critical revision, writing and supervision. MLP analyzed and interpreted data and offered critical revision and administrative support and JEC conceived of the study.

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