



Non-screw glenoid augmentation constructs for shoulder instability with bone loss: A biomechanical assessment of static and elastic cerclage constructs[☆]

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ABSTRACT

Purpose: This study aims to compare the biomechanical performance of elastic and static suture-based cerclage systems to traditional screw constructs in the setting of modeled glenoid bony augmentation.

Methods: Biomechanical testing was conducted on polyurethane cellular foam blocks modeling a 20 % glenoid defect repaired with a coracoid graft. Constructs consisted of an elastic suture-based cerclage, static suture-based cerclage, and a two-screw construct. Biomechanical testing was performed on material testing system, using a 7-phase, 100 cycle per phase, 1Hz, sinusoidal cyclic loading protocol, following a stair-step pattern in load control. Failure for cyclic loading was assessed at 0.8 mm linear displacement. The absolute end level for load-to-failure was 7.0 mm.

Results: Static suture-based cerclage failed at 5–50 N (Cycles 2 through 4), 2-screw constructs failed at 25–50 N (Cycle 4), and elastic suture-based cerclage failed at 100–200N (Cycles 6 and 7). Elastic cerclage exhibited superior performance compared to static cerclage beginning in Cycle 2 ($p = 0.0440$) and compared to SOC 2-screw construct beginning in Cycle 4 ($p = 0.0118$). 2-screw construct exhibited superior stability performance compared to static cerclage beginning in Cycle 3 ($p = 0.0001$). Elastic cerclage reached failure at 558.141 ± 4.508 N, while 2-screw construct and static cerclage reached failure at 422.009 ± 24.998 N and 366.770 ± 66.653 N, respectively. Elastic cerclage demonstrated superior biomechanical stability in load-at-failure performance to static cerclage ($p < 0.0001$) and the screw construct ($p < 0.0001$), while static cerclage demonstrated inferior biomechanical stability to the screw construct ($p = 0.0343$).

Conclusion: This biomechanical study comparing the performance of elastic cable and static suture tape cerclage fixation methods identified that the elastic cable cerclage exhibits a higher load-at-failure and less displacement under repetitive stress. In addition, elastic cable cerclage fixation exhibits greater strength and construct rigidity than traditional metal screw fixation.

1. Introduction

Numerous advancements have been made in the management of anteroinferior glenohumeral instability since the first reported use of distal tibial allograft. Glenoid bone augment procedures, however, particularly the Latarjet procedure, have a high rate of complications, with symptomatic hardware being one of the main contributors.^{1–4}

Traditional screw fixation can lead to graft fracture, graft malpositioning, osteolysis, direct mechanical irritation, subsequent articular cartilage injury, and hardware breakage which may lead to revision surgeries and implant removal.^{2,5–8} In light of these complications, alternative systems have been proposed for glenoid graft fixation, most notably suture-based fixation techniques.^{9,10}

The initial suture-based fixation technique described by Tavera et al.

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utilized two cortical buttons attached by a looped suture through two parallel drill holes.¹¹ Suture-based fixation, in either a linear construct as with suture-buttons or a cerclage technique in which a single cerclage suture tape is used, has potential advantages over traditional screw fixation. Advantages include a reduced risk of metal-induced osteolysis and soft tissue impingement, bilateral extracortical compression, and adequate graft alignment.^{9,18–25} Other cerclage materials such as elastic cerclage materials are used in orthopaedic trauma and revision arthroplasty, particularly in periprosthetic fracture cases.^{26,27} Despite the theoretical advantages of suture-based fixation, cerclage construct materials have not been assessed to determine influence upon biomechanical performance of glenoid augmentation techniques.

Given the potential benefits of metal-free fixation strategies, there remains a need to determine the ideal non-screw, suture-based fixation construct for glenoid augmentation. The aim of this study is twofold. The first aim is to compare the biomechanical performance of cerclage fixation to screw fixation using a standardized, reproducible testing protocol. The second aim is to compare the biomechanical performance with two different non-metal materials used in the cerclage construct. The authors hypothesize that cerclage with elastic material will demonstrate superior biomechanical performance when compared to the suture-based cerclage, evidenced by increased construct rigidity and strength.

2. Methods

2.1. Constructs of interest

The biomechanical performance of two suture-based cerclage designs and traditional metal screws were compared in the setting of modeled glenoid bony augmentation based upon prior reported models.²⁸ SuperCable Iso-Elastic™ Polymer Cerclage (Kinamed Camarillo, CA) and FiberTape Cerclage (Arthrex Naples, FL) were chosen as clinically applicable elastic and static suture-based cerclage systems, respectively. The Kinamed SuperCable is composed of ultra-high-molecular-weight polyethylene strands braided over a nylon core with a titanium alloy clasp mechanism that secures the free ends of the cerclage once the desired tension is met. The SuperCable system utilizes a tensioning device that allows up to 530 N of tension to be applied to the cerclage. In contrast, FiberTape is composed of polyester strands braided over a polyethylene core in the form of a 2 mm flat tape. The cerclage is secured with a pre-tied hitch loop and utilizes a tensioning device that allows 80 N of tension to be applied. For the screw constructs, 3.75 mm diameter by 32 mm cannulated screws (Arthrex Naples, FL) were used as a comparison for cerclage system performance. The screws were tightened to a standardized 8 Nm torque using a torque measuring screwdriver to simulate “two finger tightness” to prevent stripping as determined during pilot testing. Five constructs were produced and tested for each of the three groups, resulting in a total of 15 models. Sample size was chosen based on prior study methodology.²⁹

2.2. Sawbones model specifications

To model a 20 % glenoid defect repaired with a coracoid graft, polyurethane cellular foam blocks from Sawbones (Pacific Research Labs Vashon Island, WA) were chosen for consistent testing across each specimen. The density of these blocks was chosen to be 15 lb/ft³ to adequately resemble suboptimal-case scenarios of in vivo glenoid and coracoid.^{28,30–32} While some prior studies have tested specimens including a unilateral 102 lb/ft³ short fiber filled epoxy resin laminate with the model cortical bone to resemble outer cortex of both glenoid and graft pieces, preliminary testing revealed non-clinical bony performance, yielding failure values well above what is demonstrated in cadaveric biomechanical studies, as well as failing to achieve plate penetration into the cortical surface.^{33,34} Rectangular geometry and dimensions of the glenoid piece were based on previous work.²⁸ The

glenoid was dimensioned 39 mm × 40 mm × 23.2 mm (width × height × depth, respectively) to represent a 20 % defect in the glenoid (Fig. 1).³⁵ The graft piece was dimensioned to reflect prior work by Willemot et al. whose geometric parameters were ultimately based on previous investigations of harvested coracoid samples.^{28,36} Final dimensions of the graft piece were 26.4 mm × 13.7 mm × 9.3 mm (Fig. 1). Two holes were drilled in each model to simulate drill holes used for securing the coracoid graft to the native glenoid. The distance between the center of each drill hole measured 9 mm. The drill holes in the glenoid were 2.75 mm in diameter, while the corresponding holes in the coracoid graft were 4 mm in diameter.

2.3. Construct assembly

The graft piece was secured to the glenoid piece using two screw fixation, SuperCable cerclage fixation, FiberTape cerclage fixation (Fig. 2). The glenoid model was placed in a benchtop vice, and the holes of the glenoid piece were aligned with those of the graft piece via an alignment jig. For screw constructs, two screws, as defined previously, were inserted into the pre-drilled holes of the graft piece and secured with the torque-measuring screwdriver. For the SuperCable and FiberTape constructs, the free ends of each cerclage fixation were fed through one of the holes of the glenoid piece and out the graft piece, followed by being fed back through the second hole of graft piece and out the glenoid piece. This model simulated inserting the cerclage cable through the posterior aspect of the glenoid and out the anterior graft piece, followed by insertion into the anterior graft piece in the second drill hole and back out through the posterior glenoid. The models without cortex were augmented with a 2-hole plate (Arthrex Naples, FL) on the anterior face of the graft to prevent cut through of the suture as seen in preliminary testing and in prior work (Fig. 2).³⁷ The construct was then tensioned to the maximum value with the tensioner (Kinamed 530 N, Arthrex 80 Nm) and secured according to the respective technique guide. To prevent cut-through, the Kinamed SuperCable metal clasp was augmented with two small aluminum cylinders approximately 1 cm in length to displace force across the glenoid block and account for lack of curvature typically seen with the coracoid graft. An additional 2-hole plate (Arthrex, Naples, FL) was fixed between the FiberTape knot and the posterior glenoid surface for mechanical similarity.

2.4. Biomechanical testing

An aluminum testing jig was constructed to hold the assembled

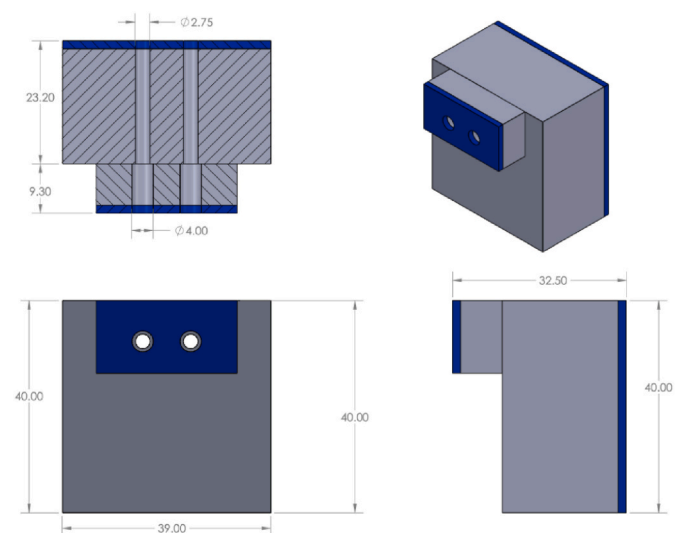


Fig. 1. SolidWorks 3D rendering of graft and glenoid assembly, two holes, 15 lb/ft³ polyurethane cellular foam.

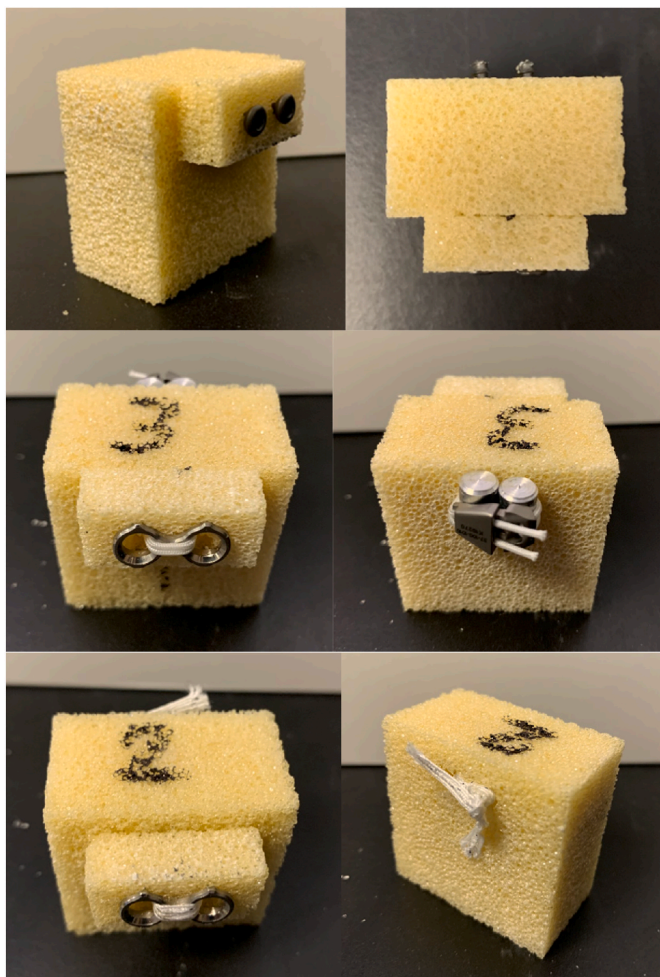


Fig. 2. Construct assembly with Sawbones based glenoid and coracoid graft with screw fixation (top), elastic cable cerclage (middle), and static suture tape (bottom).

constructs securely during the testing procedure. Testing was performed on a Materials Testing System (MTS 858 MiniBionix Eden Prairie, MN). Each sample was preloaded between 2N and 5N to remove slack from the system, as done in previous work.^{28,37,38} The MTS was used to replicate the cyclic loading parameters outlined in Willemot et al. (2018): 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–5 N, (2) 5 N–10 N, (3) 10 N–25 N, (4) 25 N–50 N, (5) 50 N–100 N, (6) 100 N–150 N, and (7) 150 N–200 N.²⁸ Following cyclic loading test completion, the models were returned to 0 mm displacement to allow for a baseline load-to-failure testing. Load-to-failure ramp function displacement was controlled at a rate of 0.5 mm/s. Failure for cyclic loading was marked in the dataset as 0.8 mm linear displacement to mimic post-operative micromotion, which was based on prior literature.²⁸ The absolute end level for load-to-failure was 7.0 mm below the zero-point defined at the beginning of each test, a displacement value based on previous work.^{14,16} Time, force, and displacement data were collected continuously at a sampling rate of 500 Hz for five individual specimens of each model. Load values were captured with a 1500 N load cell, and displacement was measured by the built-in linear displacement transducer from the actuator.

2.5. Data and statistical analysis

Cyclic loading and load-to-failure values were recorded in an electronic data set and analyzed by an experienced biostatistician using SAS

software (SAS Institute Cary NC, USA). Averages and standard deviations were determined with descriptive statistics. Means were compared using a general linear model within each subset of data, with individual subsets composed of either load-at-failure data or cyclic displacement per cycle. Significance was established at $p = 0.05$.

3. Results

3.1. Construct rigidity

Regarding cyclic loading displacement performance with failure defined as 0.8 mm linear displacement, the elastic cable cerclage construct failed at 100–200 N (Cycles 6 and 7); the 2-screw constructs failed at 25–50 N (Cycle 4); and the suture tape cerclage construct failed at 5–50 N (Cycles 2 through 4). The elastic cable cerclage construct exhibited superior performance compared to the suture tape cerclage beginning in Cycle 2 ($p = 0.0440$) and compared to the 2-screw construct beginning in Cycle 4 ($p = 0.0118$). The 2-screw construct exhibited superior performance compared to suture tape cerclage beginning in Cycle 3 ($p = 0.0001$; Table 1).

3.2. Construct strength

Regarding load-at-failure comparison with failure defined as 7.0 mm linear displacement, the elastic cable construct reached failure at 558.141 ± 4.508 N, while the 2-screw and the static suture-based constructs reached failure at 422.009 ± 24.998 N and 366.770 ± 66.653 N, respectively. Elastic cable demonstrated superior load-at-failure performance compared to suture-based cerclage ($p < 0.0001$). The elastic cable construct demonstrated superior biomechanical stability in load-at-failure performance when compared to the 2-screw construct ($p < 0.0001$), while static suture-based cerclage demonstrated inferior biomechanical stability to the 2-screw construct ($p = 0.0343$; Table II).

4. Discussion

The results of this study show elastic cable cerclage is biomechanically comparable to traditional screw fixation methods and superior to static suture tape cerclage fixation.^{23,39,40} This is the first study to biomechanically compare static suture tape and elastic cable cerclage fixation constructs using a standardized and reproducible Sawbones modeled bony glenoid augmentation procedure.

4.1. Elastic cable versus screw

This study found that elastic cable cerclage demonstrated greater rigidity and higher load-at-failure than screw fixation. The superior performance may be attributed, in part, to the inherent nature of a cerclage-type fixation, which applies bilateral compressive forces from both the coracoid graft and the native glenoid.⁹ Conversely, traditional screw fixation is dependent on thread engagement with glenoid cancellous and cortical bone to provide compression through the single screw head on the graft side of the construct alone. A perceived lack of stability in a cerclage construct may be alleviated with the use of an instrument tensioner, which allows a once flexible cerclage to be transformed into a rigid construct, similar to a bolt which provides a “cone of compression”.²³ By increasing this “cone of compression” between the graft and glenoid, a cerclage may be more likely to result in a successful bony union of the graft to the glenoid (Fig. 3).^{9,41,42} This wider distribution of compressive forces across the graft may limit screw-related complications including risk of graft fracture, osteolysis, and possibly stress shielding seen in many series.^{18–22} Use of a suture tensioner, through precise tightening of the assembly, decreases the risk of screw “two-finger tightness” overtightening with resultant osteolysis and graft fracture or under-tensioning and subsequent graft instability, migration, and nonunion.^{23,24} Ultimately suture-based fixation for

Table 1
Cyclic loading displacement of cerclage and double screw constructs.

Cycle (Load)	Construct	Displacement (mm)	St. Dev. (mm)	Correlation Matrix (p-value)		
				Elastic Cable	Suture Tape	2SC ^a
Cycle 1 (0–5N)	Elastic Cable	0.019	0.008	–	0.3003	0.7628
	Suture Tape	0.283	0.487	0.3003	–	0.4610
	2SC ^a	0.095	0.087	0.7628	0.4610	–
Cycle 2 (5–10N)	Elastic Cable	0.038	0.012	–	0.0440	0.5643
	Suture Tape	0.711	0.708	0.0440	–	0.1444
	2SC ^a	0.228	0.128	0.5643	0.1444	–
Cycle 3 (10–25N)	Elastic Cable	0.081	0.022	–	0.0001	0.0856
	Suture Tape	1.466 F	1.011	0.0001	–	0.0183
	2SC ^a	0.661	0.109	0.0856	0.0183	–
Cycle 4 (25–50N)	Elastic Cable	0.158	0.027	–	< 0.0001	0.0118
	Suture Tape	2.698	0.707	< 0.0001	–	0.0002
	2SC ^a	1.158 F	0.190	0.0118	0.0002	–
Cycle 5 (50–100N)	Elastic Cable	0.340	0.038	–	< 0.0001	0.0098
	Suture Tape	3.781	0.645	< 0.0001	–	< 0.0001
	2SC ^a	1.612	0.184	0.0098	< 0.0001	–
Cycle 6 (100–150N)	Elastic Cable	0.728	0.079	–	< 0.0001	0.0062
	Suture Tape	4.517	0.666	< 0.0001	–	< 0.0001
	2SC ^a	2.189	0.229	0.0062	< 0.0001	–
Cycle 7 (150–200N)	Elastic Cable	1.423 F	0.212	–	< 0.0001	0.0038
	Suture Tape	5.369	0.607	< 0.0001	–	< 0.0001
	2SC ^a	2.935	0.352	0.0038	< 0.0001	–

Failure (F) indicates average sample displacement has surpassed 0.8 mm failure threshold.

^a 2SC: 2-Screw construct.

Table 2
Average load-at failure comparison of cerclage and double screw constructs.

Construct	Load-at-Failure (SD) ^b , Newtons	Difference relative to 2SC ^a , Newtons	p-value
Elastic Cable	558.1 (4.5)	136.1	< 0.0001
Suture Tape	366.7 (66.6)	–244	0.0343
2SC ^a	422.0 (25)		

^a 2SC: 2-Screw construct.

^b SD: standard deviation.

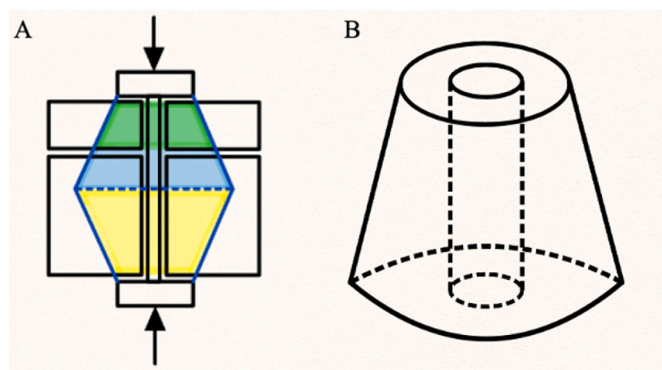


Fig. 3. Theory of bolted joint stiffness. (A) Pressure distribution “cone of compression” throughout thickness of glenoid-graft interface (B) Frustum-shaped stress affected zone. Stress imparted by the suture button construct will propagate out from original point of contact (superior aspect of image) until it meets with stress affected zone of contralateral side.

accommodation of the juxtaposed surfaces without sacrificing stability, promoting self-correction and consistent, adequate graft alignment.^{23,39,40} Given the promise of metal-free fixation strategies in the Latarjet procedure and the demonstrated superior performance, an elastic cable cerclage may be a viable alternative to screw fixation in clinical practice and may exhibit decreased graft malpositioning, hardware failure, and other commonly reported metal-based hardware

complications, particularly in patients with poor bone quality.

4.2. Elastic cable versus suture tape

Through biomechanical testing of cyclic loading to simulate post-operative micromotion and load-at-failure to simulate a catastrophic incident postoperatively, the elastic cerclage proved to be superior to static suture tape cerclage. A variety of factors likely contributed to the improved performance of elastic cerclage over the static cerclage. Elastic cable cerclage has been reported to have a tensile strength of 5377N in some models,⁴³ while the tensile strength of a static suture tape cerclage is 4359N.⁴⁴ While not compared directly, multiple studies have demonstrated that elastic cable cerclages have high resistance to wear without any changes visualized even after one million load cycles.⁴⁵ Arguably the biggest difference between elastic and static cerclage systems is the ability of the elastic cable cerclage to exert compressive forces despite bone resorption that may occur. Bone resorption is natural in the setting of bone healing and remodeling, in which there is an intricate cycle of resorption by osteoclasts and bone formation by osteoblasts.⁴⁶ This process, termed ‘coupled remodeling’, may be assisted by increased compressive forces exerted by an elastic cerclage system to improve healing rate in the case of excessive resorption.^{47,48} Elastic cable cerclages have been shown to have up to 20 times greater elastic spring back than other static cerclages, allowing compressive forces to be maintained despite displacement of compressed bone graft and construct components.^{45,49} Additionally, the manufacturer-provided tensioning devices for each system allow the elastic cerclages to be tensioned to higher values than the static cerclages, 530N compared to only 80N. Furthermore, the elastic cable cerclage system relies on a metal clasp to secure the cable rather than knots as in the static cerclage system, perhaps allowing the construct to avoid knot slippage and improving the ability of the elastic cable cerclage system to resist higher degrees of force.^{50–52}

4.3. Suture tape versus screw

Whereas elastic cable cerclage exhibited improved biomechanical performance compared to metal screw fixation, the static suture tape cerclage exhibited inferiority in both cyclic loading testing and load-to-failure. Clinically, Hardy et al. demonstrated increased recurrence rates

with suture buttons (8.3 %) compared to screws (2.5 %).⁵³ While our study did not specifically investigate reasons for static suture tape cerclage underperformance, the cause may be associated with knot slippage. Knot slippage is common phenomenon, It is plausible to infer that as testing progressed, lengthening of the suture tape loop may have resulted in slippage, precipitating earlier failure.^{54–57} This phenomenon was also observed by Nolte et al. in their recent comparison of metal screws and suture tape cerclage constructs.³⁷ In addition, the use of hand tensioning over instrument tensioning the constructs may have precipitated knot slippage. Additionally, as mentioned previously, the Tensioner and Technique Guide followed for the suture tape cerclage instrument tensioning dictates a maximum construct tensioning of 80N, which may limit the performance of the system relative to screw-based constructs. However, there is likely an upper limit of acceptable compression to be applied to the system to prevent graft collapse and cut through of suture which requires further investigative work.

4.4. Inconsistencies within current literature

One of the strengths of this study is the standardization of the testing protocol based on pilot testing of prior protocols. This process was undertaken as there is inability to draw sound, clinically relevant conclusions regarding biomechanical performance of suture based and metal screw constructs primarily due to methodology inconsistencies and limitations of individual study sample sizes. While a small number of studies have attempted to systematically review the biomechanical literature to make comparisons between constructs, these studies are largely invalid due to notable discrepancies in experimental technique.^{58–60} Some groups attempt to use cadaveric specimens with ages ranging from 55 to 90 years.^{13–17,38,61,62} This is not clinically applicable, as glenoid augmentation procedures occur most commonly in younger patients with better bone quality.⁶³ Regarding Sawbones techniques, no consistency exists within density of specimens chosen or with the inclusion or exclusion of cortical models.^{12,28,29,31,64} Failure values have large ranges when examining the totality of the literature due to these differences, as extremely dense bone models allow for significantly greater compression forces from a construct before crumbling. The technique proposed in this study is reproducible and exhibits clinical relevance due to specimen choice, and standardization of methodology which will allow for future study comparisons.

4.5. Limitations

This study was limited by several factors, many of which are related to the biomechanical nature of the study. First, Sawbones models were used in this study rather than anatomic specimens in a biomechanical lab setting or in vivo, limiting the conclusions that may be drawn from this study. Furthermore, these samples did not model a cortex, thus altering the estimation of forces that could be overcome in true clinical applications of this technology. However, this model provides a “worse-case scenario” and may be useful for patients with rather poor bone quality. Additionally, the metal clasp of the elastic cable cerclage, designed to sit on the surface of a rounded long bone, did not fit well on the flat glenoid piece of this model, requiring the placement of aluminum cylinders between the clasp and model to create a more appropriate resting surface for the clasp. While this alteration should not influence the biomechanics or fixation strength of the elastic cables, it adds an additional factor to the study and would require remedy prior to utilizing this construct for fixation in clinical studies. With any procedure, human error may be introduced with construct assembly. To minimize these errors and differences between constructs, knots were tied by one fellowship-trained surgeon as specified in each respective technique guide.

Future research regarding cerclage type fixation with glenoid bone augment procedures should focus on clinical applications and clinical studies. Though not used due to financial factors, Sawbones scapula

replicas may provide a more realistic testing model. It would be prudent to evaluate long term success of cerclage fixation methods, including time to pull out and displacement over a greater length of time. Lastly, in this study an aluminum jig was used to drill holes through the model glenoid and graft pieces ensuring the holes were consistently aligned. It is recognized that in clinical practice this ideal scenario would not be the case as the holes in the graft and the glenoid are often drilled separately, creating potential for variance in drill angle and therefore surface mismatch between the graft surfaces. Prior work has examined the impact of lack of perfect alignment on various fixation types as well as long term effects, and additional study should examine the effects of hole malalignment in static and elastic cerclage constructs.^{29,65}

5. Conclusions

This biomechanical study comparing the performance of elastic cable and static suture tape cerclage fixation methods identified that the elastic cable cerclage exhibits a higher load-at-failure and less displacement under repetitive stress. In addition, elastic cable cerclage fixation exhibits greater strength and construct rigidity than traditional metal screw fixation.

CRediT authorship contribution statement

Kyle Paul: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **John N. Manfredi:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Mathew Hargreaves:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Mitchell K. Messner:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Clay A. Rahaman:** Methodology, Validation, Resources, Writing – review & editing. **Brent Ponce:** Resources, Supervision, Project administration, Writing – review & editing. **Amit M. Momaya:** Resources, Supervision, Project administration, Writing – review & editing. **Eugene Brabston:** Resources, Supervision, Project administration, Writing – review & editing.

Consent statement

As this was a biomechanical study, there were no patients to consent.

Ethical statement

This biomechanical study had no direct contact with patients or their data, so there was no potential to unethically treat patients or patient data.

Funding statement

There was no source of internal or external funding for this study.

Declaration of competing interests

The following authors have the stated interests: **Amit Momaya:** CONMED Corporation- Other Professional Activities; **Eugene Brabston:** EBSCO-Editorial or governing board, Link Orthopaedics-Paid consultant, Orthopaedic Design NA-Paid consultant; **Aaron Casp:** American Orthopaedic Society for Sports Medicine-Board or committee member, Arthrex, Inc-Paid consultant; **Brent Ponce:** American Orthopaedic Association: Board or committee member, Help Lightning: Stock or stock Options, Orthopaedic Designs North America Inc.: Paid consultant, Smith & Nephew: Paid consultant, Stryker: IP royalties; Paid consultant; Paid presenter or speaker.

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