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# Biomechanical Evaluation of Shear Force Vectors Leading to Injury of the Biceps Reflection Pulley

## A Biplane Fluoroscopy Study on Cadaveric Shoulders

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**Background:** The clinical importance of the biceps reflection pulley (BRP), which stabilizes the long head of the biceps tendon (LHB) as it exits the joint, has been shown. However, there is controversy on the pathomechanism of injury to the BRP. The angular orientation of the LHB relative to its origin and distal course changes with joint positions and may place the BRP at risk for injury.

**Purpose:** To measure the course of the LHB in common arm positions and to determine the shear and normal (stabilizing) force vectors as well as the excursion of the LHB.

**Study Design:** Descriptive laboratory study.

**Methods:** The LHBs of 8 fresh-frozen cadaveric shoulders were marked with arthroscopically injected microbeads and mounted in a custom-built shoulder rig. Data for neutral arm position, forward flexion, and abduction were collected in internal, neutral, and external rotation using biplane fluoroscopy. Bone and LHB position were reconstructed in 3 dimensions.

**Results:** The shear component of the resulting vector was significantly higher during internal (28.4% ± 18.1%) compared with external rotation (18.9% ± 9.7%; $P = .0157$) and was highest in neutral arm position with internal rotation (39.2% ± 12.7%) and forward flexion with neutral rotation (36.2% ± 10.7%). The normal force vector, stabilizing the LHB, was significantly higher in abduction (55.2% ± 9.6%) compared with forward flexion (39.1% ± 12.4%; $P < .0001$) and neutral positions (39.1% ± 11.4%; $P < .0001$). The LHB excursion was significantly lower for neutral arm positions (0.7 ± 6.0 mm) compared with forward flexion (12.6 ± 8.3 mm; $P < .0001$) and abduction (12.0 ± 6.5 mm; $P < .0001$).

**Conclusion:** Increased shear load at forward flexion with internal or neutral arm rotation and internal rotation at neutral arm position may cause injury to the BRP. Additionally, a sawing mechanism caused by the 12-mm linear excursion combined with a load of the LHB through the BRP during elevation may also lead to lesions.

**Clinical Relevance:** Knowledge of the pathomechanisms of BRP injury may help in developing specific treatment and rehabilitation strategies as well as tests for physical examination.

**Keywords:** long head of the biceps tendon; biceps reflection pulley; biceps instability; pathomechanism of pulley lesion

The long head of the biceps tendon is a common cause for anterior shoulder pain as the proximal third of the tendon has a high degree of innervation.[10] Inflammation, fraying, partial tears, or instability of the long head of the biceps tendon are some of the more common clinically reported causes for anterior shoulder pain.[35,42]

There is controversy about the function of the long head of the biceps tendon, especially for anterosuperior stability of the humeral head.[20,31,39,43] The biceps tendon may play a substantial role in reducing anterosuperior translation of the humeral head, particularly in positions of forward flexion.[31] Imprints on the chondral surface of the humeral

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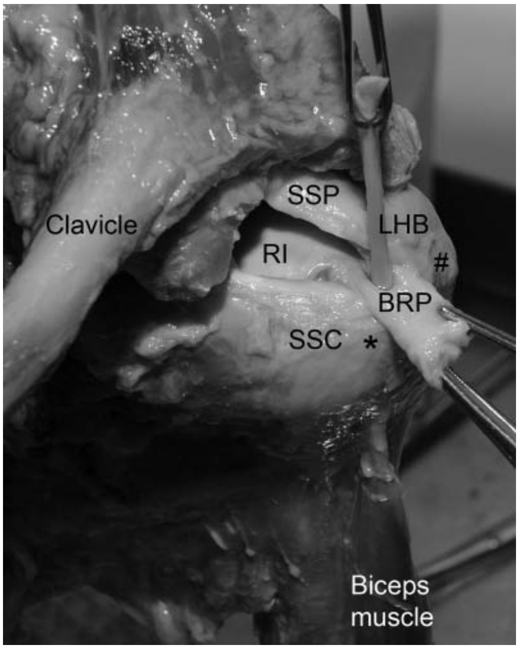


**Figure 1.** A dissected left shoulder viewed from anterior-superior shows the biceps reflection pulley after the deltoid muscle has been removed and the rotator interval has been opened. RI, rotator cuff interval; SSP, supraspinatus tendon; SSC, subscapularis tendon; LHB, long head of the biceps tendon;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

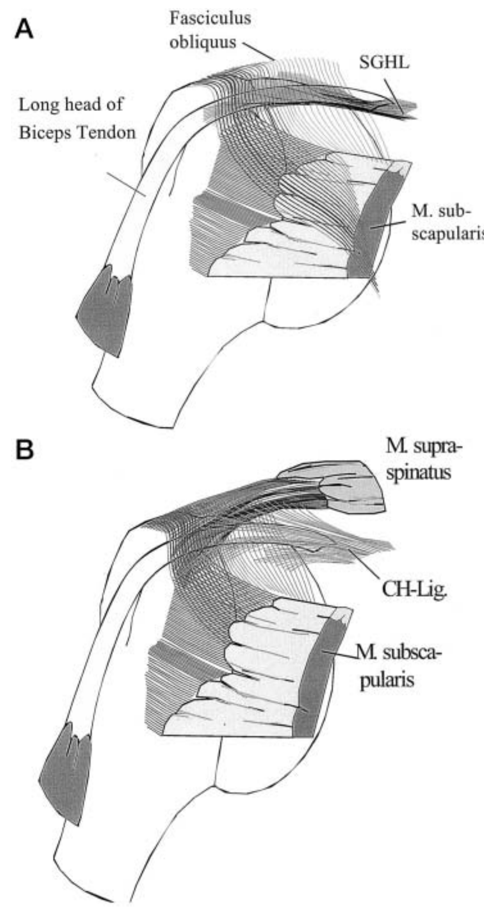


**Figure 2.** A, The deep layer of the rotator cuff interval. B, The superficial layer of the rotator cuff interval. Both deep and superficial layers build the biceps reflection pulley sling. From Werner et al.[40]

head have been reported in cases of biceps tendon dislocation, and this implicates high forces on the long head of the biceps tendon.[9] The mechanical properties of the long head of the biceps tendon, with its high stiffness, indicate its ability to transmit the large load of the muscle.[27] Habermeyer et al[19] described a 30° to 40° turn of the biceps tendon as it exits the joint and stabilizaton of the tendon by a pulley sling. Figure 1 shows a dissected cadaveric specimen and visualizes the biceps reflection pulley sling after taking down the deltoid muscle and opening the rotator cuff interval. The biceps reflection pulley sling is made up of fibers of the superior glenohumeral ligament (SGHL), the coracohumeral ligament (CHL), and partially by fibers blending in from the subscapularis and supraspinatus tendons.[7,18,40] Figure 2 is a schematic drawing of the anatomical structures and course of fibers from the work of Werner et al.[40] The orientation of the fibers in the biceps reflection pulley also suggests that substantial anteromedial shear forces are absorbed by the biceps reflection pulley system.[18,40] More distally, the transverse humeral ligament does not appear to play a key role in stabilizing the long head of the biceps tendon, and additionally, it is not present consistently in all individuals.[17,24,25,32] The shape of the bony bicipital groove has an additional effect on the long head of the biceps tendon's stability.[32,38]

There is speculation that the angular orientation of the long head of the biceps tendon relative to the humeral head changes with joint positions and may place the biceps at risk for instability.[2] Repetitive wear and trauma to the restraining structures of the long head of the biceps tendon may result in medial or lateral subluxation or dislocation of the tendon, which in many cases is related to tears of the subscapularis or supraspinatus tendon (S. Braun et al, unpublished data, 2009).[5,13,14,36,37] Anteromedial instability of the long head of the biceps tendon has been described by various authors (W. F. Bennett, unpublished data, 2008).[2,5,11,20] Lafosse et al described a series of patients with posterolateral instability of the tendon.[3,4,13,19,22,36] Different classifications of subluxation and dislocation patterns of the long head of the biceps tendon with or without associated lesions of the subscapularis or supraspinatus tendon have been published.[5,19,22,36]

However, there is little information on the pathomechanisms that lead to such tears of the biceps reflection pulley. Various studies have described the anatomy of the biceps reflection pulley and clinical and arthroscopic appearance of injury, but no laboratory study has investigated the biomechanics of the biceps reflection pulley system, the long head of the biceps tendon, and possible pathomechanisms of injury (W. F. Bennett, unpublished data, 2008).[3-5,7,10,13,15,18,19,22,23,30,36,37,40]

To better understand the possible mechanisms of injury of the biceps reflection pulley system, we need to know how the course of the long head of the biceps tendon changes with movement as a sharp angle between the biceps anchor, the pulley sling, and the distal insertion may create high shear forces on the soft tissue sling. Moreover, in certain glenohumeral positions, the resultant force vector may point directly into the bicipital groove, stabilizing the tendon, whereas in other positions, the tendon may directly load the soft tissue sling, potentially contributing to instability or injury. We hypothesize that lesions of the biceps reflection pulley occur in a position of forward flexion and internal rotation because anatomically this would create a sharp angle in the tendon at the biceps reflection pulley. This tendon position in conjunction with significant sliding of the tendon in and out of the joint would create a sawing mechanism that could lead to erosion of the biceps pulley sling and the tendon over time.

The purpose of this study, therefore, was to measure the course of the long head of the biceps tendon using biplane fluoroscopy in 3 common arm positions in internal, external, and neutral rotation and to determine the shear force vector in those positions as well as the amount of excursion of the long head of the biceps tendon.

## MATERIALS AND METHODS

Ten fresh-frozen shoulders of 5 cadaveric specimens (5 left, 5 right; mean age, 69 years; range, 61-73 years; 3 female, 2 male) were inspected arthroscopically for injuries to the long head of the biceps tendon, the biceps reflection pulley system, and the rotator cuff tendons. Exclusion criteria were a disruption of the biceps reflection pulley system, a complete tear of the subscapularis or supraspinatus tendon, and tearing of the long head of the biceps tendon. One specimen (specimen 2, right shoulder, 61-year-old male) was excluded because of severe osteoarthritis with rotator cuff arthropathy and high-grade stiffness of the joint. Another specimen (specimen 9, left shoulder, 72-year-old female) was excluded because of medial tearing of the biceps reflection pulley system and dislocation of the biceps tendon over the subscapularis tendon. All remaining 8 specimens were found to satisfy the inclusion criteria. The online appendix shows the details of the cadaveric specimens used in the study (available at http://ajs.sagepub.com/supplemental).

Subsequently, the cadaveric specimens were dissected down to the subacromial bursa. Eight tantalum microbeads with a diameter of 1.0 mm (Wennbergs Finmek AB, Gunnilse, Sweden) were injected arthroscopically in the long head of the biceps tendon through an 18-gauge Tuohy spinal needle. An arthroscopic grasper was introduced through the rotator interval to hold the intra-articular portion of the tendon (Figure 3). The microbeads were administered evenly across the length of the tendon, starting as close to the supraglenoid tubercle as technically possible. The joint was moved, and the long head of the biceps tendon was pulled into the joint with a grasper to inject the beads more distally. Two additional, most distal beads were injected directly from the outside for a total of 10 beads per tendon. The correct intratendinous positions were verified arthroscopically after the procedure of injection of the beads. The distal end of the long head of the biceps tendon was whipstitched with Fiberwire No. 2 sutures (Arthrex, Naples, Florida). The tendon of the pectoralis major muscle was sewed to the tendinous insertion of the latissimus dorsi muscle to stabilize the long head of the biceps tendon in its course distal to the bicipital sheath.

**Figure 3.** Arthroscopic injection of the microbeads with a Tuohy spinal needle.

Each specimen was mounted in a custom-built shoulder rig to allow positioning of the shoulder in the biplane fluoroscopy system. The scapula was clamped to a standard specimen holder (Pacific Research Laboratories Inc, Vashon, Washington). The humerus was mounted in a PVC tube with 2 crossed screws. The PVC tube allowed rotation in its attachment to a second tube that was mounted on a pneumatic arm holder (SPIDER, Tenet, Calgary, Canada). The arm holder was attached to a metal working bench (Figure 4). The distal end of the long head of the biceps tendon was then loaded with a 1.13-kg (2.5-lb) weight to ensure the biceps tendon was taut. The anatomical line of action of the biceps long head was preserved by running the Fiberwire through an eyelet in the PVC tube.

### Data Collection

The pneumatic arm holder was used to position the humerus relative to the scapula and to apply a joint compression force. The orientation of the humerus relative to the scapula was measured using a goniometer, while a centered glenohumeral position was verified in the biplane fluoroscopy images for all tested joint positions. Rotation of the humerus was determined using the distal projection of


**Figure 4.** Testing setup overview. The cadaveric shoulder was clamped on a commercial rig with the humerus mounted in PVC tubes that allows attachment to a pneumatic arm holder. This setup was placed in the biplane fluoroscopy system.

the bicipital groove as a reference. Neutral rotation position was defined with the bicipital groove rotated 30° externally.[21] Marks on the tubes were used to apply standardized rotations.

Data collection was performed in 3 glenohumeral positions corresponding to the in vivo arm positions of neutral, forward flexion of 90°, and abduction of 90° in the scapular plane combined with 3 rotation positions: neutral, 45° internally rotated, and 45° externally rotated, for a total of 9 positions for each specimen. Preliminary data from an in vivo study of normal shoulder kinematics in 10 healthy subjects using biplane fluoroscopy were used to estimate the corresponding glenohumeral joint positions for this study.[16] In this preliminary data, the neutral arm position corresponded to a glenohumeral abduction angle of 20° and a plane of elevation of 10° of the humeral shaft axis anterior to the line through the angulus acromialis and the root of the spine of the scapula. Arm abduction of 90° in vivo corresponded to 60° of glenohumeral abduction also with a plane of elevation of 10° anteriorly. Lastly, 90° of forward arm flexion in vivo corresponded to 60° of glenohumeral abduction in a plane of elevation of 50° anteriorly.[28]

For every position, stereoscopic fluoroscopy images were recorded using a biplane fluoroscopy system. High-resolution computed tomography (CT) scans (Aquilion 64, Toshiba America Medical Systems, Tustin, California) of all specimens were also taken for 3-dimensional (3-D) geometry reconstruction of the bones. The long head of the biceps tendons with the marking beads were removed before the CT scans to avoid image artifacts due to the beads and for macroscopic inspection of the intratendinous position of the beads after the testing procedure. No noticeable migration of the beads had occurred.

The biplane fluoroscopy system consisted of 2 commercially available BV Pulsera C-arms with 30-cm image intensifiers (Philips Medical Systems, Best, the Netherlands), which were modified under appropriate United States Food and Drug Administration (FDA) guidelines and Colorado State Radiation Safety Regulations. To improve viewing volume and spacing, the image intensifiers were removed from their C-arm configuration and mounted on a custom gantry. The gantry was configured with an interbeam angle of 80°, and each fluoroscopy system had a source-to-image distance of 1.5 m (Figure 4). Images were recorded with 2 coupled, high-speed, high-resolution (1024 × 1024) digital cameras (Phantom V5.1, Vision Research, Wayne, New Jersey) interfaced with the image intensifiers of the fluoroscopy systems using a custom interface. For each position, 20 images were recorded and averaged for optimal image quality.

## Data Analysis

Data analysis consisted of 4 steps: 3-D bone geometry reconstruction of the humerus and scapula from CT data, coordinate system assignment and geometry transformation, bone pose and bead location determination in the biplane fluoroscopy data, and postprocessing to extract the parameters of interest. The 3-D geometries of the humerus and scapula were extracted from the CT data using commercial software (Mimics, Materialize Inc, Ann Arbor, Michigan). Custom software written in Matlab (Mathworks, Natick, Massachusetts) was used to assign anatomical coordinate systems to the bones[41] and to transform the bones to positions suitable for pose reconstruction. Determination of the bone poses and bead locations from the biplane fluoroscopy data were performed using Model-Based RSA (Medis Specials, Leiden, the Netherlands). For the bones, the contours of the humerus and scapula were semiautomatically extracted from the biplane fluoroscopy images. Subsequently, automatic 6 degrees of freedom optimization algorithms were used to determine the pose (position and orientation) that optimally matched the detected contours with the projected contours from the imported bone geometries. The beads in the biceps tendon were automatically detected in each image, and the locations of the beads were determined by finding the intersections of the rays originating from the focus positions of the x-ray generators and extending to the centers of the detected beads in the imaging planes. Figure 5 shows the reconstructed pose of the humerus and the digitized biceps tendon with their projections in the biplane fluoroscopic images.

The course of the biceps tendon was separated into an intra-articular segment from its origin to the entrance of the bicipital groove and an extra-articular segment from the entrance of the bicipital groove to its most distal bead. Each segment was represented by a unit vector by

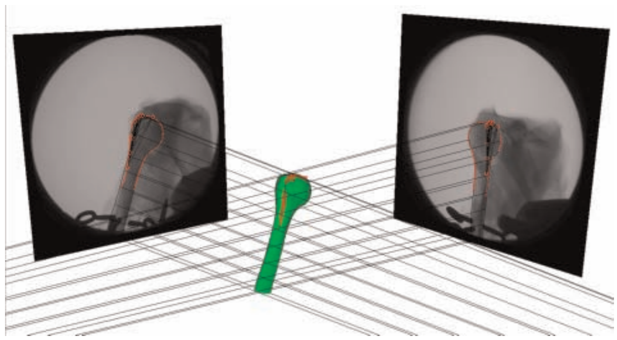

**Figure 5.** Pose reconstruction overview of the humerus, scapula, and the digitized biceps tendon as well as their projections in the calibrated biplane fluoroscopy images. Right humerus: neutral-neutral position. Scapula not displayed in the reconstruction.

fitting a least squares line to the beads of that segment. These 2 vectors were summed to calculate the resulting directional vector. A Cartesian coordinate system was defined for the bicipital groove to divide the resulting directional vector into 3 components: along the groove, normal to the groove, and a shear component. The axis along the groove was defined as passing through the most proximal and distal points on the humeral groove defined in the CT reconstructed geometry. The axis normal to the groove was defined by a vector rotated approximately 30° from a line from the center of the humeral head through the highest point of the lesser tuberosity.[21] The direction of shear was then calculated as the axis normal to the plane constructed by the groove and normal axes. Figure 6 shows the reconstruction of a humerus and the resulting direction of the coordinate system axes. Each component was then expressed as a percentage of the total resultant vector by dividing each component by the sum of all components.

The amount of linear excursion of the long head of the biceps tendon was calculated for all joint positions and rotations by measuring the distance from the entrance of the bony groove of the humerus to the most distal bead. The distance in the neutral arm position and neutral rotation of the humerus was used as the reference distance, and the excursion was calculated relative to this reference distance.

A 2-way ANOVA with independent factors of arm position (neutral, forward flexion, and abduction) and humeral rotation (neutral, internal, and external rotation) was applied to the shear and normal (stabilizing) components of the resultant vector as well as the linear excursion of the biceps tendon. Scheffé post hoc analyses were applied when significant differences were found. The level of significance was set to .05.

## RESULTS

For the shear component of the resultant force vector at the entrance of the bicipital groove (the force tending to load the biceps reflection pulley), significant main effects

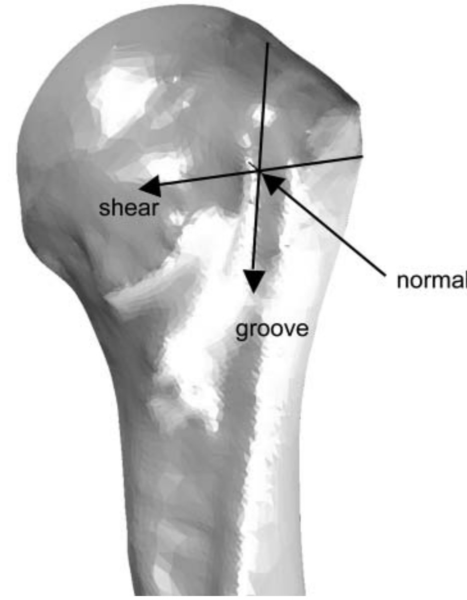


**Figure 6.** Three-dimensional reconstruction of a left humerus and the resulting force vector components. The ''shear'' vector is representing the force that can dislocate the long head of the biceps tendon medially. The ''normal'' force vector stands for the component that compresses the biceps tendon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

of arm position ($P < .0001$) and rotation ($P = .0099$) were found. Post hoc analysis revealed that the shear component was significantly smaller during abduction (16.8% ± 11.2%) compared with the forward flexion (31.7% ± 12.7%; $P < .0001$) and neutral position (25.2% ± 14.6%; $P = .0382$). Post hoc analysis also revealed that the shear component is significantly higher during internal rotation (28.4% ± 18.1%) compared with external rotation (18.9% ± 9.7%; $P = .0157$) and approached significance compared with neutral rotation (26.5% ± 11.7%; $P = .0665$). Figure 7 shows a bar plot representing the means and standard deviations for all positions. The shear force component was highest in the neutral arm position (0° of abduction) while internally rotated 45° (39.2% ± 12.7%), followed by the forward flexed, neutrally rotated (36.2% ± 10.7%), and internally rotated position (33.9% ± 16.5%).

For the normal component of the resultant force vector at the entrance of the bicipital groove (the force acting to stabilize the long head of the biceps tendon), a significant main effect of arm position ($P < .0001$) and an interaction effect ($P = .0023$) were found. Post hoc analysis revealed that during abduction, the normal force is significantly higher (55.2% ± 9.6%) compared with the forward flexion (39.1% ± 12.4%; $P < .0001$) and neutral positions (39.1% ± 11.4%; $P < .0001$). Figure 8 represents the means and standard deviations for all positions. The normal component is highest in the abducted arm position while either internally rotated 45° (60.0% ± 11.3%) or in neutral rotation (54.4% ± 8.5%).

For the amount of excursion of the biceps tendon in or out of the groove relative to the neutral position,

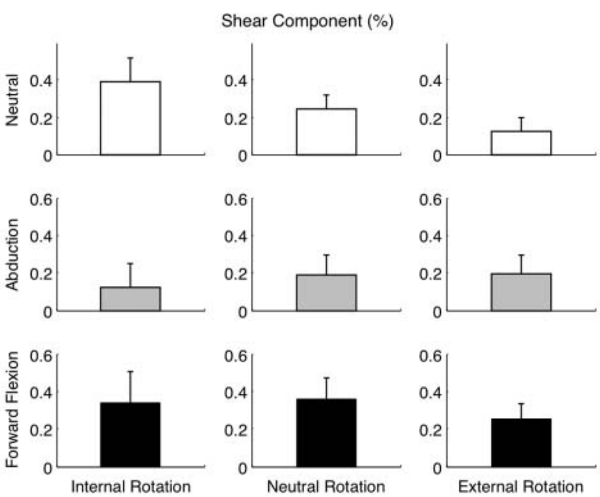


**Figure 7.** Means and standard deviations of the shear component of the resulting force vector at the entrance of the bicipital groove as a function of arm position and rotation.

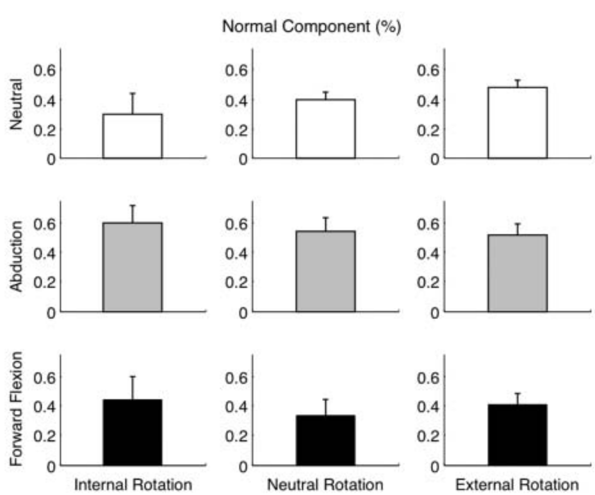


**Figure 8.** Means and standard deviations of the normal (stabilizing) component of the resulting force vector at the entrance of the bicipital groove as a function of arm position and rotation.

significant main effects of arm position ($P < .0001$) and rotation ($P < .0001$) were found. Post hoc analysis revealed that the amount of excursion was significantly lower for the neutral arm position (0.7 ± 6.0 mm) compared with forward flexion (12.6 ± 8.3 mm; $P < .0001$) and abduction (12.0 ± 6.4 mm; $P < .0001$) positions. For arm rotation, post hoc analysis showed that external rotation resulted in significantly less excursion (4.2 ± 8.5 mm) compared with neutral rotation (10.3 ± 8.6 mm; $P = .0006$) and internal rotation (10.8 ± 8.1 mm; $P = .0002$). Figure 9 shows that the greatest amount of excursion relative to the neutral reference position occurred in the forward flexed and internally rotated position (17.9 ± 7.4 mm) followed by

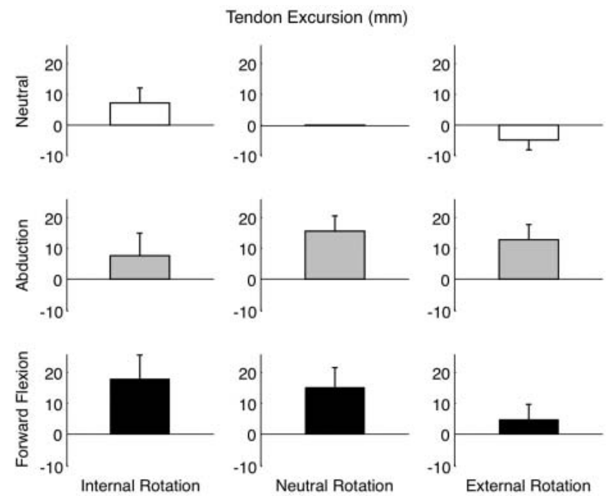


**Figure 9.** Means and standard deviations of the linear excursion of the biceps tendon in or out of the bicipital groove as a function of arm position and rotation. The excursion is normalized to the neutral arm position in neutral rotation.

the abduction–neutral rotation position (15.7 ± 4.4 mm). The least amount of linear excursion occurred during external rotation in the forward flexed arm position (4.7 ± 4.7 mm) and neutral arm position (–5.1 ± 3.1 mm). Figure 10 summarizes and visualizes the course of the long head of the biceps tendon in neutral arm position with internal rotation, forward flexion with internal rotation, and in contrast, abduction of the arm and external rotation. In addition, the figure shows the tendon's linear excursion in these 3 arm positions relative to the neutral reference arm position.

## DISCUSSION

The purpose of this study was to analyze the shear and normal (or stabilizing) force vector components of the long head of the biceps tendon in common shoulder joint positions and to determine and describe the amount of excursion of the biceps tendon through the reflection pulley system. There were 2 important findings of the present study. First, the shear component of the resultant force vector is significantly affected by the arm position, with internal and neutral rotation in the forward flexed position and internal rotation at the neutral position exhibiting the highest shear force values; and second, internal rotation in the forward flexed position and neutral rotation at abduction exhibited the greatest linear excursion of the biceps tendon through the reflection pulley system relative to the neutral reference position.

A variety of possible pathomechanisms for injury of the biceps reflection pulley have been described in the literature. Logically, they may be divided into pathomechanisms directly attributable to loads and motion of the long head of the biceps tendon itself or unrelated to the biceps tendon.

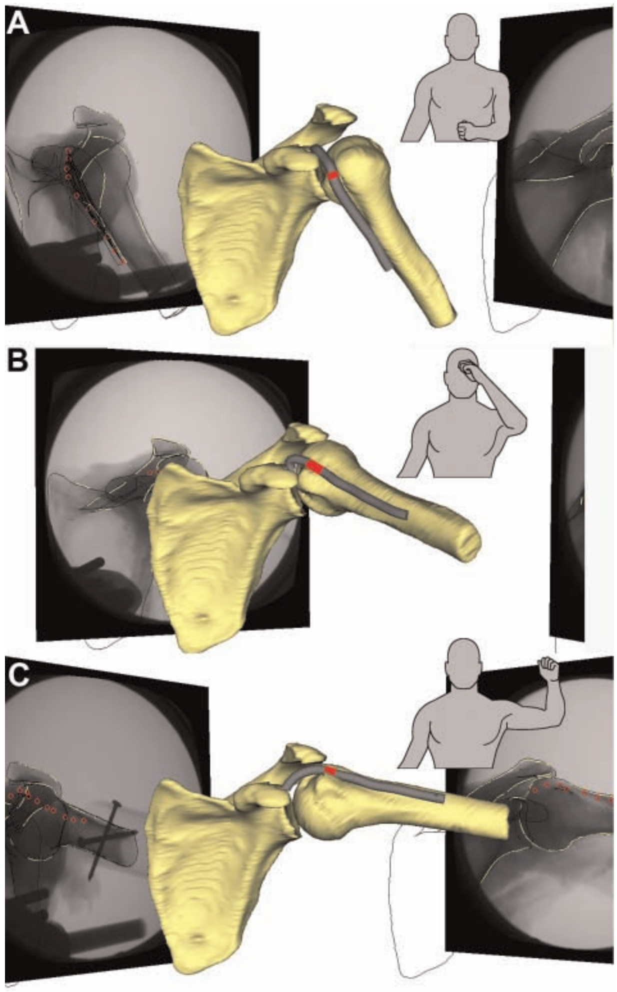


**Figure 10.** The 3-dimensional reconstruction of the shoulder with the long head of the biceps tendon visualized in the neutral-internal rotation position (A), forward flexion–internal rotation, and abduction–external rotation (ABER) (C). The portion of the long head of the biceps tendon marked in 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.

In addition, any type of pathomechanism may be degenerative or traumatic. Our objective was to elucidate possible pathomechanisms related to load and motion of the long head of the biceps itself. It was hypothesized that a relatively high load, especially when combined with a large tendon excursion, would create a sawing mechanism in which the tendon would wear away the biceps reflection pulley. The highest shear force components were found in forward flexion internal and neutral rotation positions, as well as in neutral arm position with internal rotation of the humerus. Therefore, high biceps loads in positions in front of or across the body will put high stress on the biceps reflection pulley, potentially leading to injury. The maximum sliding amplitude of the long head of the biceps tendon was found to be 17.8 mm in forward flexion with internal rotation compared with the neutral reference position. Thus, repetitive loaded elevation in front of or across the body will result in significant tendon sliding while the tendon is significantly loading the reflection pulley, indicating a potentially degenerative sawing mechanism. This is supported by previous work, which suggests that increased friction between the long head of the biceps tendon and the reflection pulley may be a reason for inflammatory and subsequent degenerative processes of the tendon.[1] Lesions of the biceps reflection pulley itself can also cause inflammatory processes of the tendon, and subsequently lead to lesions of the rotator cuff tendons.[3] The findings of this study give evidence that injury to the biceps reflection pulley sling may happen in normal working positions with the arms in front of the body such as when working and/or lifting overhead, or when lifting weights with the arms in front of the body, for example, during biceps curls.

The shear force loading the soft tissue of the medial biceps reflection pulley sling appears to be the lowest in abduction in general and for neutral arm position with external rotation. Therefore, pathomechanisms associated with these positions may be unrelated to loads in the biceps itself and more likely related to injury to the constituents of the biceps reflection pulley such as the rotator cuff and SGHL. The normal force that is directed perpendicular to the bottom of the bony groove, and therefore potentially stabilizes the tendon into the groove, is the lowest in forward flexion neutral and internal rotation and the highest in abduction, supporting the conclusions above.

The pathomechanisms proposed below are most likely unrelated to the biceps tendon itself. Traumatic subscapularis tendon tears can lead to lesions of the biceps reflection pulley and subsequently to subluxation or dislocation of the long head of the biceps.[11,12] The pathomechanism for traumatic subscapularis tendon tears has been described as trauma in abduction or hyperextension and external rotation.[12] In addition, hyperextension–external rotation was described as a potential pathomechanism for disruption of the biceps reflection pulley system by direct overtensioning of the coracohumeral ligament.[40] While this position was not tested in this experiment, visualizing the vectors in this position suggests a mostly normally directed vector and, therefore, a mostly stabilizing force from the LHB on the biceps reflection pulley.

Other authors believe that overhead throwing motion is possibly a mechanism of injury.[23,30] Bennett states that the shoulder position of abduction and external rotation creates posterior SLAP lesions and causes injury of the medial biceps reflection pulley (W. F. Bennett, unpublished data, 2008). Habermeyer et al[19] hypothesized that a forcefully stopped throwing motion leads to injury of the biceps reflection pulley. As described by Habermeyer et al, this can happen in positions of abduction and external rotation if the acceleration phase is stopped by external forces. According to the findings of our study, these pathomechanisms may not be correlated to the load of the biceps tendon but to direct injury of the BRP anatomical constituents.

In baseball pitching, ball release occurs in a position of approximately 105° of abduction, 15° of horizontal abduction, and 130° of external rotation.[33] While this position was not specifically tested, in abduction with external rotation, the normal force stabilizing the biceps tendon is high and the shear component is low compared with most other positions. Thus, during ball release, the biceps reflection pulley may be comparatively safe. During follow-through, however, the horizontal adduction angle increases as the arm moves toward the body's center line while the arm internally rotates. The current data suggest that both for horizontal adduction and internal rotation, the normal force decreases while the shear force increases. Therefore, our data support that the follow-through position may be more deleterious to the biceps reflection pulley than ball release during the baseball pitch.

A recently published study on 1007 retrospectively analyzed shoulder arthroscopies shows a prevalence of 7.1% of biceps reflection pulley lesions as the main pathological finding. An isolated injury of the SGHL was observed in 73.6%, and a combined lesion of the SGHL and the rotator cuff adjacent to the rotator interval was reported in 26.4%. Forty-three percent of these patients had a history of trauma.[3] Other studies report an even higher correlation of biceps reflection pulley lesions and rotator cuff tears.[7,36]

The association between dislocation of the long head of the biceps tendon and rotator cuff tears is generally accepted.[12,34] Articular-sided partial tearing of the supraspinatus tendon can lead to lesions of the supraglenohumeral ligament, which allows subtle subluxation of the long head of the biceps tendon, which can subsequently cause an articular-sided partial tear of the subscapularis tendon.[6,8] With progression of this lesion, the biceps tendon may dislocate medially.[2,6,8]

A traumatic event in internal rotation can lead to injury of the rotator interval, subsequently destabilizing the biceps.[23] The data of our study support this proposition. The shear forces are significantly higher in positions of forward flexion with internal and neutral rotation, as well as in neutral arm position and internal rotation compared with the neutral reference.

Anterosuperior impingement has been described as a cause of degenerative wear of the subscapularis tendon and the biceps reflection pulley, subsequently leading to instability of the long head of the biceps tendon.[13,14] It occurs in positions of forward flexion and internal rotation as the lesser tuberosity impinges on the coracoid process. In contradiction, Habermeyer et al[19] interpreted arthroscopic findings that anterosuperior impingement is the result of biceps reflection pulley lesions. Lesions of the biceps reflection pulley can also occur in isolation without any associated lesion of the ligamentous or tendinous complex that stabilizes the biceps in its course.[30,37] A large clinical series could not confirm anterosuperior impingement alone as a possible reason for lesions of the biceps reflection pulley, but lesions of the biceps reflection pulley were more common in patients who participated in overhead activities at work or in sports.[3,13,19]

From our data, we cannot conclude whether traumatic or degenerative pathomechanisms are more likely. The mechanism of injury of the biceps reflection pulley is highly complex, and there are obviously various starting points of the pathological condition. However, the data shown by our study suggest that both traumatic and degenerative injury to the biceps reflection pulley can occur by pathomechanisms related to increased shear forces of the long head of the biceps tendon at the entrance to the groove and that the amount of travel of the tendon in these positions may cause an additional sawing mechanism.

The clinical implications of this study are also important. In several studies, repair of the biceps reflection pulley in the case of traumatic subscapularis tendon tears has shown good results that were comparable with biceps tenodesis.[4,26,29] Potentially, repair of the biceps reflection pulley restores the anatomical function of the biceps tendon complex. The effect of joint positions on loading of the biceps reflection pulley sling that have been gleaned from this study should be considered for developing rehabilitation protocols for patients treated nonoperatively or with repair of lesions of the biceps reflection pulley complex, the subscapularis tendon, or rotator interval. Based on the findings of this study, we recommend avoidance of loading the biceps tendon in positions of forward flexion, internal or neutral rotation, as well as neutral arm position and internal rotation for patients with lesions or repair of the biceps reflection pulley.

Furthermore, the "at-risk" positions found in this study where there is increased loading on the soft tissues of the biceps reflection pulley may also be the positions where patients with pathological conditions of the pulley experience symptoms. Thus, knowledge of the loading of the biceps reflection pulley may also help in the development of specific physical examination tests to detect biceps tendon pathology. According to our findings, loading the biceps in a neutral or slightly forward flexed arm position with internal rotation increases the shear force on the biceps reflection pulley sling while minimizing any potential impingement. Adding elevation from the neutral internally rotated arm position while still loading the biceps may aggravate symptoms of biceps reflection pulley lesions, as the previously described sawing mechanism comes into play. This clinical test would potentially help to detect isolated biceps reflection pulley injuries and maybe help in clinically distinguishing symptoms from rotator cuff injury and/or anterior superior impingement, which could mask the pulley symptoms. A thorough clinical investigation will be needed to evaluate whether this test is sensitive and specific in identifying pulley lesions during physical examination.

The methods applied in this study represent a novel way to visualize and analyze the location and motion of soft tissues with very high accuracy. By injecting beads into the soft tissue, soft tissue locations and their relative motion as well as relative motion to bony structures can be investigated, providing a powerful and novel tool in orthopaedic research.

In summary, the mechanism of injury of the biceps reflection pulley is highly complex, and there are most likely various ways in which damage to the long head of the biceps tendon or the reflection pulley can commence. Our findings suggest that the increased shear load in a forward flexion position with internal or neutral rotation and in a neutral arm position with internal rotation may cause direct injury to the biceps reflection pulley during high loads. Furthermore, the sawing mechanism due to the large excursion in addition to the load of the biceps tendon in and of itself could also be a primary contributing factor to injury of the pulley sling. We hypothesize that the described mechanisms could lead to wear and failure of the biceps reflection pulley in common working positions, particularly when working and/or lifting overhead, or when lifting heavy weights with the arms in front of the body, for example, during biceps curls.

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