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Suspensory fixation for bone transfer procedures in shoulder instability is superior to screws in an angled construct: a biomechanical analysis

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Background: The Latarjet procedure is a common bony augmentation procedure for anterior shoulder instability. Historically, screw fixation is used to secure the coracoid graft to the anterior glenoid surface; however, malpositioning of the graft leads to oblique screw insertion that contributes to complications. Suture buttons (SBs) are a more recent fixation technique that have not been studied alongside standard screw fixation in the context of biomechanical models of angulated fixation. This study aims to compare the biomechanical strength of single and double, screw and SB fixation at various levels of angulation.
Methods: Testing was performed using polyurethane models from Sawbones. The graft piece was secured with screw fixation (Arthrex, Naples, FL, USA) or suspensory button (ABS Tightrope, Arthrex, Naples, FL, USA). Single or double constructs of screws and SBs were affixed at 0°, 15°, and 30° angles to the face of the glenoid component. An aluminum testing jig held the samples securely while a materials testing system applied loads. Five constructs were used for each condition and assessed load to failure testing.
Results: For single fixation constructs, suspensory buttons were 60% stronger than screws at 0° ($P < .001$), and 52% stronger at 15° ($P = .004$); however, at 30°, both were comparable ($P = .180$). Interestingly, single suspensory button at 15° was equivalent to a single screw at 0° ($P = .310$). For double fixation, suspensory buttons (DT) were 32% stronger than screws at 0° ($P < .001$) and 35% stronger than screws at 15° ($P < .001$). Both double fixation methods were comparable at 30° ($P = .061$). Suspensory buttons at 15° and 30° were equivalent to double screws at 0 ($P = .280$) and 15° ($P = .772$), respectively.
Conclusion: These measurements indicate that the suspensory button has a significantly higher load to failure capacity over the screw fixation technique, perpendicularly and with up to 15° of angulation. These analyses also indicate that the suspensory button fixation offers superior strength even when positioned more obliquely than the screw fixation. Therefore, suspensory button fixation may confer more strength while offering greater margin for error when positioning the graft.

Anterior glenoid bone loss is common following a glenohumeral dislocation. Increased glenoid bone loss often requires glenoid bony augmentation to reduce recurrent instability.[27,29] The most common bony augmentation procedure is the Bristow/Latarjet procedure which utilizes 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.[3,11,20,24,25,36,40,42] Historically, screw fixation has been used to secure the glenoid graft. More recently, in an attempt to reduce potential hardware-related complications associated with screws, non-screw fixation techniques including the use of SBs and cerclages have been described with promising early results.[4,5,14]

The initial report of a nonscrew glenoid augmentation technique involved a SB.[34] A SB fixation is a device with a multistrand, ultra-high molecular weight polyethylene (UHMWPE) and braided polyester suture looped through two opposing stainless-steel

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buttons and passed through parallel sets of two holes: 1 drilled through the coracoid process graft and the other through the anterior glenoid face. This construct forms a continuous loop of suture to secure the coracoid graft onto the glenoid surface, achieving stable fixation and reported healing rates of 95% of the bone block interface.[5,7,15,18,24] In addition to avoiding common hardware complications associated with traditional screw fixation, potential SB fixation advantages over screw fixation include removal of less bone with a smaller drilling surface area, lower neurologic injury, and improved graft positioning (Fig. 1).[4,5,10,32,33]

While the alignment of the graft is crucial to the construct stability and clinical success of the procedure, proper positioning poses a challenge. Due to anatomical constraints, off axis non-perpendicular drilling may occur, even in the hands of an experienced surgeon. Due to poor exposure, tight working space, and limited visualization of the anterior inferior glenoid face in the classic Bristow/Latarjet procedure, malpositioning can occur, with superior and lateral displacement occurring in 36% and 10%-50% of malpositioned Latarjet cases.[4,5,13,15] In the traditional open Bristow/Latarjet technique, the screw holes for the coracoid graft and the glenoid are often separately drilled freehand, which may lead to position variability and nonparallel graft-host angulation[35] (Fig. 1). That is, despite two straight drill holes, the independently drilled paths may not align given surface topography.[34-36]

For both open and arthroscopic techniques, screw alignment is dependent on bone graft positioning. Not only can improper positioning result in biomechanical instability of the graft fixation and inadequate compression for proper graft union, but the occurrence of nerve damage and early onset osteoarthritis have also been reported.[5,6,17] Beyond superior-inferior and medial-lateral graft malpositioning, the bony surfaces of the glenoid and graft can be malpositioned with off-axis drilling. Frank et al assessed the impact of 15° off-axis angled fixation with screws and found significantly reduced failure loads with off-axis alignment of the coracoid and glenoid drill paths.[9]

To our knowledge, there are no biomechanical studies that have directly investigated the mechanical stability of screw fixation and SB fixation at varying levels of angulation to appreciate if one fixation construct is superior to another with oblique fixation. The purpose of this study is to compare SB to screw biomechanical stability various levels of off-axis angulation. The authors hypothesize that due to the ability to have a nonlinear route of fixation, SB fixation will offer greater mechanical stability to the coracoid graft when compared with the screw fixation at varying levels of angulation from the perpendicular axis.

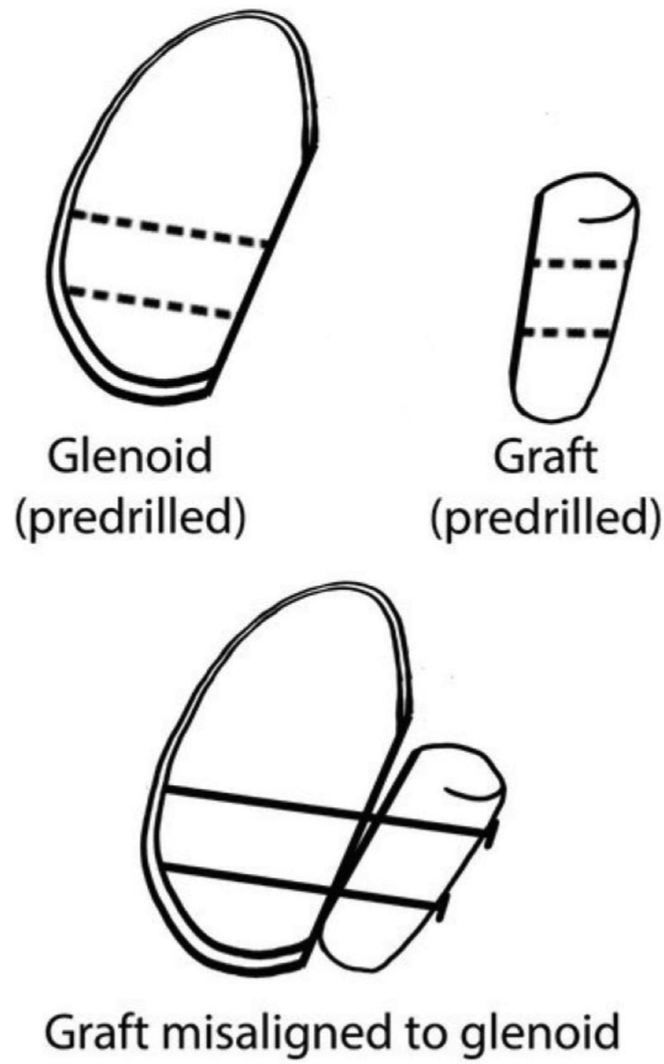

Figure 1 Off-axis suture button angulated glenoid fixation.

Methods

Constructs of interest

The biomechanical stability of SB constructs and traditional metal screws of various trajectories were compared in the setting of modeled glenoid bony augmentation. Four-strand suture strand Arthrex TightRope ABS (Arthrex, Naples, FL, USA) 8 mm × 12 mm AR-1588TB with steel button was chosen as the representative SB construct (Arthrex, Naples, FL, USA). This construct, similar to other SB constructs, is composed of multi-stranded long chain UHMWPE core with a polyester and UHMWPE braided jacket constructed with an adjustable loop mechanism and two opposing stainless steel cortical buttons, and a tensioning device that allows up to 80 N of tension to be applied to the construct. For the screw constructs, 3.75 mm × 38 mm partially threaded, cannulated screws were used as standard-of-care comparison for SB performance and were tightened to 8 Nm torque. This value was selected through pilot testing to prevent screw-hole stripping as limited by construct integrity. In accordance with prior literature,[5,8,28,30,38] five constructs of each fixation system for each insertion trajectory were examined in a both a single and double formation. Groups included single screw (SS0, SS15, SS30), double screw (DS0, DS15, DS30), single SB (SSB0, SSB15, SSB30), and double SB (DSB0, DSB15, DSB30). Numbers in construct abbreviations reflect degrees off parallel axis to the glenoid surface (0°, 15°, and 30°).

Sawbones model specifications

To model a glenoid defect repaired with a coracoid graft, polyurethane cellular foam blocks from Sawbones® (Pacific Research Labs, Vashon Island, WA, USA) were chosen for consistent testing across each specimen. Both 240 kg/m^3 (15 lb/ft^3) and 320 kg/m^3 (20 lb/ft^3) blocks were selected and pilot tested as prior studies have identified coracoid and glenoid bone density to vary between 256-320 kg/m^3 (15-20 lb/ft^3).[21,38] Prior studies have varied in the density of testing materials ranging from 480 kg/m^3 (30 lb/ft^3 non-cortical block[9] up to 1602 kg/m^3 (100 lb/ft^3).[38] A density of 240 kg/m^3 (15 lb/ft^3) was selected as pilot testing results identified better appreciation of differences in construct strength similar to testing failure values of cadaveric specimens. The 240 kg/m^3

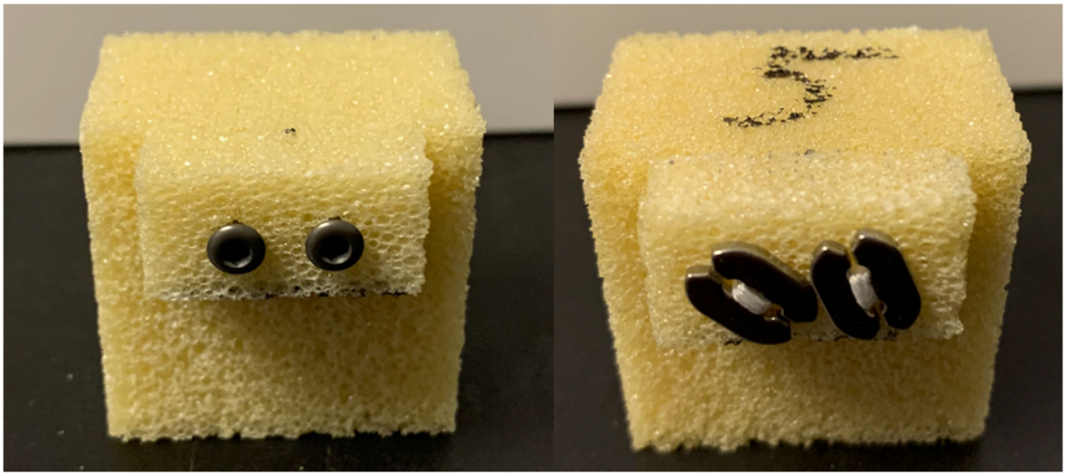

Figure 2 Graft fixation with double screw (*Left*) and double suture-button (*Right*).

(15 lb/ft^3) density was felt to reflect a worse case scenario of in vivo glenoid and coracoid biomechanical strength in an individual with clinically realistic suboptimal bone quality.[8,9,21,30,38,41]

Rectangular geometry and dimensioning of the glenoid piece was based on previous work.[25,38] The glenoid was dimensioned 39 mm × 40 mm × 23.2 mm (width x height x depth, respectively) which model the average glenoid width and height after the generation of a 25% defect in the glenoid. The graft piece was dimensioned based on samples in Willemot et al, which were values established by previous investigations of harvested coracoid samples.[30,38,41] Final dimensions of the graft were 26.4 mm × 13.7 mm × 9.3 mm (Fig. 2).

Construct assembly

Each model was each drilled with 1 hole for the single fixation technique and 2 holes for the double fixation technique to simulate drill holes using prefabricated drilling jigs with appropriate hole angulation (Fig. 3). The graft piece was then secured to the glenoid piece with either screws or SBs in the specified single or double formation using a benchtop vice alignment jig. Screws were tightened to 8 Nm torque. In accordance with the technique guide, SBs were tensioned to 80 N via tensioning device.[16] Two square knots were tied in each SB construct following tensioning by a single fellowship-trained orthopedic surgeon. Coracoid graft drill diameter was 4 mm, positioned 7.7 mm from top of construct, and 4.5 mm from the vertical centerline. Glenoid component drill inner diameter 2.75 mm.

Biomechanical testing

An aluminum testing jig was fabricated to hold the samples securely during the testing procedure. Testing was performed on a materials testing system (MTS 858; MiniBionix, Eden Prairie, MN, USA). Each sample was preloaded between 2 N and 5 N to remove slack from the system, as done in previous work.[38]

The Multipurpose Testware was used to replicate the cyclic loading parameters outlined in Willemot et al[38] a 7-phase, 100 cycle per phase, 1 Hz, sinusoidal cyclic loading protocol, following a stair-step pattern in load control. The phases were (1) 0 N to 5 N, (2) 5 N to 10 N, (3) 10 N to 25 N, (4) 25 N to 50 N, (5) 50 N to 100 N, (6) 100 N to 150 N, and (7) 150 N to 200 N of inferiorly directed force. These were immediately followed by return to 0 mm displacement and then a load-to-failure ramp function in displacement control at a rate of 0.5 mm/s. The absolute end level for load to failure was defined as 7.0 mm below the zero-point defined at the beginning of each test, a displacement value based on previous work.[28,39] There was an n = 5 for both the cycle displacement and load to failure testing for each single and double screw fixation and SB fixation techniques. Time, force, and displacement data were collected continuously at a sampling rate of 500 Hz. Load values were captured with a 1500 N load cell and displacement was measured by the built-in linear displacement transducer of the actuator.

Data and statistical analysis

Cyclic loading data and load-at failure values were recorded in an electronic data set and analyzed by a biostatistician in using SAS software (SAS Institute, Cary, NC, USA). Averages and standard deviations were determined with descriptive statistics. Generalized Linear Models with LSD post hoc testing was used to compare load to failure and cycle displacement between each construct. Statistical significance was set to $P < .05$.

Results

Cyclic displacement

When assessing displacement for all 7 cycles, the single screw and SSBs had comparable displacement at both 0° (SS0 vs. SSB0, $P = .470$) and 15° (SS15 vs. SSB15, $P = .428$). At 30°, the SS30 construct had on average 44% less displacement compared to the SSB30 ($P = .001$). Regarding double constructs, no difference was found between screws and SBs at any of the 3 angles ($P > .05$) (Fig. 4).

Load-at-failure

SSB0 constructs had greater load-at-failure values than single screw constructs. When applied perpendicularly at 0° off-axis, SSB0 were nearly 60% stronger than SS0 constructs ($P < .001$). Similarly, SSB15 proved to be 52% stronger than SS15 ($P = .004$). Both constructs become comparable at 30° off axis (SSB30, SS30, $P = .180$). Although SSB30 was significantly weaker than SS15 ($P = .012$), the SSB15 testing was equivalent to SS0 ($P = .310$). Table I details the load-at-failure for each construct at the different angulations.

Compared with double screw constructs, DSB s were 32% stronger at 0° (DSB0 vs. DS0, $P < .001$) and 35% stronger at 15° (DSB15 vs. DS15, $P < .001$). Both constructs become comparable at 30° off axis (DSB30 vs. DS30, $P = .061$). Furthermore, the DSB15 testing was equivalent to DS0 ($P = .280$), and DSB30 was equivalent

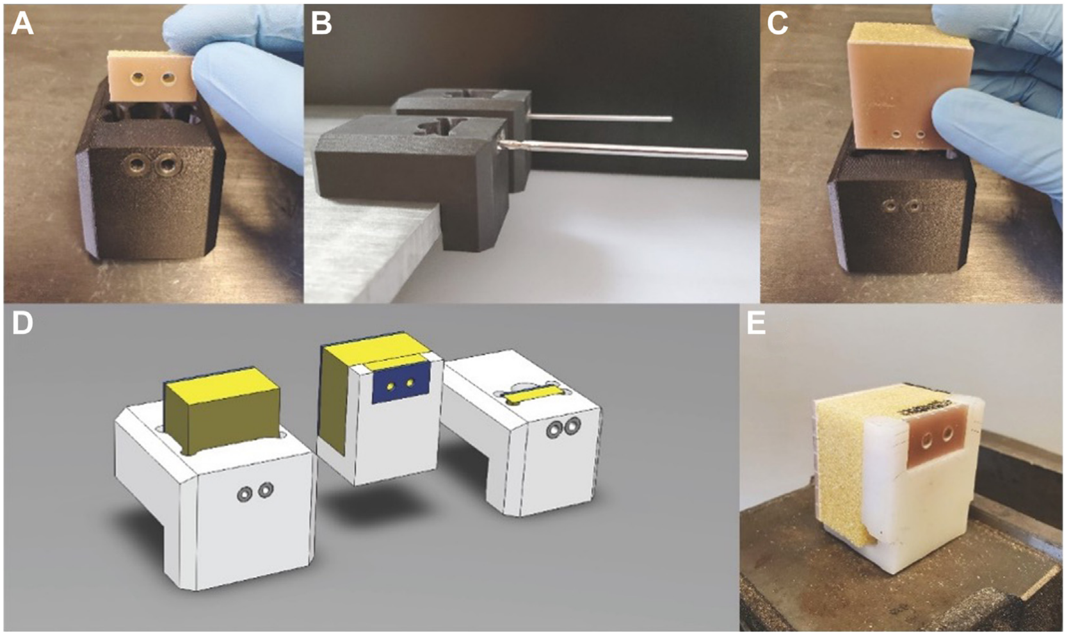

Figure 3 Different views of the drill and alignment jigs. (**A**) The drill jig for the graft is shown with a completed specimen. (**B**) The drill jigs are shown on a table edge with surgical bits inserted for demonstration of positioning. (**C**) The drill jig for the glenoid is shown with a completed specimen. (**D**) The Solidworks rendering of the drill jigs and alignment jig is shown with Sawbones blocks inserted for demonstration of positioning. (**E**) The alignment jig is shown.

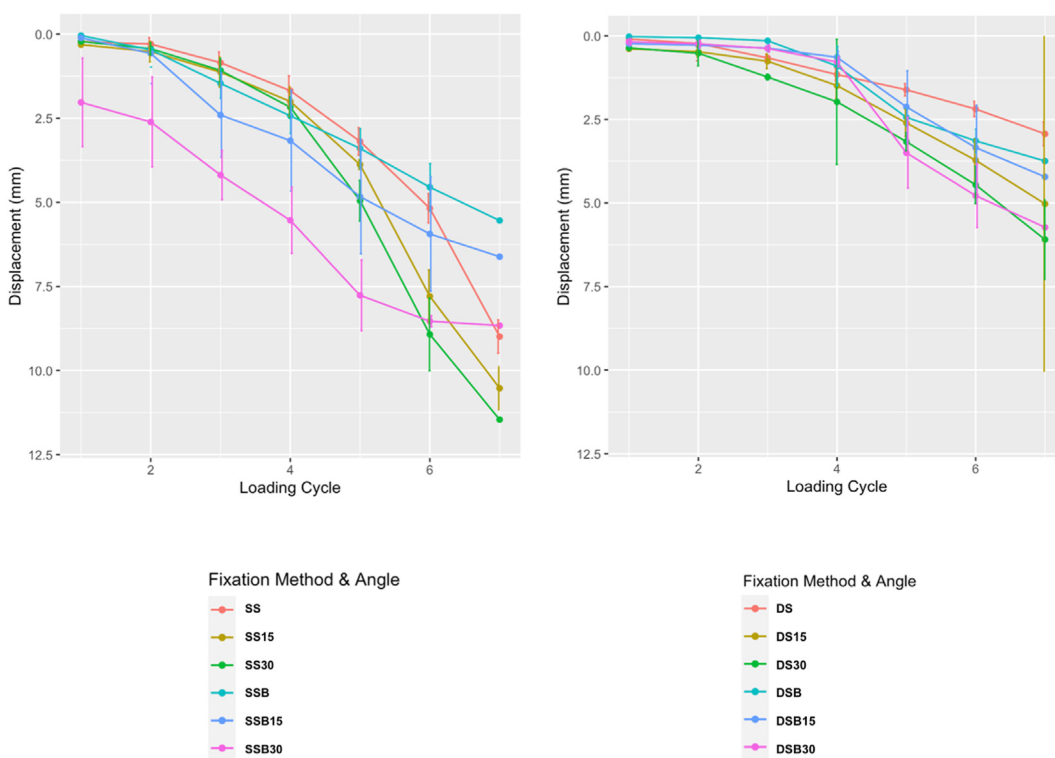

Figure 4 Screw and suture button construct single fixation (*Left*) and double fixation (*Right*).

to DS15 ($P = .772$). Table I illustrates the load to failure for double screws as compared to DSBs.

Discussion

A critical portion of glenoid augmentation procedures is the graft-glenoid interface alignment and construct stability.[15,18,24] For optimal fixation strength, fixation should be placed parallel to the glenoid articular surface, and the drilled holes of the glenoid should be concentric and aligned with those of the graft (ie, at a 0° off-axis). Nonetheless, it is not uncommon for screws to be inserted obliquely, resulting in sub-optimal biomechanical strength, inadequate compression at the graft-glenoid interface, and ultimately failed union or construct failure.[4,5,15] With the recent advent of SB fixation, the authors aimed to compare the strength and stability of traditional screw constructs and SB constructs applied at increasing

Table I
Load at failure.

Construct	Mean (N)	SD	Min	Max
Single				
Screw				
SS	196.8	5.8	187.6	201.8
SS15	146.3	8.2	133.9	152.9
SS30	114.8	7.7	108.1	126.8
Suture button				
SSB	313.7	50.7	236.9	359.6
SSB15	223.4	95.5	90.9	345.7
SSB30	80.2	11.5	68.6	99.5
Double				
Screw				
DS	422.0	25.0	387.3	452.3
DS15	291.5	34.3	252.6	344.5
DS30	250.2	40.6	186.1	285.2
Suture button				
DSB	557.2	18.6	535.7	576.6
DSB15	394.2	26.4	362.8	432.9
DSB30	299.0	42.0	260.5	360.1

SD, standard deviation.

levels of angulation (0°, 15°, and 30°). The results of this study showed superior biomechanical load at failure strength of SBs with no angulation (0°) and moderate graft hole off-axis angulation (15°) when compared with screws and no difference between constructs during severe off-axis (30°) hole angulation. Conversely, for single fixation constructs, cyclic loading was similar between SBs at no angulation, and moderate angulation (15°). Single screw fixation was superior to SSB. However, for DSB and double screw constructs, no notable differences were appreciated for cyclic loading displacement at any angle (0°, 15°, and 30°).

Precise bone block positioning is another potential benefit of SB use. Unlike a traditional Latarjet or Bristow with screw placement from anterior to posterior requiring glenoid drilling from anterior to posterior, suture button placement permits glenoid drilling from posterior to anterior. The orientation toward the glenoid from the posterior facilitates parallel alignment to the glenoid as the anterior structure of the pectoralis major often interferes with medial alignment of the drill path. Because of this, the natural anterior approach is off-axis and requires robust retraction to allow for drill and screw placement parallel to the glenoid articular surface. Additionally, precision is required to avoid graft fixation ie, proud or excessively recessed to the glenoid face. Malpositioning of an anteriorly drilled glenoid and screw fixed bone block may be up to 50% of cases.[14] However, in Boileau's series, drilling from posterior to anterior and use of a SB resulted in 95% correct axial alignment and 93% correct sagittal alignment of the anterior glenoid bone graft.[4] Also, when compared to screw fixation, cortical buttons had less angulation from the parallel axis to the glenoid, with a mean angulation of 5.7° compared to 9.7° for open and 15.7° in arthroscopic screw placement, respectively.[26]

Another theoretical benefit of a SB construct is the ability for standardized tensioning. Unless a torque limiter screwdriver is used, traditional teaching endorses the "two finger tightening" for screws despite this yielding varied torque values applied, which at the extremes can either fracture the graft or leave a graft not securely fixed to the glenoid.[1,37] While it has been noted that subsequent years of training increase not only the overall forces used when placing a screw, as well as an ability to reproduce the process more consistently, there remains a wide variation from surgeon to surgeon.[1,37] This theoretical weakness with screw fixation has not been previously reported, as there was no alternative prior to SB fixation with a recommended standardized tension value, and requires additional investigation to identify ideal construct tension settings to facilitate stability and healing.

Our current findings are concordant with Frank et al who determined that in a modeled Latarjet procedure, screws inserted perpendicularly at 0° yielded higher failure loads than those inserted at 15° off-axis.[9] The results of the present study demonstrate a similar pattern for screws and suggest that the same principle applies to SBs despite the ability for SBs to have nonlinear fixation. As constructs are inserted more parallel to the glenoid, the biomechanical stability and load-at-failure properties of the assembly increase accordingly. Screws inserted at off angles will likely increase the compression on the acute side of the angled construct, with lower compression values on the obtuse side. The effect of the suture may be to better distributes the compression across the glenoid as the suture experiences tensile forces perpendicular to the glenoid surface, permissive of angulation, and potentially without sacrificing stability.

When comparing the biomechanical strength of SB fixation and traditional screw constructs in the Latarjet procedure, Provencher et al report that despite the DSB construct yielding higher load-to-failure and higher strain-at-failure than traditional double screw fixation, the difference was not statistically significant (*P* values of 0.26 and 0.06, respectively).[28] Other studies have found similar favorable results for the use of SBs,[2,39] while others demonstrated worse performance or no difference when compared to screw fixation.[19,23,28,31] The present study demonstrated no difference in cyclic displacement between double screw and DSB constructs. In addition, DSB s demonstrated higher load-at-failure at no angulation (0°) and moderate angulation (15°). Further, this construct also demonstrated similar loads-at-failure at mild and greater angulation (DSB15 and DSB30) compared to screw fixation with no angulation and mild angulation (DS0 and DS15), respectively. The finding that SBs may be biomechanically stronger than screws, even when angulated may suggest SBs are more forgiving than screws, having equivalent construct stability even with mild off angulation compared to a perfectly aligned screw construct. These biomechanical results appear to be supported by the clinical findings of a 91% bone block healing rate on computed tomography imaging 6 months following with the additional benefit of no neurologic or hardware complications at 14 months follow-up.[28]

These biomechanical results add to the growing body of clinical literature supporting use of SB fixation in glenoid augmentation procedures. A clinical alternative to screw fixation was first pursued by Taverna et al to mitigate hardware complications inherent to the screw fixation construct.[34] This concern is supported by the literature with the most frequent complication in Latarjet/Brostow procedures being related to hardware, with up to 6.5% of cases involving hardware failure (screw bending/breakage, loosening, or malposition) and irritation (humeral head or soft tissue impingement)[7,12] Roughly 35% of cases requiring reoperation are for symptomatic hardware screw removal.[5,12] Several SB graft fixation series have been reported with favorable results, the largest being Boileau's cohort of 121 patients and continued positive clinical outcomes, with 95% of patients experiencing bony union of the coracoid graft to the glenoid rim, a 4% redislocation rate, and a 70% rate of return to sport at the same or higher level within 1 year of surgery.[4,5,22]

Limitations

This study has several limitations. Firstly, this is an in vitro model utilizing Sawbone foam blocks without a synthetic cortex, rather than more biologically representative cadaveric tissue. However, the choice of foam block specimens has the benefit of specimen uniformity, reducing the effect of bone density variation on testing outcomes.[9] By extension, our force testing modules were unable to recreate additional in vivo forces such as tension from the conjoined tendon on the coracoid process, rotational forces, strain, or differences in loading capacity secondary to bone healing.[5,9,28] However, the benefits of a consistent testing protocol allowed assessment of a single variable in a reproducible fashion that may not have been economically feasible with cadavers of varying ages, genders and resultant bone densities. Other limitations of this study are a small sample size, potential for human error during assembly, and the external validity of synthetic constructs, which is true of many biomechanical studies. An additional limitation is that biomechanical testing only provides a time zero assessment of construct stability. How construct stability is impacted with healing is not addressed with this analysis. Lastly, our study does not investigate mode of failure of the grafts, an important clinical question that can be addressed in future cadaveric studies. These findings are sound biomechanically, but will need to be validated in vivo by examining bone healing and incorporation rates using these various fixation techniques. Although, there have been promising clinical outcomes reported in the early postoperative setting, there still remains work to be done investigating outcomes at long term follow-up in order to confirm findings from biomechanical studies.

Conclusion

SBs are biomechanically stronger than screws in glenoid augmentation procedures at 0° and 15°. Off axis angulation of 15° with a SB construct provided equivalent strength to a 0° screw fixation construct.

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