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Does the use of a tensioning device improve stability for suture fixation of glenoid bone constructs? A biomechanical analysis

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Abstract

Purpose: The purpose of this study is to quantify the difference in biomechanical stability of suture button (SB) and suture tape cerclage (STC) constructs with hand tensioning versus device tensioning of anterior glenoid augmentation bone grafts in an anterior glenoid bone loss model.

Methods: Artificial bone blocks with a density of 15 lb/ft^3 (240.3 kg/m^3) were used as models for glenoid fixation with bone graft. The biomechanical stability of SB and STC tensioned by hand was compared to those tensioned by a device. Average displacement (mm) following application of various forces (50, 100, 150, and 200 N) during a 7-phase, 100-cycle, stairstep cyclic loading protocol was recorded.

Results: Both SB and STC fixation displayed significantly lower construct displacement at all tested forces when tensioned with a device versus hand ($p < 0.001$). Device-tensioned SB and STC were comparable in construct stability at forces below 100N. However, at forces above 100 N, device-tensioned SB exhibited significantly less displacement than device-tensioned STC.

Discussion: Using a tensioning device for SB or STC fixation of a coracoid graft model results in less displacement and improved stability compared to hand tensioning. Biomechanically, a tensioning device enhances the stability of suture fixation in glenoid bone graft constructs.

Keywords

biomechanical, Latarjet, suture button, tensioning device, suture fixation, glenoid fixation

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Introduction

Anterior glenoid bone loss is common following a glenohumeral joint dislocation. Increased glenoid bone loss requires glenoid bony augmentation to reduce recurrent instability.[1,2] The most common bony augmentation procedures are the Latarjet and Bristow procedures, which utilize the coracoid process as a bone graft on the anterior glenoid while integrating the conjoint tendon and subscapularis as a "sling" to provide additional stability.[3–10] Likewise, free bone block transfers of both autograft and allograft have been shown to provide similar improvements in patient-reported outcomes and comparable rates of recurrent instability, reoperation, and complications.[11,12]

Historically, screw fixation has been used to secure the graft, as compression across the bone transfer-glenoid

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interface is necessary for graft union.[13] However, screw fixation constructs experience complications at a 30% rate and are subject to reoperation in nearly 7% of cases.[14] The most frequent complication is related to hardware, with an average of 6.5% of cases involving hardware failure (screw bending/breakage, loosening, or malposition) and irritation (humeral head or soft tissue impingement).[14,15] Of the cases requiring reoperation, nearly 35% are for symptomatic hardware removal.[14]

In an attempt to reduce potential complications associated with screws, non-screw fixation techniques such as the use of suture buttons (SBs) and suture tape cerclages (STCs) have been described with promising early results.[16–19] SB suspensory fixation, using ultra-high molecular weight polyethylene (UHMWPE) sutures crossing a metal cortical buttons suspension device, has demonstrated favorable biomechanical and clinical outcomes compared to screw fixation constructs.[18,20–22] STC, using UHMWPE tape looped through two holes drilled through the coracoid and glenoid, provide the potential for an entirely metal-free construct that has shown stable fixation and proper healing, while theoretically avoiding graft irritation associated with metal hardware.[13–15,17,23] Collectively, these devices offer several potential advantages over screw fixation, such as improved graft positioning due to suspension fixation, greater preservation of bone to maximize cancellous contact area, avoidance of hardware-related complications, decreased rates of neurologic complications, and the ability for extraosseous compression.[16–18,22,24] The majority of suture-based surgical techniques report the use of a tensioner device, but this is not universal.[25–27]

To our knowledge, there are no biomechanical studies that have investigated the potential differences between hand tensioning and device tensioning of SB or STC constructs. The purpose of this study is to quantify the difference in biomechanical stability of SB and STC constructs with hand tensioning versus device tensioning of anterior glenoid augmentation bone grafts in an anterior glenoid bone loss model. The authors hypothesize that the use of a tensioning device will result in superior fixation stability of the graft compared to hand tensioning.

Methods

Construct of interest

In the setting of modeled glenoid body augmentation, the biomechanical stability of SB and STC constructs tensioned by hand was compared to those tensioned by device. The SB construct chosen for this study was the Arthrex TightRope® ABS Button 8 mm × 12 mm AR-1588TB (Arthrex, Naples, FL, USA). It includes a core consisting of multiple strands of long chain UHMWPE and a jacket that consists of UHMWPE and polyester. These components are constructed with an adjustable loop apparatus and a pair of opposing stainless steel cortical buttons. The STC chosen for this study was the Arthrex FiberTape®, which is composed of polyester strands braided over a polyethylene core in the form of a 2-mm flat tape (Arthrex, Naples, FL, USA). The tensioning device, an item that supports the application of 0 to 80 N of tension to the construct, was included with the suture system. For each tensioning technique, manual and device-assisted, five constructs per insertion trajectory were examined.

Bone model specifications

Blocks from Sawbones® (Pacific Research Labs, Vashon Island, WA, USA) were used to model the repair of a glenoid defect with a coracoid/bone graft. These polyurethane cellular foam blocks had a density of 15 lb/ft^3 (240.3 kg/m^3). This specific density was selected to represent suboptimal in vivo glenoid and coracoid case scenarios.[7,9,16,17]

The dimensions used for the glenoid were 39 mm × 40 mm × 23.2 mm (width × height × depth). These dimensions reflected those of the average glenoid with a 25% defect.[8] A previous study inspired the rectangular form of this model.[28] The samples in Willemot et al., which utilized dimensional data from prior analysis of harvested coracoid samples to generate models, served as prototypes for the grafts used in this study.[28] The utilization of the Willermot et al. samples resulted in grafts of 26.4 mm × 13.7 mm × 9.3 mm.

Construct assembly

Two holes were drilled into the models using drilling jigs with accurately angled holes. The graft hole had a diameter of 4 mm, while the inner glenoid hole was 2.75 mm in diameter. The latter hole was positioned 7.7 mm from the top of the construct and 4.5 mm from the vertical centerline. The size difference between these holes provides a more secure fixation, typical of bone transfer procedures. After the holes were properly drilled, a benchtop vice alignment jig was used to secure the SB. The SB was then tensioned either by hand or to 80 N using a tensioning device. One fellowship-trained orthopedic surgeon tied two square knots in each SB construct after tensioning. For the models using STC fixation, the STC was looped through the two holes and tensioned either by hand or to 80 N using the tensioning device. After tensioning, the fellowship-trained orthopedic surgeon tied three alternating half-hitch knots in each STC construct.

Biomechanical testing

Samples were secured using an aluminum testing jig during the procedure (Figure 1(a)–(c)). The testing was conducted

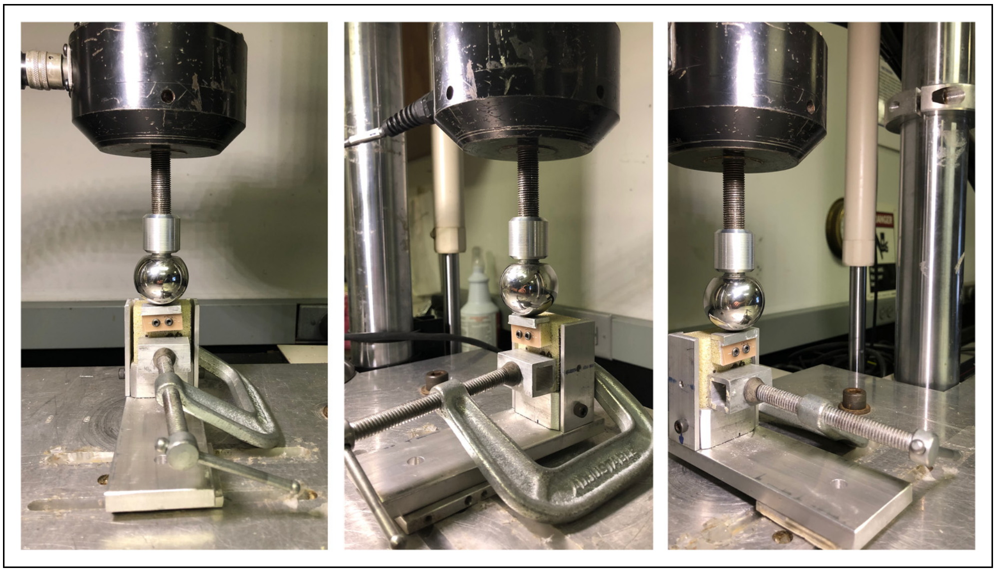

Figure 1. Aluminum testing jig used to secure test samples in the materials testing system.

with a Materials Testing System (MTS 858 MiniBionix, Eden Prairie, MN, USA). To remove slack, each sample underwent a preload ranging from 2 to 5 N, as established in a previous study.[28] Willemot et al. set parameters that were replicated by this study's Multipurpose Testware. These parameters included a 7-phase, 100 cycle per phase, 1 Hz, sinusoidal cyclic loading protocol with a stairstep pattern in load control. The stairstep pattern consisted of the following phases: (1) 0 to 5 N, (2) 5 to 10 N, (3) 10 to 25 N, (4) 25 to 50 N, (5) 50 to 100 N, (6) 100 to 150 N, and (7) 150 to 200 N. After these phases occurred, there was return to 0 mm displacement followed by a 0.5 mm/s load-to-failure ramp function. The absolute load-to-failure end-level was set at 7.0 mm under the pre-test zero-point, a value of displacement based on preceding work.[20,29] Each fixation technique underwent cycle displacement and load-to-failure testing with $n = 5$ samples. Data on time, force, and displacement were continuously collected at a sampling rate of 500 Hz. A 1500-N load cell was used to capture the load values, while the actuator's built-in linear displacement transducer recorded displacement.

Data and statistical analysis

The values for cyclic loading and load at failure for both SB and STC constructs were analyzed using SAS software (SAS Institute, Cary, NC, USA). Descriptive statistics were employed to determine standard deviations and averages. The disparity in cycle displacement and load-to-failure of each construct was compared using generalized linear models with LSD post-hoc testing. Statistical significance was set to $p < 0.05$.

Results

The use of a tensioning device for fixation of a coracoid graft model resulted in significantly less displacement during cyclic loading at equivalent force applied to SB constructs ($p < 0.001$) (Figure 2). The difference between hand-tensioned STC and device-tensioned STC was smaller in magnitude but statistically significant across all cyclic loads ($p < 0.001$) (Figure 3). Figures 2 and 3 depict averages ($n = 5$) of cyclic loading and displacement for each condition.

At each force level, device-tensioned SB and STC constructs exhibited less displacement than their respective hand-tensioned constructs upon initial exposure to each of the various forces (Table 1).

Except for 125 to 150 N (cycle 5), the displacement of hand-tensioned SB and STC constructs did not significantly differ across all tested loads (Figure 4). However, across all tested forces, hand-tensioned SB and STC constructs exhibited significantly greater displacement compared to device-tensioned constructs (Figure 4). During cyclic loading with forces exceeding 100 N, device-tensioned SB constructs experienced significantly less displacement than device-tensioned STC constructs (Figure 4).

Discussion

The primary finding of this study is that the use of a tensioning device for suture fixation of SB and STC glenoid bone graft constructs results in higher construct strength compared to hand-tensioned constructs. Further, device-tensioned SB constructs exhibited significantly less displacement than device-tensioned STC constructs at high-physiologic levels of force.

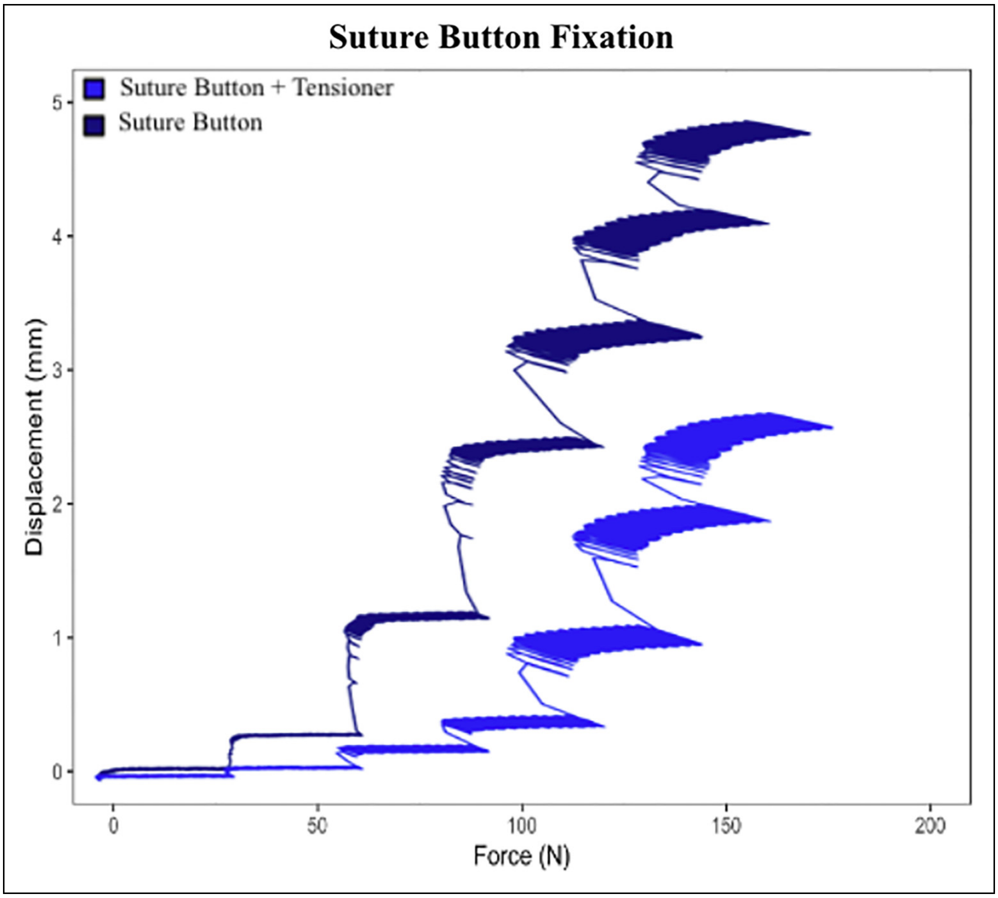

Figure 2. Suture button fixation.

Surgeons may choose to tension sutures by hand or with a specific suture tensioning device.[16,29] Several biomechanical studies have compared SB to screws.[20,21,29–32] Three of these studies demonstrated biomechanical equivalence of SB to screws.[20,21,30] Of the three studies, two of them used a tensioning device to secure the SB.[20,21] Conversely, in the two studies that identified biomechanical inferiority with SB, neither employed a tensioning device.[29,32] Lastly, Reeves et al. utilized a tensioning device and demonstrated biomechanical equivalence of SB to screws when the coracoid was used as a bone block or when conjoint tendon loading was minimized. However, under higher conjoint tendon loads, SB fixation showed biomechanical inferiority compared to screws.[31] Nevertheless, these studies collectively underscore the importance and growing use of a tensioning device for suture fixation of glenoid bone graft constructs.

The benefits of using a tensioning device include: (a) tightening the initially flexible fixation material into a rigid fixation, thereby achieving bone block stability and compression, (b) in the context of SB, applying the button directly against the surface, thus preventing interposition of local soft tissue in vivo, (c) removing the creep from a suture and avoiding late elongation of the suture with gap formation, and (d) reducing the risk of nonunion.[33] In the sole study assessing outcomes of device versus hand tensioning in Latarjet procedures, Boileau et al. demonstrated significantly higher coracoid bone block healing rates (defined as the absence of a radiolucent line between the bone block and anterior glenoid neck on computed tomography (CT) scan) at 6 months follow-up in patients whose SB were device-tensioned as opposed to hand tensioned.[33] Specifically, coracoid healing to the glenoid neck occurred in 74% (25/34) of shoulders after hand tensioning and 94% (33/35) of shoulders after device tensioning ($p = 0.023$). Boileau et al. suggested this difference might be due to residual micromotion of the coracoid bone block after hand tensioning, aligning with findings from the present biomechanical study.[33] However, it is noteworthy that the only patient to experience graft breakage was in the device tensioning group, highlighting two key limitations of this fixation technique: (a) graft breakage due to excessive over-tensioning and (b) the absence of a gold standard for determining the optimal load required to achieve

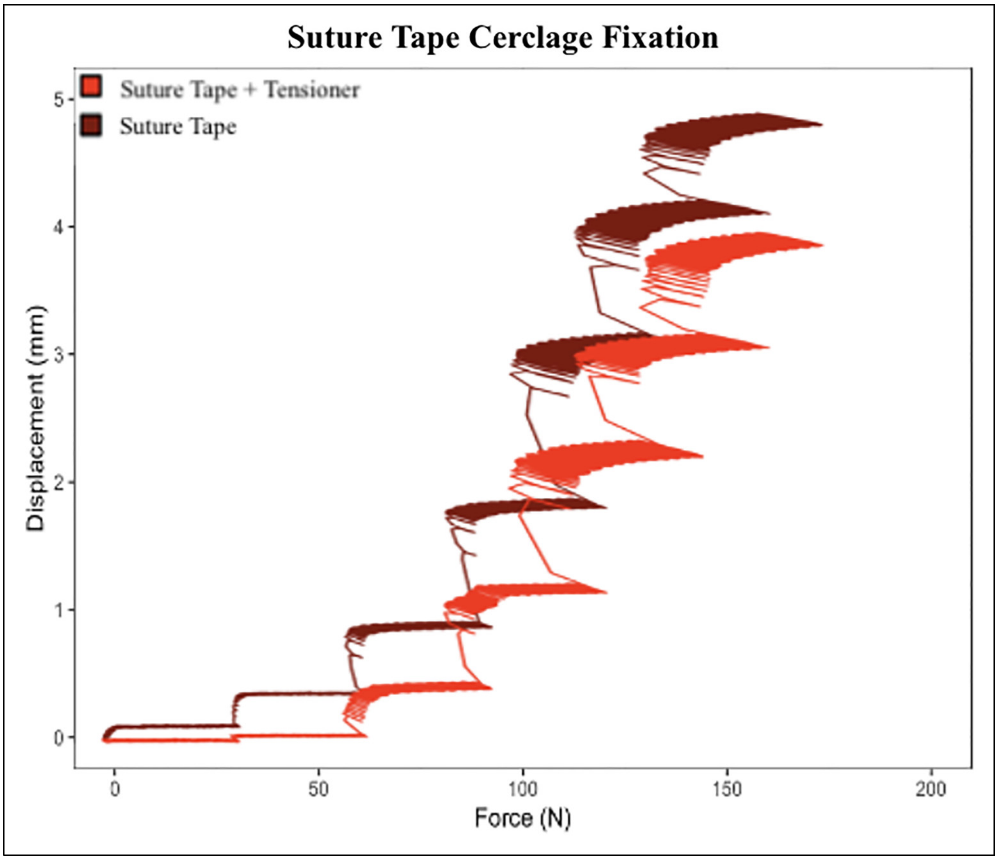

Figure 3. Suture tape cerclage fixation.

Table 1. Displacement of each construct at varying forces.

Force (N)	Displacement (mm)			
	Suture Button	Suture Button + Tensioner	Suture Tape	Suture Tape + Tensioner
50	0.291	0.076	0.334	0.045
100	1.057	0.186	0.788	0.360
150	2.850	0.847	2.668	1.919
200	4.230	2.282	4.255	3.417

bone compression. Further biomechanical studies are therefore necessary to determine the optimal force required when using a tensioning device to achieve adequate compression without compromising graft integrity.

This study is the first biomechanical study to directly compare hand tensioning and device tensioning of SB and STC glenoid bone constructs. Despite the study's notable findings, additional factors—such as the type of tensioning device and the optimal load to be applied—remain to be evaluated in future biomechanical studies. In addition to tension, the implications of other variables in screwless glenoid augmentation constructs, including suture elasticity, the number of fixation-spanning sutures, and the type and number of knots used, are poorly described in the literature. Further research is needed to assess the effects these factors may have.

Limitations

Artificial bone may not accurately reflect the in vivo performance of tensioned devices. The construct density was set to low-normal coracoid and glenoid bone density, and the difference in performance between device-tensioned and hand-tensioned constructs in healthy bone stock may be more comparable. Only double SB and STC were tested in this study, so these findings should not be extrapolated to predict the performance of single suture constructs, as their performance may be unpredictable regardless of the tensioning method. Additionally, our model constructs may not account for confounding variables such as the angle at which bore

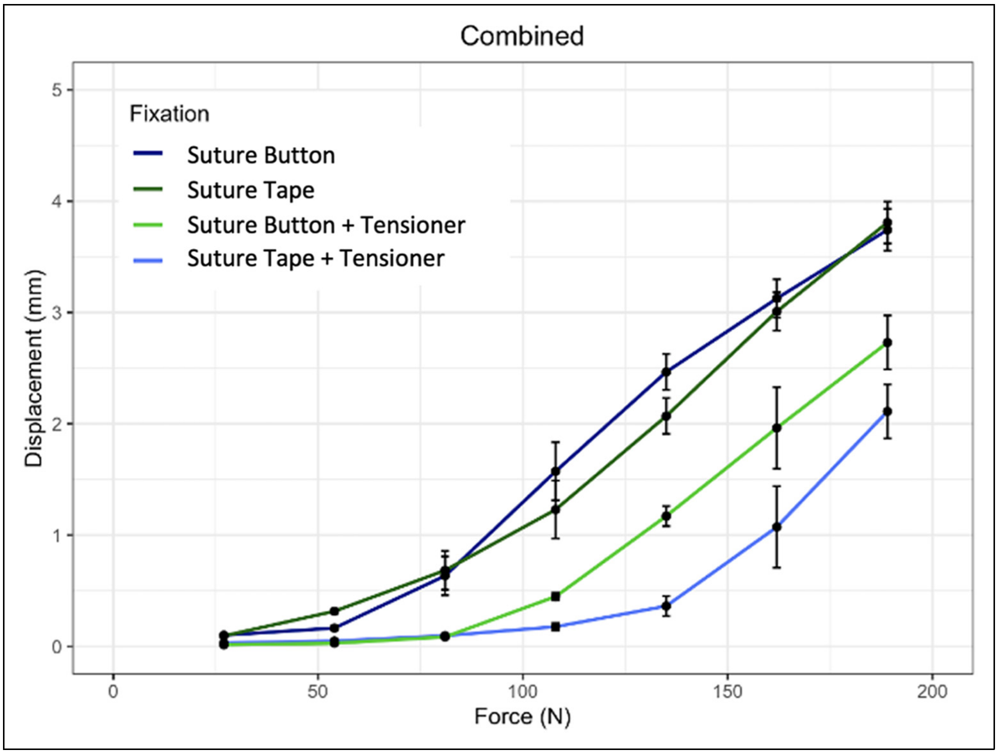

Figure 4. Combined.

holes are made during the confined surgical approach to the anterior glenoid rim. As is typical in biomechanical studies, our sample size was relatively small.

Conclusion

This study demonstrated that using a tensioning device for SB or STC fixation of a coracoid graft model results in less displacement and improved stability compared to hand tensioning. Biomechanically, a tensioning device enhances the stability of suture fixation in glenoid bone graft constructs within a bone model.

Contributorship

All authors contributed to drafting the manuscript, reviewing and editing the manuscript, and approving the final version of the manuscript.

Declaration of conflicting interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: AMM has received educational, travel, food, beverage, and lodging support from Arthrex, Inc in addition to compensation for services other than consulting, including serving as faculty or as a speaker at a venue other than a continuing education program.

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