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The Biceps Pulley: Relevant Anatomy, Mechanical Properties, Associated Injuries and Management

The shoulder contains a complex pulley system with intricate anatomy that has been reported to contribute to complaints of anterior shoulder pain.[1] Injuries to this area are often overlooked, hard to assess, or inaccurately diagnosed, which can lead to persistent complaint of shoulder pain, even after surgical intervention.[2] Recently, there has been more focus and targeted research on understanding the biceps pulley and its role in shoulder pain and injury. Understanding the anatomy of the biceps pulley, structures involved, and appropriate management of associated injuries should allow for improved recovery and patient outcomes.

Anatomy

In general, the long head of the biceps tendon (LHBT) originates on the supraglenoid tubercle and glenoid labrum within the capsule.[2] It has been found to have an average length of 99-138 mm from its origin to musculotendinous junction[3] and play a role in stabilizing the humeral head in the glenoid.[4] When understanding the biceps labral complex, it is helpful to visualize three main zones: the inside, junction, and biceps tunnel.[3] Anatomical components of the inside zone include the superior labrum and biceps anchor.[3] The intra-articular portion of the LHBT and stabilizing pulley are found in the junction zone, while the biceps tunnel includes the extra-articular LHBT beginning from the articular margin, subpectoral region, and the biceps tunnel.[3]

With regards to the inside zone, the superior labrum's posterosuperior portion has a collagen makeup similar to the LHBT while the anterosuperior portion has more elastin and semi-circular fiber orientation.[3] These qualities, especially where the glenohumeral ligament connects to the biceps tendon, allow for acceptance of greater tensile stress.[3] The labrum receives vascular supply from the suprascapular and anterior and posterior humeral circumflex arteries, however the blood supply to the superior and anterior labrum is relatively avascular, which impacts healing potential.[3] Also in the inside zone is the LHBT anchor, which is interwoven with the superior glenoid labrum and also attaches to the supraglenoid tubercle at the 12 o'clock position.[3]

The junction zone contains the intra-articular LHBT and the biceps pulley.[3] In this area, the LHBT is intra-articular, but extra-synovial and is covered by a reflection of the synovial membrane.[5] In this location, the tendon has a flatter and larger cross section when compared to the tendon coursing through the bicipital groove.[5] Proximally, the LHBT received vascular supply from the superior labrum tributaries, and distally, from the ascending anterior humeral circumflex artery.[5] When the tendon crosses the articular surface of the humeral head (12-30 mm from the origin on the supraglenoid tubercle), the blood supply is poor, which negatively impacts healing, placing the tendon at risk for rupture.[3,6] The intra-articular LHBT also has been reported to have increased nociceptive and sympathetic innervation, which has been proposed as a contributor to complaints of anterior shoulder pain.[3] (Appendix – Figure 1).

Of particular interest of this paper is the biceps pulley. The biceps pulley is a soft tissue sling that provides stabilization to the tendon in the proximal portion of the bicipital groove along the course from the articular margin to the tendon's extra-articular position.[3] (Appendix – Figure 2). This sling allows the LHB to slide while still maintaining within the groove.[4] Arthroscopically, an anteromedial and posterolateral reflection pulley have been found.[1] The pulley is formed by contributions from the superior glenohumeral ligament (SGHL), the coracohumeral ligament (CHL), the subscapularis, and supraspinatus.[2,3] The supraspinatus and subscapularis surround and reinforce the LHBT as it approaches the entrance to the bicipital groove.[5] The floor of the biceps pulley is formed by SGHL fibers, joint capsule, and the bicipital groove as it approaches the distal capsule.[2] The biceps pulley is located within the rotator interval, which is formed by the anterior edge of the supraspinatus tendon and the superior edge of the subscapularis tendons, with the coracoid process being the medial border.[2,5] The CHL courses through the rotator interval and has two distal bands, the lateral band which blends with the supraspinatus tendon as they attach on the greater tuberosity, and a medial band which crosses over the biceps tendon and blends with the subscapularis tendon as they insert onto the lesser tuberosity.[2] As it courses through the rotator interval, the LBBT is tightly surrounded by the CHL superiorly and the SGHL anteriorly.[2] (Appendix – Figure 3). The SGHL's function is to stabilize the LHBT along its intraarticular course and a predominate radial orientation of the fibers support this function as they appear to be able to withstand anterior shearing forces proximal to the bicipital groove.[7,8]

The biceps tunnel zone includes the extra-articular LHBT beginning from the articular margin, subpectoral region, and the biceps tunnel. The extra-articular biceps tendon has a different appearance compared to the intra-articular portion and is smaller and more circular.[5] The biceps tunnel is further subdivided into three zones.[3] Zone 1 is from the bony groove from the articular margin (pulley) to the distal margin of the subscapularis.[3] Zone 2 is considered "no man's land" as the tendon can't be visualized on arthroscopy and spans from the distal margin of the subscapuarlis to the proximal margin of the pectoralis major tendon.[3] Zone 3 runs from the subpectoralis region to the pectoralis major tendon.[3] (Appendix – Figure 4). The bicipital groove's medial wall is higher that the latera wall.[4] This larger medial wall is helpful to maintain the biceps tendon since the bicipital groove lies at a 30 degree angle in relation to the humeral head, causing the biceps tendon to lie more medially in the groove. This orientation however, has also been proposed to possibly predispose the tendon to degeneration due to wear.[5]

Mechanical and Biomechanical Properties

The LHBT's mechanical properties have been investigated. A study by McGough et al. found that the elastic modulus (at 3-6% strain) of the LHBT to be 421 MPa, the ultimate tensile strength to be 32.5 MPa, the ultimate strain at failure to be 10.1% and strain energy density to be 1.9 MPa.[9] Tendon has a high collagen content, which has been reported to strain ~10% prior to failure,[10] which the LHBT demonstrates. The high collagen content and high stiffness of the LHBT allows it to transmit force of the muscle.[9,10] For comparison to other areas in the body, the ultimate tensile strength is less than the patellar tendon (53.6 MPa), but almost twice that of the supraspinatus tendon (16.5 MPa).[9] The different subdivisions of the LBGT have also been investigated. (Appendix – Figure 5). A study by Kolz et al. found that the suprapectoral region had the greatest tensile strength, followed by the intra-articular region, then the subpectoral.[11] The suprapectoral and subpectoral regions had a greater elastic modulus value compared to the intra-articular region, and the suprapectoral region demonstrating the greatest failure at stress when normalized for cross-sectional area.[11] There were no significant differences among stiffness in all three regions.[11] Another interesting study by Kurdziel et al. investigated the differences of the LHBT in rotator cuff (RC) deficient and rotator cuff intact shoulders.[12] There was decreased collagen orientation of the LHBT and increased proteoglycan production in the RC deficient sample, indicating tissue degeneration.[12] Interestingly, in both samples, the LHBT demonstrated histological findings of tendinopathy, indicating that other injuries or processes (i.e. arthritis), may impact the makeup of the tendon, not the RC alone.[12] There was also a trend for the LGBT to have a larger cross sectional area in RC deficient samples, indicating possible tissue adaptation to change in functional and load demands in the absence of the RC.[12]

Tendon pulleys are unique in that several forces are being exerted on the tissue, including tensile stress, compressive stress from the resultant of tensile stress being applied at both ends of the tendon, and frictional abrasion due to the tendon sliding, which is influenced by the magnitude of the muscle tendon force.[13] With regards to the biceps tendon specifically, the stress placed on the tendon appears to be influenced by arm position.[14] (See Appendix – Figure 6). Forward flexion with internal rotation and neutral rotation demonstrated the greatest shear resultant force vector.[14] Increased shear force is suspected to contribute to traumatic and degenerative injuries to the biceps pulley as the LHBT courses into the bicipital groove.[14] At the level of the pulley, the biceps has an excursion of 10-13mm.[3] This excursion paired with the increased shear force in this position is thought to largely contribute to degeneration and wearing down of the LHBT against the pulley via a “sawing mechanism”.[3,14] Frictional damage between the pulley, subscapularis and anterior superior glenoid rim has also been reported with repetitive and forceful internal rotation of the shoulder above the horizontal plane and is thought to contribute to anterosuperior impingement (ASI).[15] Aside from shear stress and frictional abrasion, a normal/compressive force vector also acts to stabilize the long head of the biceps tendon at the entrance to the bicipital groove.[14] (See Appendix – Figure 7). This normal force is greatest when the shoulder is abducted with neutral or 45* internal rotation.[14] There is also a tensile force, or “groove” force as described by Braun et al., that is occurring in the biceps muscle due to the distal attachment of the biceps tendon.[14] It is important to note that biomechanical studies of the LHBT have been performed using cadaver specimens, making it difficult to impose physiologic loads to the area and recreate all the forces acting on the glenohumeral joint.[16] The different forces working on the LHBT in various arm positions paired with varying mechanical properties and the complex anatomical involvement play a large role in the development of shoulder pathologies.

Pulley Lesions and Associated Injuries

Lesions of the biceps pulley can be due to trauma, degenerative changes, repetitive microtrauma, or associated RC tears.[2] Pulley lesions have been classified in a couple different manners. In the Habermeyer classification (Appendix – Figure 8), a group 1 lesion represents an isolated lesions of the SGHL, a group 2 lesion also has a partial articular-side supraspinatus tendon tear where the biceps tendon is dislocated anteriorly, a group 3 lesion is a SGHL tear with a partial tear of articular-side subscapularis tendon and biceps dislocation into the subscapularis tear, and a group 4 is when the biceps tendon is dislocated outside the biceps pulley due to a SGHL tear and tears of both the supraspinatus and subscapularis.[2,7,17] There is also a Bennett's classification not detailed in this paper.[17] Another classification is based off of morphological changes of the biceps pulley assessed during arthroscopy in the presence of a RC tear.[18] A type I is normal stretch with no pulley irritation; type II is when there is fraying, synovitis, or hypertrophy detected, but the overall structural integrity of the medial pulley is intact; type III is when pathological changes (partial tears) and pulley instability is detected; type IV is when the whole pulley is disrupted and subscapularis and biceps tendon lesions are present.[18]

Out of 207 patients undergoing shoulder arthroscopy for a non-pulley related injury, 32% had pulley lesions, with 48 patients having an anteromedial injury, 32 having a posterolateral injury, and 13 having a combined lesion.[1] Pulley lesions are thought to result in LHBT instability or pathology.[1,5] Braun et al. found the presence of a pulley lesion to be significantly associated with a subluxed or dislocated LHB,[1] while Hsu et al. reports 90% of patients diagnosed with a pulley lesion also had LHBT pathology.[5] With a pulley tear, the LHB becomes unstable in the intraarticular space, which further leads to a medial subluxation of the LHB, which contributes to anterior translation of the humeral head.[2,7] This resulting translation of the humeral head places the shoulder at risk for ASI, which was confirmed by an arthroscopic study identifying 44% of patients with pulley tears also had ASI.[7] ASI has been reported to be seen more in patients with a group 3 or 4 Habermeyer lesion classification.[2] Habermeyer et al. reported the greater the number of lesions of the pulley, LHB, and RC, the higher the frequency of ASI.[7] Instability of the LHBT can also lead to increase friction and further damage to the tendon because the tendon is allowed to "windshield wiper" over the tuberosities with internal and external rotation of the arm.[4]

SLAP lesions can also occur in the presence of biceps pulley injuries. Braun et al. found a significant association ($p=0.003$) between SLAP tears and pulley tears in individuals assessed via shoulder arthroscopy.[1] The superior migration of the humeral head due to lack of pulley stability places strain on the superior labrum,[3] which is thought to contribute to SLAP tears. Nakata reports "the presence of a SLAP lesion suggests injuries to the rotator interval and long head of biceps tendon".[2 pg 807] Due to the anatomy and attachment of the LHBT on the labrum, a force that causes a SLAP lesion could also cause a pulley lesion[2] and vice versa, therefore both injuries should be ruled out. Taylor et al. reported, however, that a FOOSH mechanism of injury was predictive of a SLAP tear, while a FOOSH mechanism of injury with the arm in IR was predictive of a pulley lesion.[3]

Based on anatomy and pulley lesion classification, it is no surprise that pulley lesions and rotator cuff tears are closely related. In 107 subjects undergoing shoulder arthroscopy with either a partial or full thickness RC tear, 67 had pulley tears, 45 had supraspinatus lesions, 15 had infraspinatus lesions, and 30 having partial or complete subscapularis lesions.[1] Furthermore, it is well documented that biceps instability occurs with RC tears.[2] In 200 RC tears, 45% had biceps instability, with anterior instability being associated with subscapularis tears and posterior instability being associated with supraspinatus tears.[5] Articular-side partial tearing of the supraspinatus contributes to lesions of the SGHL, whose function is to stabilize the LHBT.[1] This leads to instability of the LHBT, which in turn contributes to tearing of the articular-side subscapularis.[1] Choi et al. reports that if a pulley lesion is present, this may be an indirect sign for an associated subscapularis lesion as well.[18] This author also believes that since the subscapularis tendon is less elastic than the pulley, it sustains more damage.[18]

Injuries can also occur to the rotator interval. Since the biceps pulley lies in/courses through the rotator interval, one author believes there is no difference between "reported rotator interval lesions and biceps pulley lesions".[2 pg 799] Due to complex anatomical contributions to the biceps pulley and rotator interval, any injury to one of the structures warrants evaluation of the entire complex.[2]

Degenerative changes and repetitive microtrauma can also contribute to pulley injuries. This is commonly seen in repetitive overhead occupations or athletes.[2] In athletes specifically, there is a large acceleration and deceleration force demand on the shoulder, which can lead to transverse humeral ligament or subscapularis tears, which disrupt the bicipital groove.[2] With increased laxity of the biceps in the groove, further degeneration of the rotator interval and biceps pulley can occur.[2] Trauma or degenerative changes to the bicipital groove can also create a secondary tendinosis of the biceps tendon,[5] which can lead to breakdown of the tendon and possibly cause inflammation or rupture.[4] LHB ruptures are more commonly seen in individuals over the age of 50[4], often due to degenerative tendon changes and poor blood supply.[6] Biceps tendinitis can also occur due to an hourglass mechanical condition where the intra-articular portion of the LHBT becomes inflamed and thickened, causing entrapment of the tendon, most noticeable with forward shoulder elevation with elbow extension and shoulder abduction.[5,16] Junctional biceps chondromalacia, which is the wearing down/abrasion of the humeral head along the articular margin below the LHBT, has been reported in patients who had a failed SLAP repair or other pathologies, such as biceps synovitis, RC tears, or multi-directional instability.[3]

Clinical Detection, Diagnosis, and Management

Clinical detection of biceps pulley injuries is difficult due to the complex anatomical involvement and chance of coinciding shoulder pathologies. A thorough history regarding pain presentation, MOI, trauma, and inflammatory conditions is recommended.[5] A complete shoulder examination should also be performed. The subscapularis should be assessed via the belly-off or lift-off tests and impingement (Neer, Hawkins Kennedy), glenohumeral instability (O'Briens, Speed's), and biceps pathology (Speed's, Yergason's, bicep's load, bicep's instability) tests should also be assessed.[5] Detailed palpation of the biceps tendon, especially 3-6 cm below the anterior acromion with the arm in 10* internal rotation is recommended to determine tenderness.[5] Unfortunately, there is no special test to assess for biceps pulley lesions, however, Braun et al. recommends applying a biceps load in neutral or slight shoulder forward flexion with internal rotation as this position causes an increase shear force and can stress the biceps reflection pulley without being in an impingement position.[14] By further performing shoulder elevation with neutral internal rotation with the biceps load, the sawing mechanism of the biceps can be created, possibly allowing for useful distinction from RC or impingement pathologies, which can often mask pulley injuries.[14] The authors encourage psychometric study of a special test in this position to determine validity/reliability.[14]

Diagnosis of pulley lesions is equally difficult due to the complex anatomical contribution and the blending of some of the structures at distal attachment sites.[2] MR arthrogram has been reported to be highly sensitive and specific to detecting pulley lesions[3] when compared to MRIs. In MRIs, only the extra-articular biceps tendon, CHL in 60% of cases, and no SGHL where visualized in a patient sample,[2] compared to a direct MR arthrogram when the CHL, SGHL, entire biceps tendon (intra and extra-articular portions), rotator interval, and capsular structures were clearly visualized.[2] Specifically, a T-1 weighted MR arthrogram[17] should be performed with images gathered from all 3 planes, with the oblique coronal plane providing images of the RC and labrum, the oblique sagittal plane parallel to the plane of the glenoid fossa providing images of the rotator interval and contents, and axial plane showing the biceps pulley complex and biceps tendon within the bicipital groove.[2]

Diagnostic arthroscopy is another option, with maximal visualization offered in the "beach chair position" of 30* shoulder flexion, 40* shoulder abduction, and 90* elbow flexion.[3] A cadaver study determined that in this "beach chair position" 50% of the proximal biceps tendon could be pulled out of the groove by using a probe (called the pull test).[19] Arthroscopy is reported to be able to visualize SLAP lesions, RC tears, subscapularis tears, pulley injuries, and arthritic changes,[5] yet there can still be hidden lesions that go undetected. Unfortunately, almost half of the subjects who had a junctional lesion or labral tear also had hidden tunnel lesions that couldn't be visualized with arthroscopy.[3] It is believed that due to poor visualization of the tendon with arthroscopy, lesions are going undetected, contributing to poorer surgical outcomes with patients still experience pain or symptoms.

Another less invasive, though not a specific diagnostic option for pulley lesions, is the use of a corticosteroid with local anesthetic injection.[5] If a RC pathology is suspected, injection into the subacromial space is recommended whereas if a joint pathology or biceps tendon pathology is suspected, injection into the intra-articular joint is recommended.[5] The patient should have a decrease in pain and possible improvement in function if injected into the appropriate location for the suspected pathology. Knowing the intricate and complex nature of biceps pulley injuries and other shoulder pathologies, however, this technique may not offer much diagnostic information and only mask the patient's pain temporarily. Also, complications associated with the use of corticosteroid injections have been reported[20] therefore caution should be used with such injections due to the effect it has on collagen/tissue.

Conservative management for general biceps pathology includes rest, use of non-steroidal anti-inflammatories, activity modification, and possible immobilization.[4,5] Once pain subsides, physical therapy to improve internal rotation ROM and strengthening the rotator cuff, deltoid and scapulostabilizers is recommended.[5] General recommendations for pulley injuries include heating and stretching the tissue if decreased flexibility of the muscle is present and examining surrounding structures for soft tissue restrictions, which can cause increased stress on the injured tissue.[13] For biceps pulley lesions, activities that load the biceps in forward flexion with internal rotation or neutral rotation should be avoided due to the shear stress placed on the biceps pulley.[14] Unfortunately, biceps pulley lesions don't often respond to conservative treatment.[17] Proposed reasons included LHB instability that continues to cause damage, pain, and loss of function.[17] Surgery is often recommended and required when conservative treatment fails.[4,5,17] Pulley lesions have been treated with a repair as well as by tenodesis or tenotomy,[16] though surgical intervention and management are not the focus of this paper.

The biceps pulley is a complex structure with numerous anatomical contributions. Lesions of the biceps pulley can be due to trauma, degenerative changes, repetitive microtrauma, or associated RC tears[2] and are closely associated with other common shoulder pathologies. Biceps pulley lesions are hard to detect on clinical exam and with imaging. Because of this, they often are inaccurately diagnosed or overlooked, contributing to complaint of anterior shoulder pain, even after addressing other shoulder pathologies. Continued research on the biceps pulley, its' influence on shoulder biomechanics and other shoulder pathologies, and how to prevent pulley lesions, as well as clinically manage them, is warranted. Clinicians need to be aware of the intricate anatomical makeup of the biceps-labral complex, including the biceps pulley, and the stresses being applied to this area when working with patients with shoulder pain to maximize clinical outcomes.

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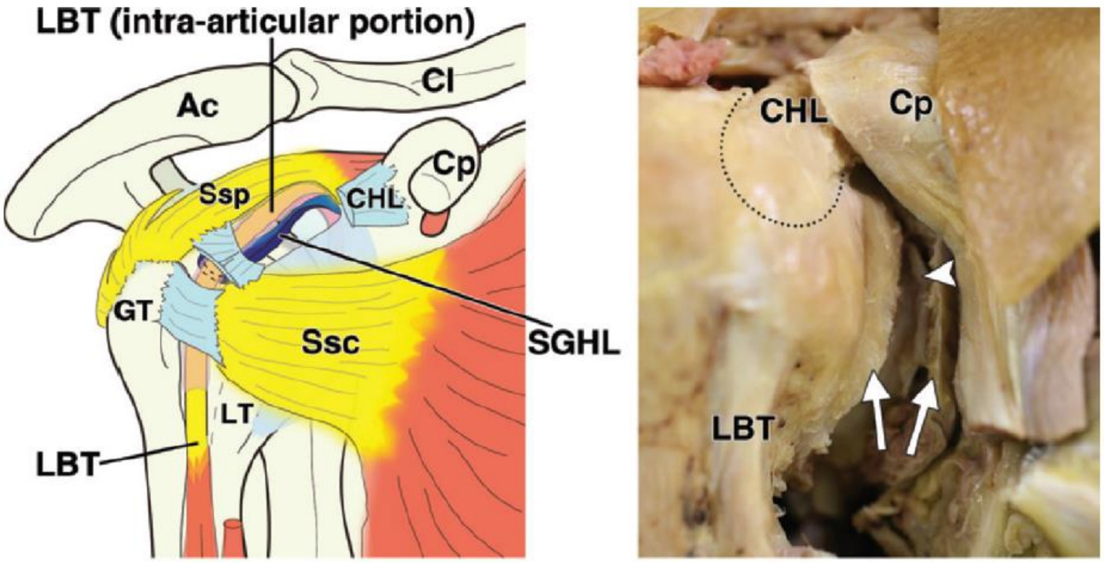
Appendix

Figure 1: Anatomy of the Biceps Pulley[2] – Nakata, 2011 page 792



a. b.

Figure 3. **(a)** Drawing illustrates the normal anatomy of the biceps pulley. The CHL is cut so that the superior glenohumeral ligament *(SGHL)*, focal capsular thickening, and the intraarticular portion of the LBT can be seen. *Ac* = acromion, *Cl* = clavicle, *Cp* = coracoid process, *GT* = greater tuberosity, *LT* = lesser tuberosity, *Ssc* = subscapularis tendon, *Ssp* = supraspinatus tendon. **(b)** In the corresponding cadaveric photograph (anterolateral view), the subscapularis tendon (arrows) and the joint capsule (arrowhead) are cut. *Cp* = coracoid process, dotted line indicates the rotator interval.

Figure 2: Anatomy of the Biceps Pulley[14] – Braun, 2010 page 1016

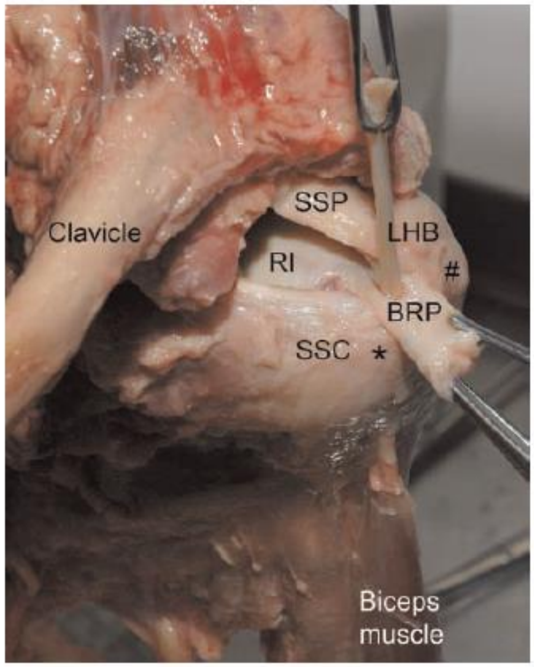


Figure 1. A dissected left shoulder viewed from anterior-superior shows the biceps reflection pulley after the deltoid muscle has been removed and the rotator interval has been opened. RI, rotator cuff interval; SSP, supraspinatus tendon; SSC, subscapularis tendon; LHB, long head of the biceps tendon; BRP, biceps reflection pulley sling. *Lesser tuberosity; #greater tuberosity.

Figure 3: Anatomy of the Rotator Interval[7] – Habermeyer, 2004 page 6

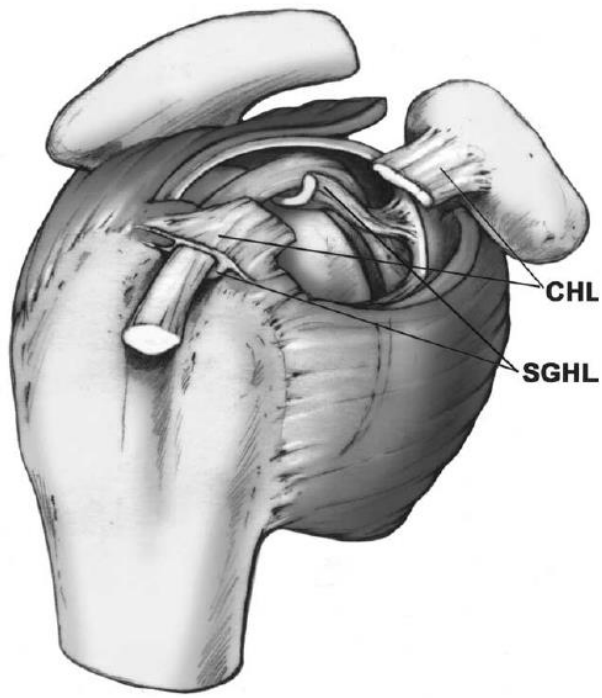


Figure 1 Anatomy of rotator interval. The CHL and SGHL blend together, forming the reflection pulley, which encloses the LHB at the entrance of the intertubercular groove.[22]

Figure 4: Zones of the Bicipital Tunnel[3] - Taylor, 2016 page 6

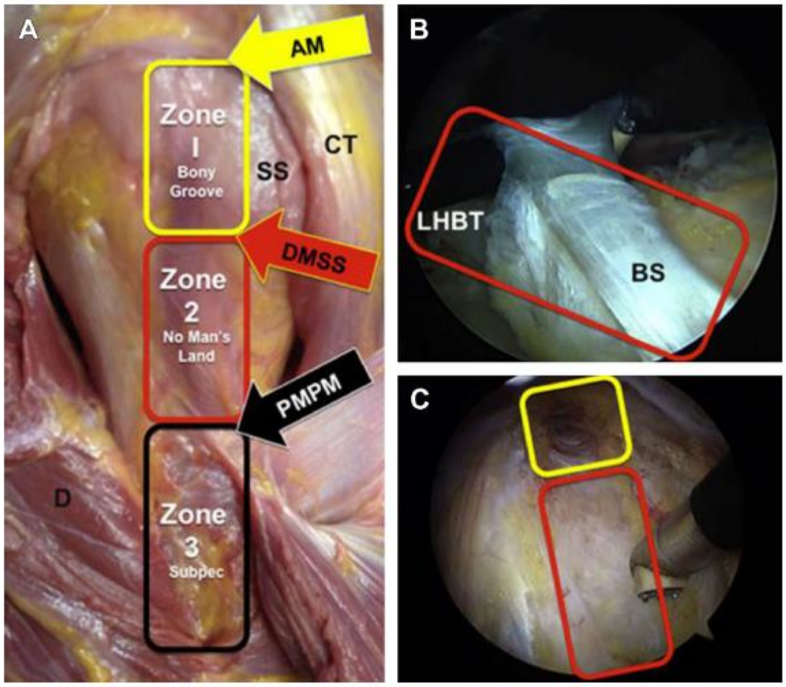


Fig. 2. A soft tissue sheath (*A*, *B*) consistently covers the LHBT to the level of the proximal margin of the pectoralis major tendon (PMPM) and contributes to the roof of the bicipital tunnel. The sheath is clearly visible during open procedures (*A*) and extra-articular arthroscopic procedures within the subdeltoid space (*B*, *C*). The fibro-osseous bicipital tunnel consists of 3 distinct anatomic zones (*A*). Zone 1 represents the traditional bony bicipital groove (*yellow box*) beginning at the articular margin (AM) and ending at the distal margin of the subscapularis tendon (DMSS). Zone 2 (*red box*) extends from the DMSS to the PMPM and represents a "no man's land" because it is not viewable from arthroscopy above or from subpectoral exposure below. Zone 3 is distal to the PMPM and represents the subpectoral (Subpec) region. The sheath overlying zone 2 can be robust (*B*). BS, bicipital sheath; CT, conjoint tendon; D, deltoid; SS, subscapularis. (*From* Taylor SA, Fabricant PD, Bansal M, et al. The anatomy and histology of the bicipital tunnel of the shoulder. J Shoulder Elbow Surg 2015;24(4):513; with permission.)

Figure 5: Functional Regions of the LHBT[11] – Kolz, 2015 page 941

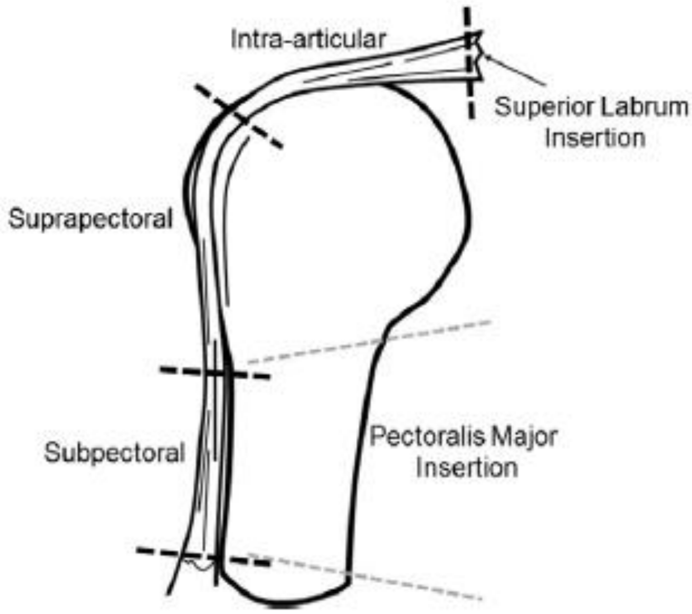


Fig. 1. Demarcation of the three functional regions of the LHB tendon. The intra-articular, suprapectoral, and subpectoral regions were defined by the insertion into the superior labrum, proximal margin of the bicipital groove, proximal edge of the pectoralis major insertion, and musculotendinous junction. This equated to 30%, 40%, and 30% of the total tendon length, respectively.

Figure 6: Influence of Arm Position on Biceps Tendon Excursion[14] – Braun, 2010 page 1021

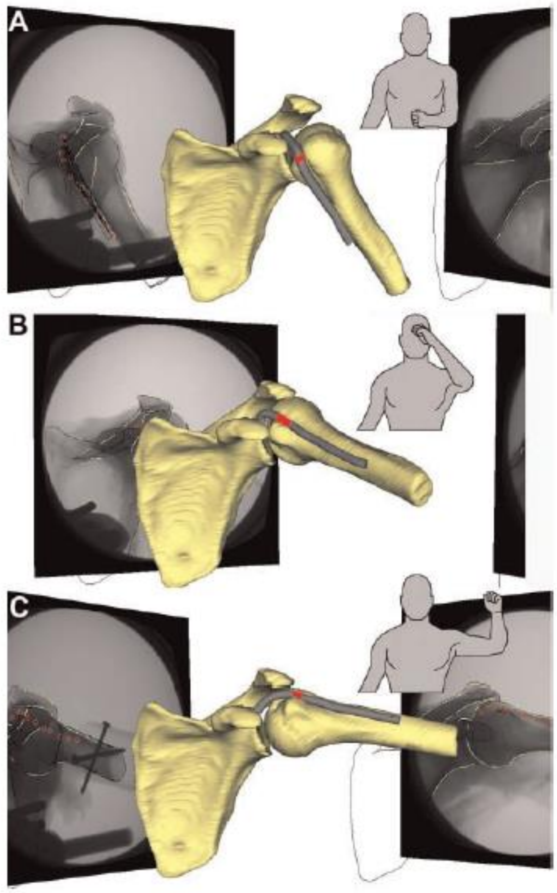


Figure 10. The 3-dimensional reconstruction of the shoulder with the long head of the biceps tendon visualized in the neutral-internal rotation position (A), forward flexion–internal rotation, and abduction–external rotation (ABER) (C). The portion of the long head of the biceps tendon marked in red in each position (A-C) represents the linear excursion of the tendon sliding extra-articularly in the shown arm positions from the level of the biceps reflection pulley sling at the entrance to the bicipital groove.

Figure 7: Biomechanical Forces on LHBT[14] – Braun, 2010 page 1019

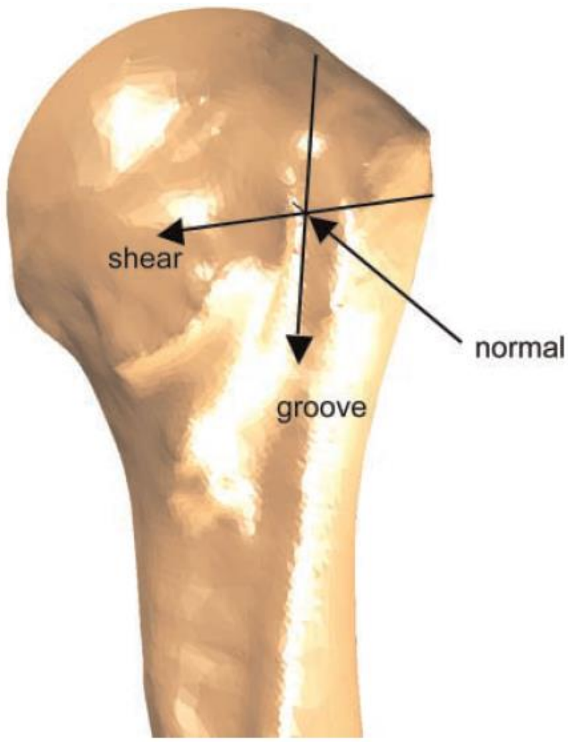


Figure 6. Three-dimensional reconstruction of a left humerus and the resulting force vector components. The ''shear'' vector is representing the force that can dislocate the long head of the biceps tendon medially. The ''normal'' force vector stands for the component that compresses the biceps tendon into the bony groove (stabilizes). The force pulling on the distal end of the biceps tendon is the ''groove'' vector.

Figure 8: Habermeyer Classification of Biceps Pulley Lesions[17] – Martetschlager, 2016 page 21

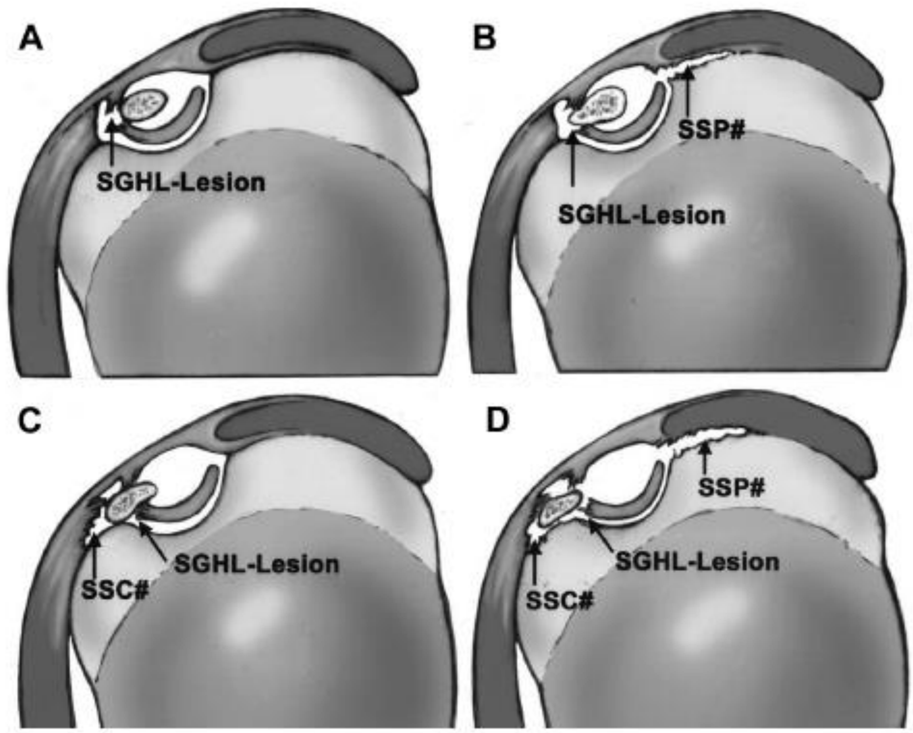


Fig. 2. Habermeyer classification of BRP lesions. (*From* Habermeyer P, Magosch P, Pritsch M, et al. Anterosuperior impingement of the shoulder as a result of pulley lesions: a prospective arthroscopic study. J Shoulder Elbow Surg 2004;13:5–12; with permission.)