An Original Study

Congruency of Scapula Locking Plates: Implications for Implant Design

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Abstract

We conducted a study to evaluate the congruency of fit of current scapular plate designs. Three-dimensional image-processing and -analysis software, and computed tomography scans of 12 cadaveric scapulae were used to generate 3 measurements: mean distance from plate to bone, maximum distance, and percentage of plate surface within 2 mm of bone. These measurements were used to quantify congruency.

The scapular spine plate had the most congruent fit in all 3 measured variables. The lateral border and glenoid plates performed statistically as well as the scapular spine plate in at least 1 of the measured variables. The medial border plate had the least optimal measurements in all 3 variables.

With locking-plate technology used in a wide variety of anatomical locations, the locking scapula plate system can allow for a fixed-angle construct in this region. Our study results showed that the scapular spine, glenoid, and lateral border plates are adequate in terms of congruency. However, design improvements may be necessary for the medial border plate. In addition, we describe a novel method for quantifying hardware congruency, a method that can be applied to any anatomical location.

Scapular fractures are relatively rare and account for 1% of all fractures and 5% of fractures about the shoulder.[1] As the thick soft-tissue envelope and mobility of the scapula allow forces to dissipate, fractures of the scapula require high-energy trauma. Approximately 50% of scapular fractures occur in the body of the scapula, 25% in the glenoid neck, 10% in the glenoid fossa, and 7% in the acromion and coracoid.[1]

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With increased fracture displacement and angulation, some scapular fracture patterns have suboptimal clinical results with nonoperative management.[2-4] Because scapular fractures occur relatively infrequently and lack clear evidence-based indications for internal fixation, osteosynthesis is usually obtained with use of non–anatomical-specific plating. Fixation methods include small or mini fragment plates and screws, reconstruction plates, and tension banding and wire fixation. With these fixation methods, the hardware removal rate is as high as 7.1%, because of either implant-related discomfort or failure.[5]

Anatomical fit is important in minimizing overlying tissue irritation, aiding in fracture reduction, and improving the mechanics of the bone–plate construct. Locking scapular plates (Acumed, Hillsboro, Oregon), with their site-specific contouring, may allow for decreased soft-tissue irritation and operative time by reducing or precluding the need for intraoperative plate bending. Plates are available for 4 anatomical areas: scapular spine (S), glenoid (G), lateral border (LB), and medial border (MB). MB plates are available in 2 sizes. The potential reduction in surrounding-tissue irritation could reduce the need for hardware removal later. With precontouring, scapular anatomy can also be more easily reconstructed. These plate designs also direct fixation to relatively higher quality areas of bone, as out-

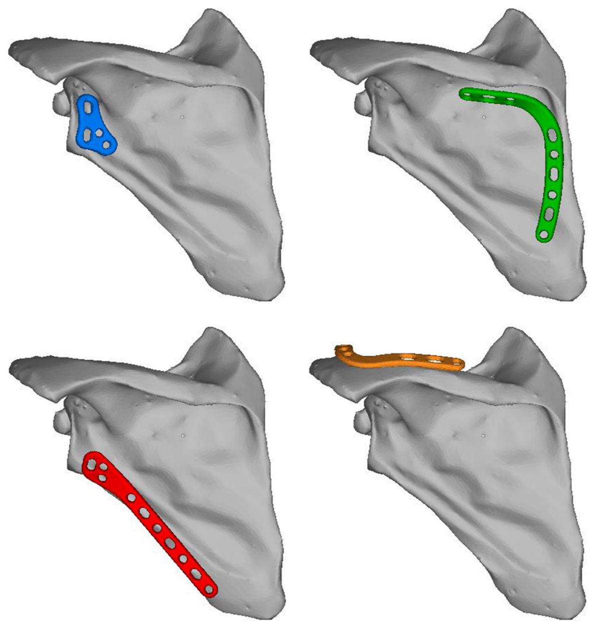

Figure 1. Placement of locking scapular plates on respective locations. Top left, glenoid; top right, medial border; bottom left, lateral border; bottom right, scapular spine.

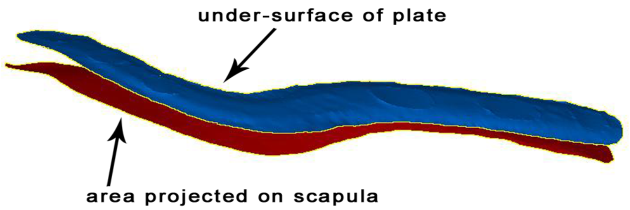

Figure 2. Distance between plate and bone of representative scapular spine plate.

lined by Burke and colleagues.[6] Site-specific precontoured locking plates may offer advantages over non–anatomical-specific fixation methods.

We conducted a study to evaluate the congruency of current scapular plate designs. We used sophisticated 3-dimensional (3D) modeling techniques to virtually place fragment-specific locking plates on computer tomography (CT) reconstructions of multiple cadaveric scapulae. All 4 plate designs from a single manufacturer were considered. To our knowledge, this is the first study to evaluate the congruency of fit for locking scapular plates. This study also describes a novel method by which plate design and congruency can be evaluated in any anatomical location.

Materials and Methods

Twelve scapulae from 6 fresh-frozen cadaveric torsos (5 male, 1 female) were scanned with a clinical CT scanner (MX8000 IDT 16 CT; Philips, Amsterdam, Netherlands) with slice thickness of 1 mm in 0.5-mm increments and 0.57 mm/pixel in-phase spatial resolution. Cadaveric specimens were used because of the difficulty in obtaining CT scans of healthy scapulae from clinical patients. Mean age at death was 71 years (range, 49-95 years).

The scans were imported into a commercial 3D image–processing software system (Mimics 12.1; Materialise, Leuven, Belgium) to create 3D triangulated surface mesh reconstructions of the scapulae (1.5 mm/side, approximately triangle shaped). Locking scapular plates were scanned at 680×480 pixels with a 3D digitizer (Vivid 9i; Konica-Minolta, Toyko, Japan) to create computer-aided design representations of the hardware. Left and right were scanned for each of the 4 plates: S, G, MB, and LB. Two lengths were available for the MB plate and the appropriate size was determined by Dr. Park. Dr. Park then virtually applied each plate to its respective location on the scapula (Figure 1).

Commercial 3D image–analysis software (3-Matic, Materialise) was used to quantify plate congruency for each

Table I. Statistical Significance Between Groups for Means

Plate	Distance, mm		Statistical Significance[a]		
	Mean	SD			
Scapular spine	1.78	0.68	A	—	—
Lateral border	2.24	0.6	A	B	—
Glenoid	2.63	0.64	—	B	—
Medial border	3.77	0.76	—	—	C

[a]Levels connected by same letter for a particular measurement are statistically similar; levels not connected by same letter are significantly different (*P*<.05). For example, scapular spine and lateral border plate values are significantly similar (A, A), and scapular spine and glenoid plate values are significantly different (A,B).

Table II. Statistical Significance Between Groups for Maximums

Plate	Distance, mm		Statistical Significance[a]		
	Maximum	SD			
Scapular spine	4.24	1.22	D	—	—
Lateral border	7.05	2.78	—	E	—
Glenoid	5.38	1.14	D	E	—
Medial border	9.3	2.12	—	—	F

[a]Levels connected by same letter for a particular measurement are statistically similar; levels not connected by same letter are significantly different (*P*<.05).

Table III. Statistical Significance Between Groups for P2 Values

Plate	% <2 mm (P2)[a]		Statistical Significance[b]		
	Mean	SD			
Scapular spine	63.59	24.87	G	—	—
Lateral border	52.8	15.7	G	H	—
Glenoid	37.5	13.96	—	H	I
Medial border	29.98	8.67	—	—	I

[a]Percentage of plate surface within 2 mm of bone.
[b]Levels connected by same letter for a particular measurement are statistically similar; levels not connected by same letter are significantly different (*P*<.05).

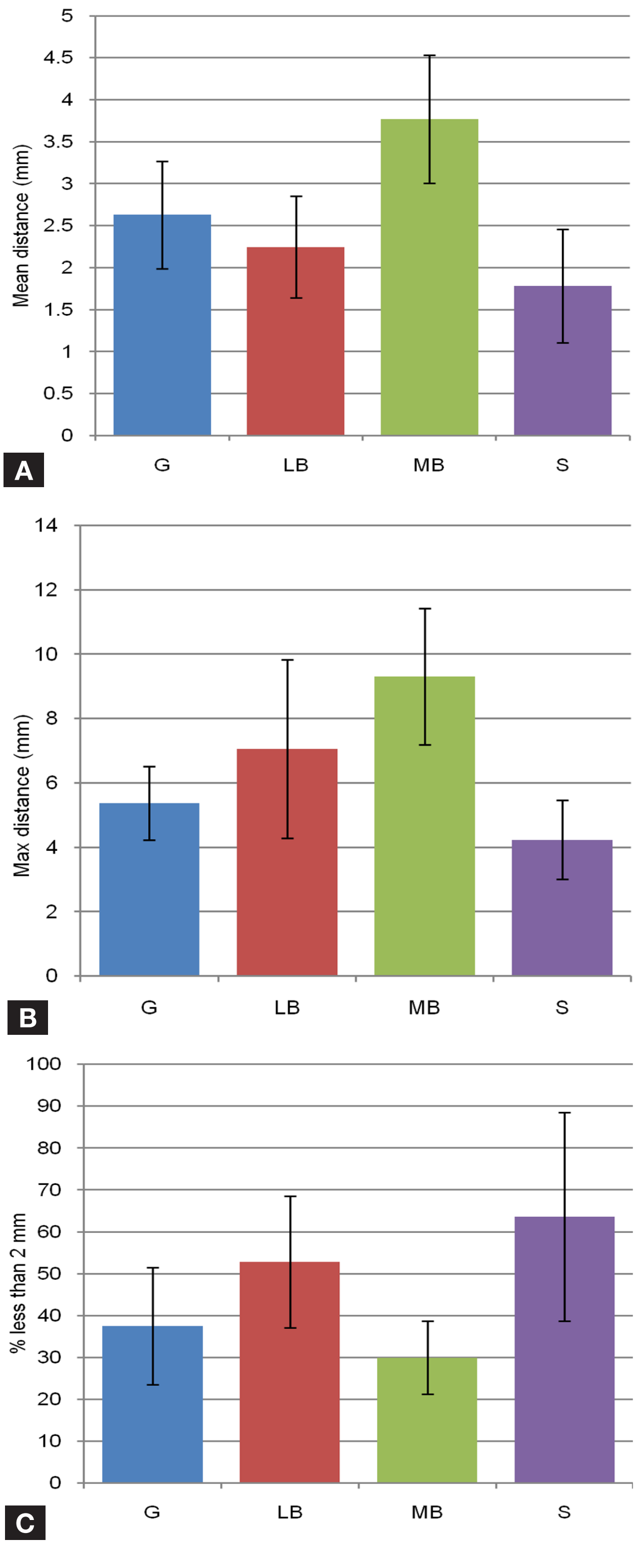

Figure 3. Plots comparing differences in mean distance **(A)**, maximum distance **(B)**, and percentage of plate surface within 2 mm of bone **(C)**. Abbreviations: G, glenoid; LB, lateral border; MB, medial border; S, scapular spine.

specimen. First, the back surface of the plate was projected onto the scapula in the direction normal to the plane of the plate creating a volume of the gap. Then the perpendicular distance of this volume was obtained at every triangle in the mesh. The back surface of a representative plate and its projection onto the scapula are shown in Figure 2. Minimum distance from plate to scapula was then subtracted from every measurement to create a best-fit scenario.

Three measurements were used to quantify congruency: mean distance from plate to bone, maximum distance, and percentage of plate surface within 2 mm of bone (P2). P2 was based on a previous biomechanical study, which showed increased plate stability when fixed within 2 mm of bone, compared with plates placed with a gap of 5 mm.[7] This measurement has also been used as a measure of congruency of distal medial tibia plates.[8] Plate designs were compared to each outcome measure using repeat-measures analysis of variance, followed by paired *t* tests with Tukey post hoc adjustment for comparisons between individual groups.

Results

The measured distances from plate to bone are summarized in Figures 3A-3C and the statistical significance between plates is outlined in Tables I through III. The S-plate had the smallest mean (SD) distance, 1.78 (0.7) mm, and the smallest maximum (SD) distance, 4.24 (1.2) mm. Compared with the S-plate, the LB plate was statistically similar in terms of mean distance but statistically different in terms of maximum distance. The G-plate was similar to the S-plate in terms of maximum (SD) distance, 5.38 (1.1) mm, but differed significantly in terms of mean (SD) distance, 2.63 (0.6) mm. The MB plate had the largest mean (SD) and maximum (SD) distances, 3.77 (0.8) mm and 9.31 (2.1) mm, respectively.

Compared with the percentage of plate within 2 mm of bone (P2), the S-plate had the highest value (64%) and was similar to the LB plate (53%) and significantly different from the G-plate (37%) and the MB plate (30%). The MB plate had the lowest P2.

Discussion

Our study results indicated that the S-plate had the best overall fit of the scapular plate designs tested. The S-plate consistently demonstrated the most optimal values for all the congruency measures considered in this study. The LB plate and the G-plate also provided good anatomical fit and these plate designs demonstrated congruency comparable to that of the S-plate in at least 1 of the outcome measures. In contrast, the MB plate had the least congruent fit for all 3 measurements. This is consistent with the challenging anatomy of the scapula in this particular region. The bend and rotation of the plate attempting to contour to the medial border and inferior surface of the spine form a complex relationship. The angle of the plate along the medial border and spine also did not seem to correlate well with the angles of our specimens. We found the angle of the plate to be excessively acute in most cases. In the sagittal plane, each scapula had a dorsal convexity that also created an anatomical challenge to MB plate congruity. These likely explain the least appropriate fit measurements in our study.

Other studies that have described scapular osseous anatomy have shown that the medial and lateral borders had sufficient bone within 1 cm of the edge to support fixation.[9] In an anatomical study by von Schroeder and colleagues,[10] the scapular body was thin and often translucent, which emphasizes the importance of contouring plates to the medial border for optimal fixation.

Clinical studies of scapular fractures have shown that the lateral border and glenoid regions are more likely than other areas to undergo open reduction and internal fixation. Armitage and colleagues[11] indicated that 68% of fractures that required surgery involved the inferior aspect of the glenoid, 17% were intra-articular, and 22% involved the spinoglenoid notch just medial to the glenoid concavity. In a systematic review, Lantry and colleagues[5] found that the most common indication for scapular fixation was a glenoid fossa fracture, and the second most common indication involved the neck. Our study results showed that locking-plate designs used in this region have relatively high congruency, which is encouraging given that increased congruency correlates with increased mechanical stability[7] and likely decreased soft-tissue irritation. Measurements of congruency for these plate designs are consistent with values from other studies on anatomical fit of more commonly used distal tibia medial locking plates.[8] Mean maximum distance was 5.4 mm from G-plate to bone and 7.1 mm from LB plate to bone, comparable to the mean maximum distance of 6.3 mm from the distal tibia medial plate to bone. In addition, Schmutz and colleagues[8] found P2 ranged from 19% to 60%, which is in line with P2 findings: G of 37%, LB of 53%, MB of 30%, and S of 64%.

Strengths of this study include its virtual application of plates to scapulae. The clinical and implant design applications of this study are valuable, as are the methods used to obtain results. This study allowed for virtual, noninvasive analysis of several different measurement variables. This 3D image–analysis technique can be used to evaluate the congruency of any implant with any surface. Any number of implants may be studied in this manner. As suggested by Schmutz and colleagues,[8] this method could also be used in preoperative planning to determine optimal plate positioning relative to fracture fragments and other anatomical landmarks. This study also accounts for some anatomical variability with several scapular specimens.

The main limitation of this study is its relatively small sample. However, the sample was large enough for statistical significance between plate-design groups, though we acknowledge its power is relatively low. A secondary goal of this study was to develop a new method for objectively evaluating and quantifying plate congruency, and our numbers seemed appropriate for that. Other limitations include use of cadaveric tissue and single-surgeon hardware application. However, the fresh-frozen scapulae were scanned in torso, avoiding artifact associated with CT imaging of isolated bone segments. In addition, single-surgeon plate application was modified and adjusted by subtracting the minimum distance from plate to bone to create a best-fit scenario. This study also did not account for surgical exposure constraints or anatomical considerations. Previous work has shown that the suprascapular nerve is 1.8 cm from the posterior glenoid rim at the spinoglenoid notch and that the circumflex scapular artery is 2.9 cm from the inferior glenoid rim along the scapular lateral border.[12] These structures may become obstacles during placement of plates, the G-plate and the LB plate in particular. As for the S-plate, this region is relatively subcutaneous and has little soft-tissue coverage, creating a challenge with respect to internal fixation on the superior surface of the acromion.

With locking-plate technology used in a wide variety of anatomical locations, the locking scapula plate system can allow for a fixed-angle construct in which bone stock can be limited. This study showed that the G-plate, the LB plate, and the S-plate are adequate in terms of congruency. However, design improvements may be necessary for the MB plate. Future work in this investigation will include a larger sample and experienced surgeon plate application. This study is also valuable beyond just scapular plate evaluation. A novel 3D virtual method was described for quantifying hardware congruency and this method can be applied to hardware in any anatomical location where plate profile and congruency are of clinical concern.

Authors' Disclosure Statement

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