Original Research

Biomechanical Analysis of Plate Fixation Compared With Various Screw Configurations for Use in the Latarjet Procedure

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Background: The biomechanical properties of coracoid fixation with a miniplate during the Latarjet procedure have not been described.

Purpose: To determine the biomechanical properties of miniplate fixation for the Latarjet procedure compared with various screw fixation configurations.

Study Design: Controlled laboratory study.

Methods: A total of 8 groups ($n = 5$ specimens per group) were tested at a screw insertion angle of 0°: (1) 3.75-mm single screw, (2) 3.75-mm double screw, (3) 3.75-mm double screw with washers, (4) 3.75-mm double screw with a miniplate, (5) 4.00-mm single screw, (6) 4.00-mm double screw, (7) 4.00-mm double screw with washers, and (8) 4.00-mm double screw with a miniplate. In addition, similar to groups 1 to 3 and 5 to 7, there were 30 additional specimens ($n = 5$ per group) tested at a screw insertion angle of 15° (groups 9-14). To maintain specimen uniformity, rigid polyurethane foam blocks were used. Testing parameters included a preload of 214 N for 10 seconds, cyclical loading from 184 to 736 N at 1 Hz for 100 cycles, and failure loading at a rate of 15 mm/min until 10 mm of displacement or specimen failure occurred.

Results: All single-screw constructs and 77% of 15° screw constructs failed before the completion of cyclical loading. Across all groups, group 8 (4.00-mm double screw with miniplate) demonstrated the highest maximum failure load ($P < .001$). There were no differences in failure loads among specimens with single-screw fixation (groups 1, 5, 9, and 12; $P > .05$). All specimens in groups 9, 10, 11, 12, 13, and 14 (insertion angle of 15°) had significantly lower maximum failure loads compared with specimens in groups 2, 3, 4, 6, 7, and 8 (insertion angle of 0°) ($P < .001$ for all).

Conclusion: These results indicate significantly superior failure loads with the miniplate compared with all other constructs. Across all fixation techniques and screw sizes, constructs with screws inserted at 0° performed better than constructs with screws inserted at 15°.

Clinical Relevance: The use of a miniplate for coracoid fixation during the Latarjet procedure may provide a more durable construct for the high-demand contact athlete.

Keywords: shoulder; instability; glenoid reconstruction; biomechanics; Latarjet

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The Latarjet procedure has become the treatment of choice in the management of anterior glenohumeral instability with clinically significant degrees of glenoid bone loss.[3,9,17] Hovelius et al[12-17] reported multiple studies with long-term follow-up, demonstrating the success of this procedure. The Latarjet procedure is performed by transferring the osteotomized coracoid process through a split in the subscapularis tendon to the anterior inferior glenoid neck and internally fixing it to the glenoid rim. Several distinct mechanisms are responsible for maintaining glenohumeral stability after the Latarjet procedure. Specifically, the coracoid bone block creates a bony extension of the glenoid surface. In addition, the conjoined tendon and the inferior half of the subscapularis tendon act as a sling, preventing anterior subluxation when the arm is brought into abduction and external rotation.[18] Finally, choosing to repair the inferior capsule to the stump of the coracoacromial ligament provides additional restraint to anterior glenohumeral translation.

Previous biomechanical studies have attempted to assess the advantages of various differences in the surgical approach,

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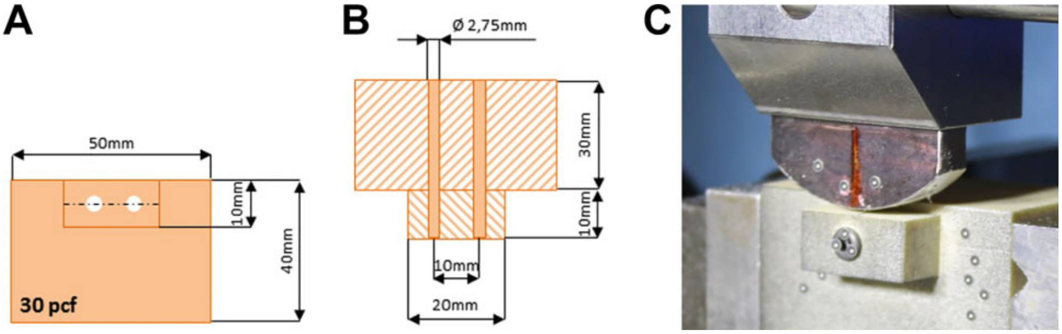

Figure 1. (A, B) Dimensions of the larger foam block used to represent the glenoid (30 × 50 mm) and the smaller foam block used to represent the coracoid bone graft (10 × 20 mm). (C) Test setup with coracoid and glenoid bone blocks and a custom-made load applicator.

implant choice (type and number of screws), and location of graft placement during the Latarjet procedure.[6,9,10,18,20,21] Certainly, advances in the technique and implant design continue to improve the procedure. Multiple constructs to achieve fixation of the coracoid transfer have been described to include screw constructs with varying screw sizes (eg, fully threaded, partially threaded, cannulated, 2 screws, single screw). Nevertheless, screw breakage in patients undergoing the Latarjet procedure for shoulder instability with bone loss has been noted anecdotally as a complication and can result in devastating clinical outcomes.[3-5,19]

To our knowledge, no analysis has been performed to compare miniplate and screw fixation versus screw-only fixation for the Latarjet procedure. The purpose of this study was to determine the biomechanical properties of miniplate fixation for the Latarjet procedure and to compare these findings with various screw fixation configurations. We hypothesized that the use of a miniplate during the Latarjet procedure may provide more durable coracoid fixation.

METHODS

There were 2 types of screws tested with 4 different fixation types at 2 different angles. Both were cortical screws made from titanium, which were cannulated and partially threaded, and had a total length of 32 mm. The smaller of the 2 screws was 3.75 mm in outer diameter and had a thread length of 10.5 mm. The larger screw had an outer diameter of 4.00 mm and a thread length of 16.0 mm. For each screw type, single-screw, double-screw, double-screw with washer, and double-screw with plate configurations were tested. Both washers and plates were made from titanium as well. The dimensions of the plate were as follows: 8.5 mm at its widest point and 2.4 mm at its narrowest part. All implants were obtained from a medical device manufacturer (Arthrex). The configurations were tested at 0° and 15° insertion angles (relative to the face of the glenoid). A 15° insertion angle was chosen as a worst-case scenario with respect to screw deviation relative to the surface of the plate. With a sample size of 5, a total of 70 specimens were prepared and tested. To maintain specimen uniformity, rigid polyurethane foam blocks of uniform composition and density of 30 lb/ft^3 were cut into samples, representing the geometry of the glenoid (30 × 50 mm) and the coracoid bone graft (10 × 20 mm) (1522-04; Sawbones) (Figure 1). The 10 × 20–mm bone block size was chosen to replicate the size of the coracoid bone block after coracoid harvest in vivo.[2] In accordance with the manufacturer's surgical technique, the following procedure was performed for all groups. A parallel guide was used to insert a 1.6-mm K-wire through both foam blocks and overdrilled with a cannulated 2.75-mm drill (Arthrex). Afterward, the 32 mm–long partially threaded cannulated screws were inserted and fixed with a 0.8-N·m torque measured with a torque meter. The necessary insertion torque was previously determined by 3 surgeons applying "2-finger"

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Ethical approval was not sought for the present study.

TABLE 1
Test Groups (n = 5 Each)

	0° Angulation		15° Angulation	
	3.75 mm	4.00 mm	3.75 mm	4.00 mm
Single screw	Group 1	Group 5	Group 9	Group 12
Double screw	Group 2	Group 6	Group 10	Group 13
Double screw with washer	Group 3	Group 7	Group 11	Group 14
Double screw with plate	Group 4	Group 8		

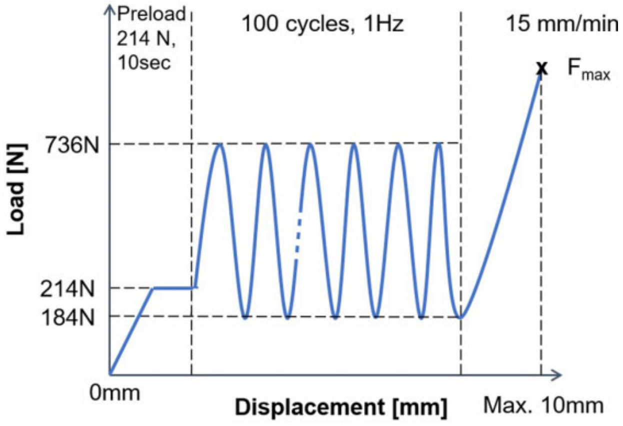

Figure 2. Graph of the biomechanical test protocol.

TABLE 2
Ultimate Failure Loads at 0° Insertion Angle[a]

	Single Screw, n	Double Screw, n	Double Screw With Washer, n	Double Screw With Plate, n
3.75 mm	653.5 ± 63.2	1341.0 ± 121.5	1628.9 ± 51.5	1766.4 ± 85.9
4.00 mm	575.9 ± 35.7	1337.4 ± 37.5	1565.4 ± 88.2	2052.6 ± 65.3

[a]Data are presented as mean ± SD.

TABLE 3
Ultimate Failure Loads at 15° Insertion Angle[a]

	Single Screw, n	Double Screw, n	Double Screw With Washer, n
3.75 mm	569.3 ± 30.4	926.6 ± 164.5	726.7 ± 25.9
4.00 mm	573.2 ± 40.2	792.3 ± 40.2	739.0 ± 2.8

[a]Data are presented as mean ± SD.

tightness to the screws. A total of 8 fixation groups with 5 specimens per group were tested at a screw insertion angle of 0° (groups 1-8). In addition, 6 groups were tested at a screw insertion angle of 15°, as this angle was agreed upon as a worst-case clinical scenario (groups 9-14; n = 5 per group). Table 1 displays the different groups.

A materials testing system (ElectroPuls E10000; Instron) was used for biomechanical testing. All specimens underwent the same testing protocol. Based on pretest results, testing parameters included a preload of 214 N for 10 seconds, cyclical loading from 184 to 736 N at 1 Hz for 100 cycles, and failure loading at a rate of 15 mm/min (Figure 2). End of the test was defined if 10-mm displacement was exceeded or if the construct failed. These parameters were determined during pilot testing in which a load-to-failure test was performed to determine appropriate cyclic loading parameters. The load was directly applied to the middle of the coracoid bone block to mimic maximum abduction and external rotation of the arm utilizing a custom load application fixture to simulate the curvature of an average humeral head.[1,11] Maximum load to failure as well as failure mode (crack vs fracture) and location (coracoid vs scapula) were the primary outcomes of interest. In addition, a full-field stereo-optical measurement system (ARAMIS; GOM) was utilized to evaluate the displacement of screws and the bone block. Displacement of both the bone block and the screws was referenced to the fixed glenoid bone block surface.

Statistical Analysis

The groups were analyzed to test differences in ultimate failure load, strain on the coracoid surface, cyclic stiffness, and cyclic and ultimate displacement. Data analysis was performed using MATLAB (Version R2018a; The MathWorks, Inc), and for ultimate failure load results, statistical analysis was performed using SigmaPlot (Version 13.0; Systat Software, Inc). Normality and equal variance were tested using the Shapiro-Wilk and Brown-Forsythe tests. For data sets that passed both tests, subsequent 1-way analysis of variance was performed, followed by the Tukey honest significant difference test for post hoc multiple comparisons. Data sets that failed either of these tests underwent the Kruskal-Wallis rank-sum test with a subsequent Dunn test for post hoc multiple comparisons. Statistical significance was defined at $P < .05$. Post hoc power analysis revealed a mean power of 0.9958, which exceeded the desired power of 0.8, thus validating our sample size of 5.

RESULTS

Ultimate Failure Load

The mean ultimate failure loads are shown in Table 2 for tests at a 0° insertion angle and in Table 3 for tests at a 15° insertion angle. At a 0° insertion angle, differences in the ultimate failure load between the 2 screw sizes were not significantly different, except for the plate constructs in which the 4.00-mm screws resulted in significantly higher ultimate failure loads than did the 3.75-mm screws (group 8 vs 4, respectively; $P < .001$). The 4.00-mm screw with plate group was significantly stronger than every other group at a 0° insertion angle (group 8 vs 1-7,

TABLE 4
Dominant Failure Modes at 0° Insertion Angle

	Single Screw	Double Screw	Double Screw With Washer	Double Screw With Plate
3.75 mm	Block fracture (100%)	Block crack (100%)	Block crack (80%)	Test end reached (100%)
4.00 mm	Block fracture (100%)	Block crack (100%)	Block crack (100%)	Test end reached (80%)

TABLE 5
Dominant Failure Modes at 15° Insertion Angle

	Single Screw	Double Screw	Double Screw With Washer
3.75 mm	Block fracture (100%)	Block crack (80%)	Block fracture (60%), block crack (40%)
4.00 mm	Block fracture (100%)	Block crack (100%)	Block crack (80%)

respectively; $P < .001$ for every test). The 3.75-mm screw with plate group was stronger than the 3.75-mm double-screw with washer group, although not significantly stronger (group 4 vs 3, respectively; $P = .059$), and significantly stronger than the remaining groups (groups 1, 2, 5, 6, and 7; $P < .001$-.019). Looking at the different fixation groups, all the double-screw and washer groups were stronger than the single-screw groups (groups 2, 3, 6, and 7 vs 1 and 5, respectively; $P < .001$ for every test), and both washer groups were stronger than both double-screw groups (groups 3 and 7 vs 2 and 6, respectively; $P < .001$-.017).

The results at 15° angulation were not normally distributed and, therefore, were analyzed with the Kruskal-Wallis rank-sum test with a subsequent Dunn post hoc test. A comparison between 0° and 15° insertion angles revealed that the 4.00-mm single-screw constructs showed equally low ultimate failure loads for both insertion angles ($P = .8345$), while the 3.75-mm single-screw, double-screw, and washer groups were significantly stronger at 0° angulation ($P = .001$-.037). At 15° angulation, the double-screw constructs were significantly better than the single-screw constructs ($P = .002$-.024), but the washer constructs were not significantly stronger than the single- or double-screw constructs ($P = .558$-.854).

Cyclic Loading

Because of the number of failures during cyclical loading, no meaningful conclusions could be drawn.

Failure Modes

The observed failure modes are listed in Tables 4 and 5, and graphic representations of the failure modes are shown in Figure 3. Because the fracture parts that were observable with the single-screw constructs were numerous, completely fell apart, and were not displayable in a picture, an example photograph was taken from the fractured block that occurred with the 15° double-screw construct.

Screw and Coracoid Displacement

For every construct with a screw angle of 15°, screws and coracoid bone blocks were already displaced >2 mm by applying the preload of 214 N. For double-screw constructs with a screw angle of 0°, screw and coracoid displacement remained <2 mm during cyclical loading, with no observable differences between the 3.75- and 4.00-mm screw constructs.

DISCUSSION

The principal findings of this study suggest that the angle of screw insertion was associated with biomechanical outcomes, with screws inserted at an angle of 15° experiencing higher displacement and lower maximum loads to failure compared with constructs with screws inserted at 0°. Moreover, single-screw constructs, in this biomechanical study, appeared to be less able to withstand similar loads compared with double-screw constructs, with the majority of specimens fracturing at low loads compared with double-screw constructs. Last, of all constructs tested, fixation with two 4.00-mm screws at 0° angulation with a miniplate provided the best biomechanical construct, with the next best outcomes seen in specimens fixated with two 3.75-mm screws at 0° angulation with a miniplate, which indicates that a bigger compression force distribution on the coracoid surface improved biomechanical stability of the construct.

Clinical failures after the Latarjet procedure can be caused by graft osteolysis, screw migration, or other hardware-related failure. By determining the optimal coracoid bone block fixation construct, the clinical outcomes in patients undergoing the Latarjet procedure for recurrent anterior glenohumeral instability may improve. It is important to note, however, that this fixation is only pertinent in the early healing stages when the screws are load-bearing. After glenoid-coracoid graft union is achieved, the screws should not experience stress, as noted in the experimental model.

In this study, compared with all tested fixation methods, a lower rate of failure was observed with double-screw with miniplate constructs. This suggests that the miniplate allowed improved stress distribution because of the larger surface area of the plate compared with washers or screw heads alone. Clinically, this may imply that adding a plate to a double-screw construct may allow for earlier rehabilitation, although clinical studies are necessary to determine any potential translational implications of these biomechanical data. It should be reiterated that the cracks/fractures observed in this study were not in actual

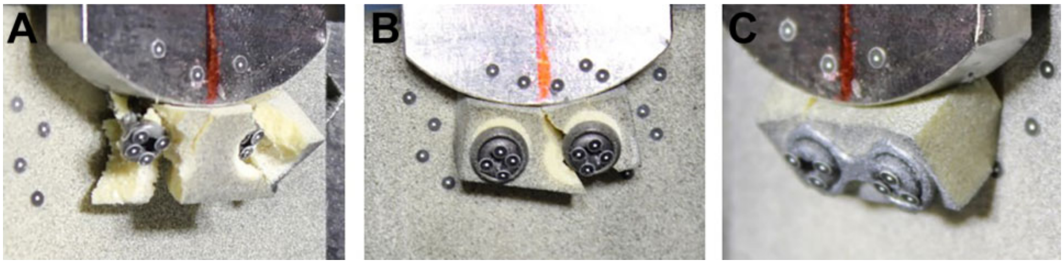

Figure 3. The 3 observed failure modes: (A) block fracture, (B) block crack, and (C) test end of 10-mm displacement reached.

coracoids but rather in synthetic foam blocks meant to model a coracoid.

Notably, in this study, the screw insertion angle was found to be a significant factor in nearly all biomechanical outcomes. In constructs with screws fixed at 15°, there were overall significantly lower ultimate failure loads and significantly higher coracoid bone block displacement observable. Furthermore, 77% of 15° specimens did not survive cyclical loading. At a 0° insertion angle, a distinct trend in increasing ultimate failure loads was observable in the following order: single screw, double screw, double screw with a washer, and double screw with a miniplate. Fixation with 4.00-mm screws resulted in higher construct stiffness and less displacement, similar ultimate failure loads, and no differences in loading at 2-mm displacement compared with the 3.75-mm screws. Among specimens with 4.00-mm screws, outcomes were comparable between the miniplate and washer constructs; however, there were more fractures/cracks and significantly lower ultimate failure loads in the washer group. The use of a parallel glenoid guide may help to avoid angled insertion during screw placement.

Di Giacomo and colleagues[7,8] reported on clinical outcomes after the Latarjet procedure utilizing a miniplate and found significantly increased graft osteolysis only in the deep part of the distal coracoid when compared with fixation without a miniplate. Importantly, the authors noted[7] no correlation of graft osteolysis with clinical outcomes at 26 ± 3 months (minimum of 18 months) in 26 patients. In a separate study[8] assessing the clinical outcomes of the Latarjet procedure with miniplate fixation, the same authors noted significantly increased rates of coracoid osteolysis (65.1%) in patients with lower degrees of glenoid bone loss (designated "no glenoid bone loss") compared with patients with greater degrees (>15%) of glenoid bone loss (osteolysis rate of 39.6%). The authors rationalized this finding by stating that the mechanotransductive effect from the humeral head on the coracoid graft influences its remodeling but only in the setting of glenoid bone loss.

Limitations

This study has several limitations, including its biomechanical nature and the utilization of biomechanical foam blocks as alternatives to cadaveric specimens. We chose artificial bone blocks to maintain uniformity of specimens and eliminate the effect that bone quality/density may have on outcomes. However, this does not eliminate the influence of the material properties of the synthetic material on test results. In addition, the geometry of the opposable surface is likely more favorable with foam blocks compared with the clinical setting. Other potentially clinically relevant biomechanical loading scenarios were not assessed in this study, including long-axis translation and off-axis rotation, and failures during the preload test phase indicated that the chosen load levels likely overestimated physiological loading. Further, there was no ability to test the potential implications of muscle pull on the bone block (clinically, the pull of the conjoined tendon on the coracoid). In addition, in this laboratory-based study, we were able to achieve perfect apposition of the bone block against the glenoid, which is not always the case clinically. Finally, this was an in vitro, time-zero biomechanical study, evaluating the effect of different fixation techniques of biomechanical foam blocks representing the coracoid and glenoid, and even though favorable clinical outcomes have already been reported, further long-term clinical follow-up studies are needed to confirm the obtained biomechanical outcomes.

CONCLUSION

The results indicate significantly superior failure loads with the miniplate compared with all other constructs, which may have clinical implications, particularly in the high-demand contact athlete. Across all fixation techniques and screw sizes, constructs with screws inserted at 0° performed better than constructs inserted at 15°. Overall, for graft fixation during the Latarjet procedure, these data suggest superior biomechanical properties with miniplate versus conventional screw fixation. These findings may be most relevant for the early postoperative time period in which a stronger biomechanical construct may allow for quicker range of motion gains without compromising graft fixation.

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