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Influence of screw type and length on fixation of anterior glenoid bone grafts

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Abstract

Background: Bone-grafting procedures for recurrent shoulder instability produce low recurrence rates, although they are associated with complications such as graft non-union. Inadequate screw purchase is considered to play a causative role. However, excessive screw length can endanger neurovascular structures. The present study aimed to investigate how type and length of screws influences construct rigidity in a simplified glenoid model.

Methods: Testing was performed on composite polyurethane foam models with material properties and abstract dimensions of a deficient glenoid and an bone graft. Three screw types (cannulated 3.75 mm and 3.5 mm and solid 4.5 mm) secured the graft in a bicortical–bicortical, bicortical–unicortical and unicortical–unicortical configuration. Biomechanical testing consisted of applying axial loads when measuring graft displacement.

Results: At 200 N, graft displacement reached 0.74 mm, 0.27 mm and 0.24 mm for the unicortical–unicortical and 0.40 mm, 0.25 mm and 0.24 mm for the unicortical–bicortical configuration of the 3.75 mm, 3.5 mm and 4.5 mm screw types. The 3.75 mm screw incurred significant displacements in the unicortical configurations compared to the bicortical–bicortical method ($p < 0.001$).

Conclusions: The present study demonstrates that common screw types resist physiological shear loads in a bicortical configuration. However, the 3.75 mm screws incurred significant displacements at 200 N in the unicortical configurations. These findings have implications regarding hardware selection for bone-grafting procedures.

Keywords

biomechanical, coracoid, fixation, Latarjet, non-union, pseudarthrosis, screw

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Introduction

Anterior glenoid rim reconstruction by bone grafting is increasingly used in the treatment of anterior shoulder instability.[1] Coracoid process transfer procedures such as described by Latarjet[2] and Bristow[3], iliac crest grafts as described by Eden and Hybbinette[4–6] and, recently, distal tibia[7] and glenoid allografts[8] have been used for this purpose. Large series have reported low recurrence rates after coracoid transfer procedures, demonstrating superiority over standard soft tissue repairs for high-risk patients. [9–11] However, anterior bone grafting procedures are associated with a 30% risk of complications and 7% risk of re-operation.[12] Graft pseudarthrosis or non-union between the coracoid process and the glenoid neck is seen in 9.4% of cases after Bristow–Latarjet. Such non-unions are often incidental findings,[13] yet symptomatic graft non-union may require revision surgery as a result of pain or recurrent instability.[14–16] Revision surgery after failed anterior bone grafting is technically demanding and not without risk.[14,15] The aetiology of graft pseudarthrosis is multifactorial.

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Bone-to-bone healing is influenced by contact gap, blood supply, hormonal milieu, neural regulation and mechanobiological environment.[17–19] The initial shear fixation stability is a recognized parameter for successful healing and is directly influenced by the fixation method.[20,21] Some studies have suggested a causative association between insufficient screw purchase and graft pseudarthrosis.[22,23] However, rigid fixation must be weighed against the risks of excessive screw length such as neurological injury.[24] The present study aimed to investigate whether screw design and length may influence glenoid-graft construct rigidity and thus contribute to graft non-union and failure.

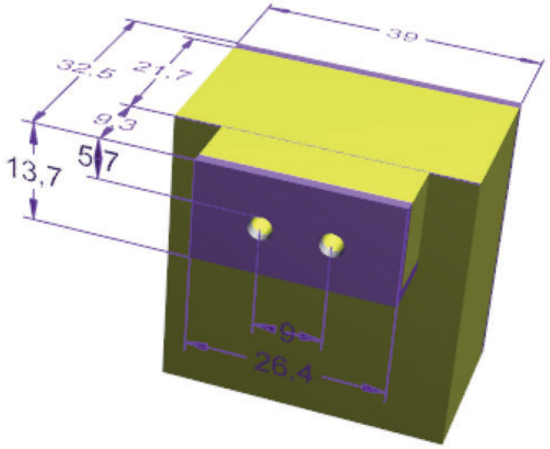

Figure 1. Three-dimensional drawing of the stylized foam bone model consisting of coracoid with pilot drill holes and glenoid. Light colour indicates cancellous bone; darker colour indicates cortical bone. Measurements are shown in millimeters.

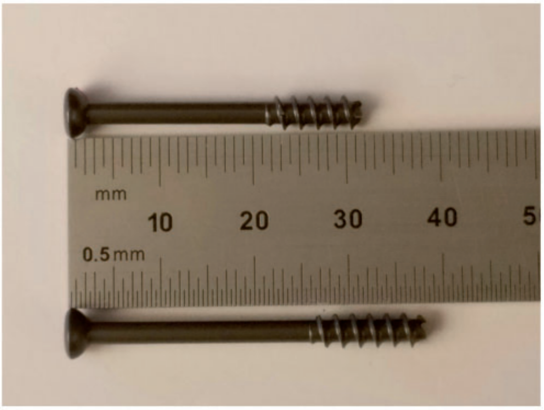

Figure 2. Photograph of the Arthrex 3.75 mm titanium cannulated screw.

Materials and Methods

Testing was performed on polyurethane foam block models to limit the experimental difficulties resulting from the use of human cadaveric bone such as inconstant anatomical dimensions, degenerative changes and variable bone quality. The generic 20 pound/cubic foot rectangular foam blocks were fitted with a 2 mm thick short fibre filled epoxy resin laminate to replicate the material properties of cancellous bone with a cortical shell (Sawbones Inc., Vashon, WA, USA).[25–27] The resin layer was machined down to a thickness of 1.5 mm to match physiological human glenoid cortex thickness.[25] Cancellous and cortical density were 20 pounds/square foot and 102 pounds/square foot, respectively. The rectangular block measured 21.7 mm × 39 mm × 40 mm, representing the average glenoid width and height after creation of a 25% defect (Fig. 1).[28] The anterior bone grafts were created from the same material. The composite graft dimensions, 13.7 mm × 9.3 mm × 26.4 mm were based on previously published measurements of harvested coracoid processes because these are the most frequently used grafts. However, a simple quadrangular shape was chosen to allow extrapolation of results to other types of grafts such as tibial plafond allografts and iliac crest autografts.[29] Similarly to clinical conditions with significant glenoid bone loss, the model contains a flat anterior cancellous surface apposed to a flat cancellous graft surface.[30]

Three commonly used screws were selected for the experiment. The Arthrex 3.75 mm titanium cannulated screw (Arthrex, Naples, FL, USA) (Fig. 2), the Mitek 3.5 mm titanium cannulated Bristow–Latarjet Instability Shoulder Screw (Depuy Synthes Mitek Sports Medicine, Raynham, MA, USA) (Fig. 3) and the Synthes 4.5 mm steel Large Fragment LCP System Malleolar Screw (Synthes, West Chester, PA, USA) (Fig. 4). The Arthrex screws (major diameter 3.75 mm, shaft diameter 2.4 mm, thread pitch 1.8 mm), part of the Glenoid Bone Loss Instrument Set, are self-drilling, self-tapping screws. They are partially threaded, and a popular choice when performing a Congruent-Arc Latarjet procedure.[31] The Mitek system (major diameter 3.5 mm, shaft diameter 3.0 mm, thread pitch 0.75 mm) includes titanium Top Hats, which are used as position holders and are inserted prior to screw insertion to prevent graft fracture. The partially threaded stainless steel Synthes screws (major diameter 4.5 mm, shaft diameter 2.9 mm, thread pitch 1.75 mm) are used for fracture fixation as part of the Synthes Large Fragment set. They are considered the 'gold standard' in glenoid bone block fixation. Technical specifications are listed in Table 1.[30]

Short and long screws lengths were selected for each screw type (Table 1). Combinations of short and/or long screws allowed for testing in three configurations: (i) both screws with unicortical purchase (unicortical–unicortical); (ii) one unicortical and one bicortical

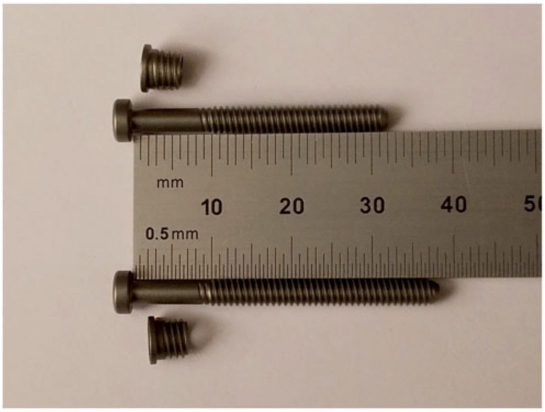

Figure 3. Photograph of the Mitek 3.5 mm titanium cannulated Bristow-Latarjet instability shoulder screw.

Figure 4. Photograph of the Synthes 4.5 mm steel Large Fragment LCP System malleolar screw.

screw (unicortical–bicortical); and (iii) both screws with bicortical purchase (bicortical–bicortical). Six constructs of each screw type and length configuration were produced, amounting to a total of 54 models. Short screw lengths were selected from the manufacturer's available range per type to minimize the variability of effective intraglenoidal length. Intra-osseous length was set at 30 mm for all screws (Table 1), replicating a realistic intra-operative scenario. Long screw lengths were chosen to guarantee bicortical purchase beyond the screws' spike tip. Two parallel pilot holes were drilled 9 mm apart, centred on the anterior cortical graft side and tapped according to the manufacturer's instructions. Screws were inserted and tightened with a digital torque measuring screw driver (Model STC50CN; Tonichi, Buffalo Grove, IL, USA). Average torque of 'two-finger tightness' was determined from the authors' mean torque measurements.

After screw insertion, bone blocks were loaded into a vice and subjected to a cyclic loading staircase protocol

Table 1. Specifications and dimensions of screws used in this study.

Manufacturer	Description	Size	Part number	Nominal length (mm)	Intra-osseous length (mm)	Thread pitch	Shaft length	Thread length	Shaft/thread length ratio
Arthrex	Screw, partially Threaded	3.75	AR-7000-32S	32	30	1.8	20	8	40%
			AR-7000-38S	38	Bicortical	1.8	24	10	42%
Mitek	Bristow – Latarjet instability shoulder screw	3.5	285121	32 (modified to 30)	30	0.75	10	20	200%
			285117	38	Bicortical	0.75	13	28	280%
Synthes	Malleolar screw	4.5	215.035	35	30	1.75	10	12	92%
			215.045	45	Bicortical	1.75	10	16	84%

based on previous work by Giles et al.[32,33] Testing apparatus consisted of an Instron Model 5944 (Instron, Norwood, MA, USA). The system was manually pre-loaded with 2 N to 5 N of force centered on the 'articular' side of the graft removing all slack from the system. The load and displacement of the grafts were then zeroed and the staircase protocol initiated. Loads were applied evenly with the help of a metal plate covering the lateral or 'articular' surface of the graft. These simulated loads are an approximation of physiological loading that may occur in the immediate postoperative period.[34] Additional loading of the graft by action of the conjoint tendon was omitted from our experiment for three reasons. First, this allows generalization of the results to all types of grafts, not exclusively the coracoid process grafts of the Latarjet-type procedures. Second, the direction and magnitude of conjoint tendon pull in the postoperative period has not been quantified accurately in the literature. Third, construct fixation strength is not considered to differ greatly between simulated loads in a pulling or pushing mode. Loading was repeated for 100 cycles at a frequency of 1 Hz. Load increments were 0 N to 5 N, 5 N to 10 N, 10 N to 25 N, 25 N to 50 N, 50 N to 100 N, 100 N to 150 N and 150 N to 200 N. Graft displacement was measured continuously (Fig. 5). Failure was set at 0.8 mm of shear displacement, based on previously published fracture healing data.[20,21]

Statistical analysis

Graft displacement was recorded as the final displacement during the last cycle of each loading increment. If an 0.8 mm displacement was achieved before maximum loading was completed, the cyclic loading was discontinued and the load and displacement at that point recorded. Statistical analyses of displacement data was performed by means of an analysis of variance (ANOVA) test for each loading step. In the case of a significant result, further analysis composed by a series of *t*-tests was performed. $p < 0.05$ was considered statistically significant. Power analyses were calculated with pilot data *a priori*, indicating that six models per condition would achieve a minimum power of $\beta = 0.8$.

Results

Graft configuration with two bicortical screws demonstrated maximal displacements of 0.26 mm, 0.26 mm and 0.25 mm (SD 0.01 mm, 0.02 mm and 0.04 mm) at 200 N loads for the cannulated Arthrex 3.75, cannulated Mitek 3.5 and solid Synthes 4.5 screws, respectively (Fig. 6). ANOVA statistical analysis did not show a significant difference between the final displacements at any of the incremental loads. Graft fixation with a unicortical and a bicortical screw exhibited a significant difference in final displacements at 100 N ($p = 0.016$), 150 N ($p = 0.003$) and 200 N ($p = 0.002$). Maximal displacement at 200 N reached 0.40 mm, 0.25 mm and 0.24 mm (SD 0.12 mm, 0.02 mm and 0.01 mm) for the respective screw types (Fig. 7). Similarly, graft fixation with two unicortical screws resulted in a significant difference of displacements at 100 N ($p = 0.005$), 150 N ($p < 0.001$) and 200 N ($p < 0.001$). Maximal observed graft displacements were 0.74 mm, 0.27 mm and 0.24 mm (SD 0.04 mm, 0.01 mm and 0.01 mm) for Arthrex, Mitek and Synthes screws, respectively (Fig. 8).

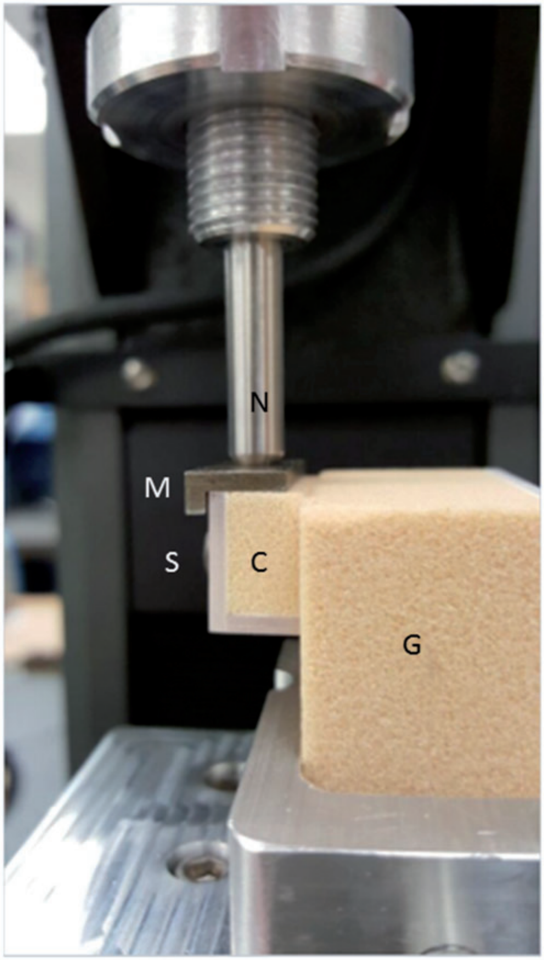

Figure 5. Photograph of mounted model during load application. G, glenoid model; C, coracoid model; S, screwhead; M, metal plate; N, loading nose.

ANOVA per screw type revealed a significant statistical difference at 200 N for the cannulated Arthrex screw 3.75 mm between the two unicortical and two bicortical configurations, as well as between the two unicortical and unicortical–bicortical configurations. The observed displacements were 0.74 mm (SD 0.04 mm) and 0.26 mm (SD 0.01 mm) ($p < 0.001$) and 0.74 mm (SD 0.04 mm) and 0.40 mm (SD 0.13 mm) ($p < 0.001$). ANOVA

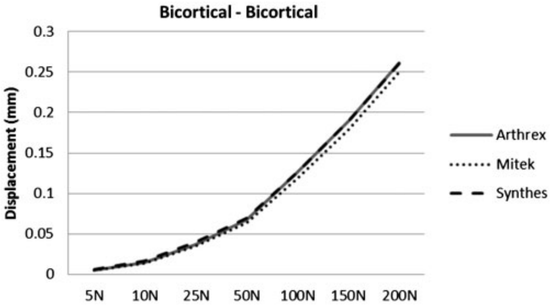

Figure 6. Line chart showing displacement (mm) versus loading (N) for the bicortical–bicortical configuration.

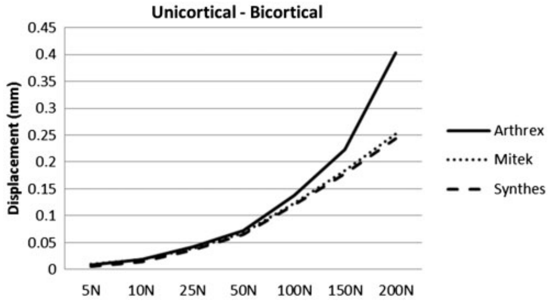

Figure 7. Line chart showing displacement (mm) versus loading (N) for the bicortical–unicortical configuration.

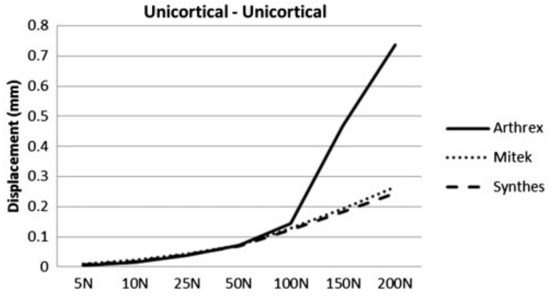

Figure 8. Line chart showing displacement (mm) versus loading (N) for the unicortical-unicortical configuration.

comparison between the unicortical–bicortical and two bicortical configurations did not reach statistical significance. Similarly, comparisons for the cannulated Mitek 3.5 mm screws showed a trend towards greater displacements in the unicortical fixation compared to the unicortical–bicortical or bicortical fixation. However, these differences were not statistically significant. The solid Synthes 4.5 mm screws at the 200 N loading demonstrated the smallest variation of all three screw types. There were there no statistically significant differences in graft displacement between the three configurations, nor were there any trends (Fig. 9).

Discussion

The Latarjet–Bristow and similar anterior glenoid bone grafting procedures are increasingly used in the treatment of patients with recurrent shoulder instability and glenoid bone deficiency.[1] Although recurrence is infrequent or even absent in some series,[9,35,36] a relatively high complication and reoperation rate has been reported.[12,13,37,38] Clinical studies have shown the importance of correct graft-to-bone healing.[14–16] However, construct strength and rigidity have to be weighed against hardware complications. As such, the fixation technique remains an area of debate.

The present biomechanical study confirms that three screw types, commonly used in the setting of glenoid bone grafting, resist repetitive physiological shear loads without clinically significant displacement when both screws attain bicortical purchase. Additionally, the present study demonstrates that, where the cannulated Mitek and solid Synthes screws performed satisfactorily in a unicortical–unicortical and unicortical–bicortical configuration, the cannulated Arthrex screws showed significantly larger shear displacement during the higher loads in those configurations. The Arthrex screws exhibited the smallest shaft diameter, the coarsest pitch, a larger thread rise and the lowest shaft/thread length ratio of the three screw types in this experiment (Table 1). The mechanism behind the inferior performance in unicortical configuration may be a result of a combination of the smaller amount of cancellous 'bone' in shear (coarse pitch and short thread length), the larger bending moment about the fulcrum point (low shaft/thread length ratio) and the passage of large threads creating bone voids (large thread rise), which may weaken the supportive bone stock.

Studies examining the biomechanical rigidity of fixation techniques for glenoid bone loss are sparse. Weppe et al.[22] compared the load to failure of a bicortical screw technique versus a bioabsorbable interference screw. In ten cadaver specimens, the median load to failure was 202 N and 110 N for the bicortical screws and the interference screw, respectively. Alvi et al.[34] compared energy and cycles to failure between 3.5 mm stainless steel cortical screws and 4.0 mm stainless steel partially threaded cannulated cancellous screws. No statistically significant differences in either parameter were found.

Load to catastrophic failure is an important parameter; however, in the present study subclinical displacement was chosen as the primary outcome parameter. The experimental set-up aimed to recreate the immediate postoperative environment before bony healing occurs. It was not the intention to simulate *in vivo* loading of anterior glenoid bone grafts in the present study, merely to assess immediate postoperative construct stability. Although, active motion is typically deliberately minimized during this postoperative period, it is assumed

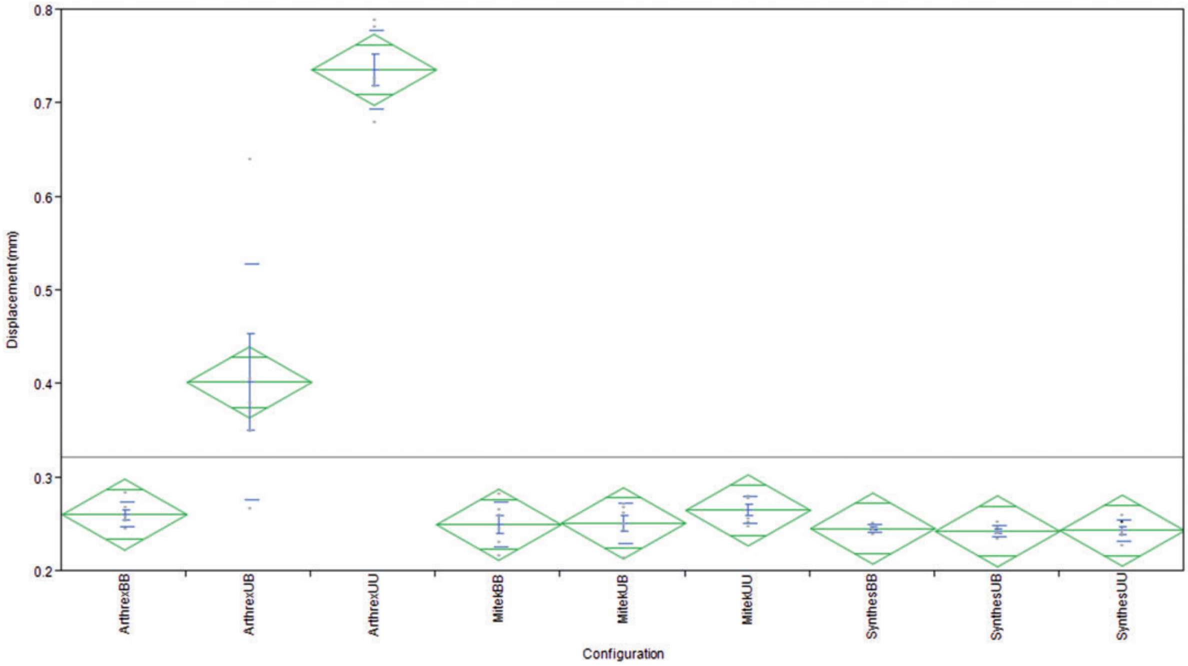

Figure 9. Diamond plot showing displacement (mm) per configuration per screw-type. Green diamonds indicate confidence interval. Blue error bar indicates mean error. Blue lines indicate standard deviation. BB, bicortical–bicortical; UB, unicortical–bicortical; UU, unicortical–unicortical.

that early micromotion plays a role in the development of pseudarthrosis. The threshold for clinically significant displacement of the graft was based on previous literature on fracture healing as adopted by Giles et al.[32]

Non-union of a coracoid or other bone block following an anterior glenoid augmentation procedure is a recognized and clinically significant complication. Non-union may result in recurrent instability and the need for revision surgery. Griesser et al.[12] evaluated performed a systematic review, analyzing 45 studies (1904 shoulders). They reported a non-union rate of 9.1%.[12] Mizuno et al.[11] reported an incidence of 1.5% in a series of 68 patients and Dumont[36] reported an incidence of 1.7% in a series of 62 patients. It has, however, been established that standard radiographic techniques are not suited to evaluate bony healing accurately.[39]

Graft position may play a role in the development of graft pseudarthrosis. Grafts placed inferiorly on the glenoid can lead to poor inferior screw purchase and decreased rotational stability, resulting in a weak biomechanical construct.[22] Grafts placed too cranially can lead to recurrent instability[40,41] or suprascapular nerve injury.[24,42] Grafts placed too medial or lateral can result in recurrence or secondary osteoarthritis, respectively.[43,44] Willemot et al.[45] recently described ideal graft positioning in the sagittal plane depending on the direction of dislocation. Proponents of arthroscopic anterior glenoid grafting procedures have cited more accurate graft placement under direct visualization as a possible advantage over open procedures.[46]

Screw depth has not been studied extensively in its relationship to graft fixation. Although most technique guides stress the placement of both superior and inferior screws in a bicortical fashion to maximize fixation strength, it is our experience that evaluation of bicortical position without the use of a postoperative computed tomography scan can be difficult. To avoid complications associated with excessive posterior screw protrusion, some surgeons will accept one or two unicortical screws. The results of the present study suggest that some commonly used solid and cannulated screws allow for one or even both screws to be placed in a unicortical manner without compromising the construct rigidity.

Limitations

The limitations of the present study were those inherent to a biomechanical study using clinical parameters in a nonclinical testing environment. The decision to use Sawbones (Sawbone Inc.) was made to increase the reproducibility and uniformity of the experiment. Most biomechanical studies related to graft fixation are performed on cadavers, yet the variability of cadaveric bone has been shown to be highly unpredictable. Mechanical properties of cadaver bone have up to 19 times the inter-specimen variability compared to uniform bone models.[47] An abstract rectangular representation of the glenoid and graft was chosen instead of an exact anatomic model. This allowed for the elimination of anatomic and mechanical variability as a confounding factor. Moreover, in the case of large glenoid defects, a relatively flat cancellous anterior glenoid surface is mated with a prepared flat cancellous graft surface, which is why it was considered that an abstract flat shape would not diminish the applicability of the results. However, the use of non-anatomic geometry remains a limitation of the present study. The conjoint tendon, capsular structures and rotator cuff action may influence graft loading postoperatively. Human factors that may affect micromotion at time zero such as soft tissue and conjoint tendon traction were not simulated in this experimental set-up. Furthermore, although the cyclic loading protocol is a peer-reviewed standard for testing graft fixation strength, this experiment did not aim to simulate the actual physiological loading environment after anterior glenoid bone grafting. The intention of the test was to assess different graft fixation modalities under carefully controlled laboratory settings.

Conclusions

The present study confirms that three common screw types used for fixation of bone grafts to the glenoid can resist simulated physiological shear loads when placed in a bicortical–bicortical configuration. Furthermore, the present study shows that the cannulated 3.5 mm Mitek and solid 4.5 mm Synthes screws were also able to resist the applied loads without producing clinically significant displacement in either a unicortical/bicortical or unicortical/unicortical configuration, whereas the 3.75 mm cannulated Arthrex screws failed to do so. Further studies are required to validate the findings and explore biomechanical rigidity of novel fixation techniques.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship and/or publication of this article: J. Burns, A. Castagna and O. Verborgt are paid consultants for ConMed Linvatec. The study was performed at the research facilities of ConMed Linvatec. ConMed Linvatec products were not tested as part of this study. There exists no financial bias related to the subject of this experiment.

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Ethical review and Patient Consent

Ethical review and patient consent were not required for this non-cadaveric biomechanical study.

Level of evidence

Basic science

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