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Biomechanical Evaluation of Different Plate Configurations for Midshaft Clavicle Fracture Fixation

Single Plating Compared with Dual Mini-Fragment Plating

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Background: Dual-plate constructs have become an increasingly common fixation technique for midshaft clavicle fractures and typically involve the use of mini-fragment plates. The goal of this technique is to reduce plate prominence and implant irritation. However, limited biomechanical data exist for these lower-profile constructs. The study aim was to compare dual mini-fragment orthogonal plating with small-fragment clavicle plates for biomechanical noninferiority and to determine if an optimal plate configuration could be identified using a cadaveric model.

Methods: Twenty-four cadaveric clavicles were randomized to 1 of 6 groups, stratified by computed tomography-based bone mineral content (BMC): precontoured superior or anterior fixation using a single 3.5-mm Locking Compression Plate (LCP), and 4 different dual-plating constructs utilizing 2.4-mm and 2.7-mm Adaptation plates or LCPs. An inferior butterfly fracture was created. Axial, torsional, and bending (anterior and superior surface loading) stiffnesses were determined through nondestructive cyclic testing, followed by a load-to-failure test in 3-point superior surface bending.

Results: For axial stiffness, the 2 dual-plate constructs with a superior 2.4-mm and anterior 2.7-mm plate (either Adaptation or LCP) were significantly stiffer than the other 4 constructs ($p = 0.021$ and $p = 0.034$). For both superior and anterior bending, the superior 2.4-mm and anterior 2.7-mm plate constructs were significantly stiffer when compared with the 3.5-mm superior plate ($p = 0.043$). No significant differences were found in torsional stiffness or load to failure between the different constructs.

Conclusions: Dual plating using mini-fragment plates is biomechanically superior for the fixation of midshaft clavicle fractures when compared with a single, superior, 3.5-mm plate and has biomechanical properties similar to those of a 3.5-mm plate placed anteriorly. With the exception of axial stiffness, no significant differences were found when different dual-plating constructs were compared with each other.

Clinical Relevance: This study validates the use of dual plating for midshaft clavicle fractures.

Clavicle fractures are common injuries, with the middle one-third of the clavicle accounting for two-thirds of all fractures[1-3]. Nonoperative management remains the predominant treatment modality for these fractures. However, the treatment paradigm has changed over the past decade following numerous high-quality randomized controlled studies indicating that nonoperative outcomes are not as favorable as once believed[4-7]. Nonetheless, the recommended indications for surgical treatment are still conflicting. Most of the debate surrounds secondary operative procedures, as the number of patients who require a second operation (8.0% to 20.8%) is considerable[6,8]. The most common indication for a secondary surgical procedure is implant irritation[8].

Although various fixation methods of midshaft clavicle fractures have been described, plate fixation remains the most established method[9]. Dual-plate fixation has become a more common technique and typically involves the use of mini-fragment plates[10-17]. It is a lower-profile construct in comparison with the traditionally used (contoured) small-fragment plates and could potentially reduce secondary surgical procedures

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A359).

TABLE I Specimen Characteristics for the Different Plate Configurations

Groups	Donor Age* *(yr)*	Clavicle Length* *(cm)*	BMC* *(g)*
3.5-mm LCP (7-hole) superiorly	81.00 ± 3.56	14.75 ± 0.60	8.41 ± 1.71
3.5-mm LCP (7-hole) anteriorly	77.50 ± 3.52	13.63 ± 0.13	8.14 ± 1.29
2.7-mm LCP (5-hole) superiorly and 2.4-mm Adaptation plate (12-hole) anteriorly	78.25 ± 3.09	14.00 ± 0.54	8.55 ± 1.24
2.7-mm Adaptation plate (12-hole) superiorly and 2.4-mm LCP (5-hole) anteriorly	86.00 ± 2.35	13.88 ± 0.24	8.21 ± 1.27
2.4-mm LCP (5-hole) superiorly and 2.7-mm Adaptation plate (12-hole) anteriorly	80.00 ± 5.15	14.38 ± 0.72	8.44 ± 1.98
2.4-mm Adaptation plate (12-hole) superiorly and 2.7-mm LCP (5-hole) anteriorly	75.25 ± 3.01	14.13 ± 0.52	8.28 ± 1.39

*The values are given as the mean and the standard error.

because of less prominent implants[13]. In a recent systematic review and meta-analysis (278 patients), a 4.2% implant removal rate was reported for the dual-plating technique, and single-plate fixation was associated with a 3.9-fold increased implant removal rate (p = 0.003)[8]. This difference in implant removal rate is less pronounced with a single plate placed anteroinferiorly compared with superior plating[18].

Limited biomechanical data exist regarding whether dual plating with smaller plate-screw constructs provides enough stability. Two biomechanical studies using synthetic clavicles showed noninferiority of dual plating and either superior or anteroinferior single plating using larger small-fragment plate-screw constructs in axial, torsional, and bending stiffnesses and in load to failure[13,19]. These findings have been further supported by a recent finite element analysis[20] and a biomechanical study in a cadaveric model[21]. Although Ziegler et al.[21] randomized their specimens, they were not able to correct for differences in bone mineral content (BMC) among the different fixation groups, possibly affecting their results. In addition, none of the previous studies reported on optimal plate configuration for the different constructs.

The hypothesis of the current study was that dual, mini-fragment, orthogonal plate fixation is biomechanically noninferior when compared with traditional, single, small-fragment clavicle plate fixation. The overall goal was to systematically compare different dual mini-fragment plate configurations to assess the noninferiority of the strength of each construct, using a clinically relevant cadaveric fracture model.

Materials and Methods

Specimen Preparation

The current study used 24 whole adult cadaveric clavicle specimens (12 pairs) without previous fractures or congenital anomalies. This study was approved by our institutional research ethics review board (REB19-0600) prior to obtaining the specimens. Using high-resolution clinical computed tomographic (CT) scans, BMC was determined for all specimens to perform a stratified random allocation of the specimens to 1 of the 6 different plate configuration groups. The characteristics of the clavicles in the different groups are listed in Table I.

Fracture Model and Fixation Technique

The 6 different plate configurations (4 per group), all from DePuy Synthes, included superior plating using a single 7-hole (110 mm in length), precontoured, 3.5-mm Superior Clavicle Locking Compression Plate (LCP); anterior plating using a single 7-hole (90 mm in length), 3.5-mm Medial Anterior Clavicle LCP; or 4 different dual-plating constructs (Table I) with superior and anteroinferior plating using a Modular Mini Fragment 5-hole 2.4-mm LCP (44 mm in length) or 2.7-mm LCP (49 mm) and a 12-hole Adaptation 2.4-mm plate (88 mm in length) or 2.7-mm plate (97 mm in length). These 4 different dual-plating constructs were chosen as they were the most commonly used in previous studies[8] and in our current clinical practice. To allow for controlled osteotomy and reproducible fixation, the superior plate (or the anterior plate in the case of a single anterior plate configuration) was applied first before creating the inferior butterfly fragment (Fig. 1). No implants were used more than once.

Applying the standard compression plating technique, 3 bicortical 3.5-mm cortical screws were placed on either side of the fracture for both the superior-plating and anterior-plating constructs. For the dual-plating constructs, 2 bicortical 2.4-mm or

Fig. 1

A 2-cm inferior butterfly fracture fragment (OTA 15.2B) was created using a mini-sagittal saw, with the apex at the superior aspect of the clavicle, extending 1 cm lateral and medial to the midpoint along the inferior surface. In this specimen, a 2.4-mm LCP was placed anteriorly and a 2.7-mm Adaptation plate was placed superiorly.

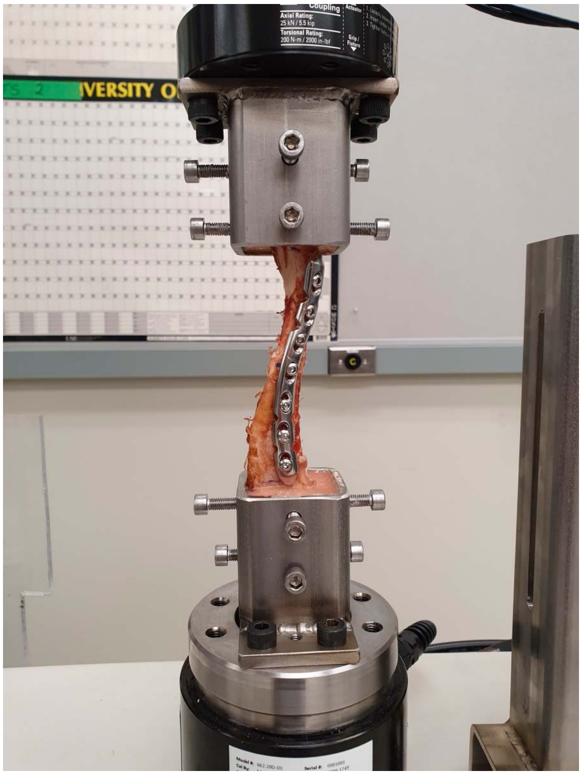

Fig. 2
For nondestructive axial and torsional testing, the potted lateral end of the specimen was mounted parallel to the actuator, with the medial end mounted vertical to the testing table.

2.7-mm cortical screws were placed in the lateral and medial fragments through the corresponding plates. The butterfly fragment was reduced, and a drill-hole was made perpendicular to the fracture (superomedial to inferolateral). A single 3.5-mm interfragmentary screw was inserted for both superior and anterior plating; for the dual-plating constructs, a 2.7-mm interfragmentary screw was used. The interfragmentary screws were inserted through the plate, with the exception of the single anterior plate construct. The plates and screws were made of stainless steel.

Biomechanical Model

For biomechanical testing, a protocol similar to that described by Ziegler et al.[21] was used. The specimens were stripped of all soft-tissue attachments. The central 11-cm portion of the clavicle was left exposed, and the remaining medial and lateral portions of each specimen were potted in polymethylmethacrylate (PMMA) after the placement of 2 screws in each of the lateral and medial ends to improve the adherence of the PMMA. A custom-made jig was used to ensure that the orientation of potting was parallel to the respective ends of the specimens (i.e., taking into account the anatomic curvature), so that no off-axis loads would be applied. Using a 858 Bionix system (MTS), axial, torsional, and bending (anterior and superior loading) stiffnesses were determined for each construct through nondestructive cyclic testing. This was followed by 3-point loading to failure by bending with superior loading. The order of testing was the same for all specimens. Loading rates were chosen to mimic non-traumatic physiological loading[21]. Nondestructive axial testing was performed by compressing each clavicle between 10 and 315 N at 0.25 Hz for 10 cycles (Fig. 2). Nondestructive torsional stiffness testing was performed along the long axis of the clavicle by rotating +1 Nm/degree and −1 Nm/degree at 0.25 Hz for 10 cycles. The 3-point anterior-load bending test was performed by placing the fulcrum at the dorsal aspect of the clavicle, 1 cm medial to the fracture site[21] (Fig. 3). The clavicles were loaded cyclically from 10 to 60 N at 0.25 Hz for 10 bending cycles. This process was repeated with the fulcrum at the inferior aspect of the clavicle for the superior-load bending test[21]. The axial, torsional, and bending stiffnesses were measured during the tenth and final cycle of the test for all specimens. The setup for the loading to failure was identical for the superior-load bending test. The specimens were loaded at a rate of 15 mm/min until a fracture was observed either audibly or visually by 2 observers (J.K., K.P.). The load value immediately preceding this drop in peak load was used for the calculation of the load to failure for all specimens.

Statistical Analysis

All specimens were randomly allocated to 1 of 6 different plate configuration groups, based on stratification by BMC. Construct stiffness and failure load were summarized using the mean, the standard error of the mean, and the 95% confidence interval (CI). Both the standard error and the 95% CI were corrected for BMC. To test for biomechanical noninferiority between the different groups, the nonparametric Kruskal-Wallis H test was applied. To determine if an optimal plate configuration could be identified, pairwise group comparisons were tested for significance using the nonparametric Mann-Whitney U test. A p value of <0.05 was considered significant. All analyses were performed using SPSS, version 25.0 (IBM).

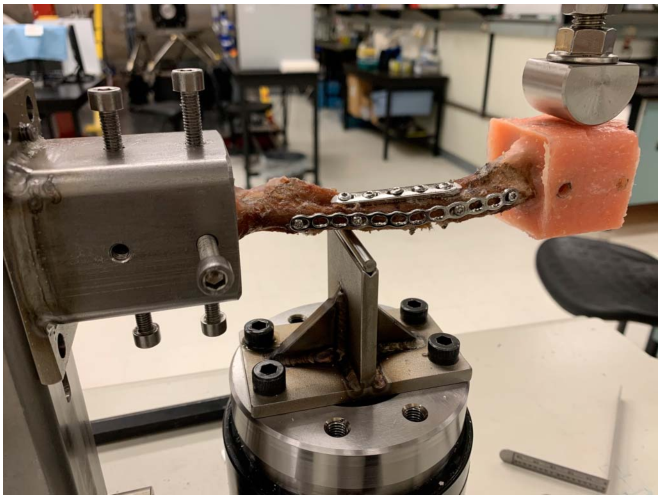

Fig. 3
For the nondestructive bending tests, the medial end of the clavicle was perpendicular to the actuator. The force was applied at the lateral PMMA-potted end of the clavicle, with the actuator 10 cm lateral to the fulcrum.

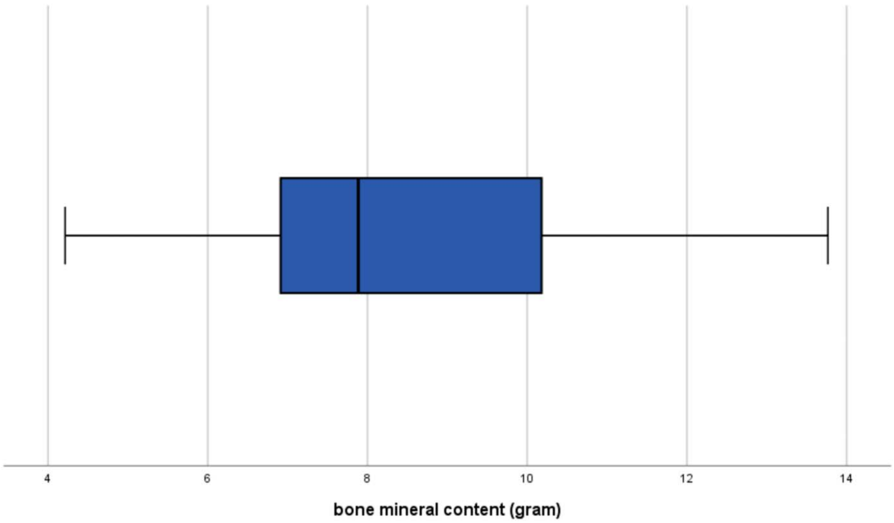

Fig. 4

Box plot for BMC in grams determined for all specimens using high-resolution clinical CT scans (120 kVp, 150 mA, with an in-plane resolution of 0.263 × 0.263 mm and a slice thickness of 0.625 mm). The line within the box represents the median, and the whiskers indicate the range.

Source of Funding

There was no external funding source.

Results

No significant differences were seen between the different groups with respect to age (mean [and standard error], 79.67 ± 1.46 years [range, 70 to 92 years]; p = 0.341), clavicle length (mean, 14.13 ± 0.20 cm [range, 13.0 to 16.5 cm]; p = 0.511), and BMC (mean, 8.34 ± 0.54 g [range, 4.23 to 13.76 g]; p = 1.000) (Fig. 4).

Axial Stiffness

The nondestructive cyclic testing for axial stiffness revealed a significant difference in stiffness (p = 0.006). The 2 dual-plate constructs with a superior 2.4-mm plate and an anterior 2.7-mm plate were significantly stiffer than the other 4 constructs when pairwise group comparisons were made (p = 0.021 for the 2.4-mm LCP superiorly and p = 0.034 for the 2.4-mm Adaptation plate superiorly) (Table II).

Torsional Stiffness

For the nondestructive cyclic testing for torsional stiffness, no significant differences (p = 0.324) were observed between the different plating constructs (Table III).

Bending Stiffness

No significant differences were seen overall for the nondestructive cyclic testing of bending stiffness with both anterior loading (p = 0.095) and superior loading (p =0.079). However, when pairwise group comparisons were made between the different plate configurations, the 2 dual-plate constructs with a superior 2.4-mm plate and an anterior 2.7-mm plate were significantly stiffer than superior plating with both anterior loading (Table IV) and superior loading (Table V) (p = 0.043 for both).

TABLE II Axial Stiffness by Plate Configuration Group

Groups	Axial Stiffness* *(N/mm)*	Significance
3.5-mm LCP superiorly	520.71 ± 121.99 (119.72 to 896.19)	NS†
3.5-mm LCP anteriorly	914.07 ± 253.24 (201.39 to 1,813.26)	NS†
2.7-mm LCP superiorly and 2.4-mm Adaptation plate anteriorly	851.75 ± 182.86 (307.43 to 1,471.28)	NS†
2.7-mm Adaptation plate superiorly and 2.4-mm LCP anteriorly	812.02 ± 117.66 (409.34 to 1,421.85)	NS†
2.4-mm LCP superiorly and 2.7-mm Adaptation plate anteriorly	2,172.83 ± 342.70 (1,267.45 to 3,448.71)	S‡
2.4-mm Adaptation plate superiorly and 2.7-mm LCP anteriorly	2,370.94 ± 392.56 (1,300.48 to 3,799.10)	S‡

*The values are given as the mean and the standard error, with the 95% CI in parentheses. †NS = nonsignificant. Configurations are not significantly different from one another. ‡S = significant. There is a significant difference between this construct and ≥1 other constructs. The 2 dual-plate constructs with a superior 2.4-mm and anterior 2.7-mm plate were significantly stiffer than the other 4 constructs (p = 0.021 for the 2.4-mm LCP superiorly and p = 0.034 for the 2.4-mm Adaptation plate superiorly).

TABLE III Torsional Stiffness by Plate Configuration Group

Groups	Torsional Stiffness* *(N•mm/deg)*	Significance†
3.5-mm LCP superiorly	0.25 ± 0.04 (0.09 to 0.37)	NS
3.5-mm LCP anteriorly	0.37 ± 0.10 (0.04 to 0.70)	NS
2.7-mm LCP superiorly and 2.4-mm Adaptation plate anteriorly	0.39 ± 0.06 (0.17 to 0.58)	NS
2.7-mm Adaptation plate superiorly and 2.4-mm LCP anteriorly	0.36 ± 0.03 (0.27 to 0.45)	NS
2.4-mm LCP superiorly and 2.7-mm Adaptation plate anteriorly	0.45 ± 0.07 (0.26 to 0.69)	NS
2.4-mm Adaptation plate superiorly and 2.7-mm LCP anteriorly	0.59 ± 0.08 (0.32 to 0.85)	NS

*The values are given as the mean and the standard error, with the 95% CI in parentheses. †NS = nonsignificant. Configurations are not significantly different from one another.

In addition, anterior plating was a significantly stiffer construct ($p = 0.043$), when compared with superior plating, in bending with superior loading (Table V).

Load to Failure

The results of the 3-point load to failure by bending with superior loading are displayed in Table VI. No significant differences ($p = 0.360$) were observed between the different groups.

Location of Failure

For both superior plating ($n = 2$) and anterior plating ($n = 4$), the most frequent fracture location was at the interfragmentary screw (Table VII). In the superior-plating group, a fracture at the bone-screw interface was observed at the first medial screw in 2 specimens. For the 4 dual-plating constructs, no fractures were observed at the interfragmentary screw; most fractures were seen at the bone-screw interface at the first lateral screw ($n = 3$) or the first medial screw ($n = 3$) relative to the interfragmentary screw, followed by a fracture at the second medial screw ($n = 1$) or the second lateral screw ($n = 1$).

Discussion

Dual plating using mini-fragment plates was biomechanically superior for fixation of midshaft clavicle fractures when compared with a single superior plate and had biomechanical properties similar to those of a single plate placed anteriorly. For axial stiffness, the 2 dual-plate constructs with a superior 2.4-mm plate and an anterior 2.7-mm plate were significantly stiffer than the other 4 constructs. This study used a cadaveric model with a priori random allocation, stratified by CT-based BMC to create homogenous groups and to minimize the effect of bone quality on our biomechanical outcomes.

Our findings are similar to those of the biomechanical study by Ziegler et al.[21], who used 18 cadaveric clavicles. In this study, no significant differences were seen between dual plating (superior and anterior, 7-hole titanium, 2.7-mm LCP, 8 standard screws) and either superior or anterior single plating (7-hole titanium, 3.5-mm LCP, 6 standard screws) for axial, torsional, or superior bending stiffness or in bending load to failure. However, in accordance with our study, dual plating did seem to have a higher mean cyclical bending stiffness (14.65 N/mm) when compared with superior plating (6.75 N/mm) ($p = 0.067$). Those authors did not report on bending stiffness with an anterior load; consequently, no comparison could be made. Although an incomplete block design was used to randomize the specimens, they were not able to correct for differences in BMC among the different fixation groups; therefore, differences in cadaveric bone quality may have affected their results.

In a biomechanical and clinical study using synthetic clavicles ($n = 19$), Prasarn et al.[13] reported similar

TABLE IV Bending Stiffness with Anterior Loading by Plate Configuration Group

Groups	Bending Stiffness* *(N/mm)*	Significance
3.5-mm LCP superiorly	25.98 ± 8.19 (2.63 to 54.76)	NS†
3.5-mm LCP anteriorly	40.73 ± 2.44 (32.97 to 48.48)	NS†
2.7-mm LCP superiorly and 2.4-mm Adaptation plate anteriorly	34.90 ± 6.81 (13.73 to 57.05)	NS†
2.7-mm Adaptation plate superiorly and 2.4-mm LCP anteriorly	60.04 ± 1.09 (55.00 to 64.37)	NS†
2.4-mm LCP superiorly and 2.7-mm Adaptation plate anteriorly	57.30 ± 6.33 (38.36 to 78.67)	S‡
2.4-mm Adaptation plate superiorly and 2.7-mm LCP anteriorly	51.34 ± 3.14 (42.27 to 62.28)	S‡

*The values are given as the mean and the standard error of the mean, with the 95% CI in parentheses. †NS = nonsignificant. Configurations are not significantly different from one another. ‡S = significant. There is a significant difference between this construct and ≥1 other constructs. The 2 dual-plate constructs with a superior 2.4-mm plate and an anterior 2.7-mm plate were significantly stiffer than superior plating ($p = 0.043$).

TABLE V Bending Stiffness with Superior Loading by Plate Configuration Group

Groups	Bending Stiffness* *(N/mm)*	Significance
3.5-mm LCP superiorly	13.84 ± 2.58 (6.27 to 22.67)	NS†
3.5-mm LCP anteriorly	33.91 ± 10.86 (6.11 to 87.34)	S‡§
2.7-mm LCP superiorly and 2.4-mm Adaptation plate anteriorly	24.35 ± 1.64 (18.04 to 28.50)	NS†
2.7-mm Adaptation plate superiorly and 2.4-mm LCP anteriorly	19.99 ± 4.36 (7.78 to 35.51)	NS†
2.4-mm LCP superiorly and 2.7-mm Adaptation plate anteriorly	27.80 ± 11.69 (2.17 to 72.27)	S‡#
2.4-mm Adaptation plate superiorly and 2.7-mm LCP anteriorly	31.22 ± 6.42 (11.10 to 51.97)	S‡#

*The values are given as the mean and the standard error, with the 95% CI in parentheses. †NS = nonsignificant. Configurations are not significantly different from one another. ‡S = significant. There is significant difference between this construct and ≥1 other constructs. §Anterior plating was a significantly stiffer construct than superior plating (p = 0.043). #The 2 dual-plate constructs with a superior 2.4-mm and anterior 2.7-mm plate were significantly stiffer than superior plating (p = 0.043).

biomechanical properties for dual plating (2.7-mm LCP superior and 2.4-mm reconstruction plate anterior, with 6 standard and 4 locking screws; material and plate length not reported) compared with superior plating and anterior plating (3.5-mm reconstruction plate, 6 locking screws; material and plate length not reported). For torsional and axial loading, no significant differences in construct stiffness were observed. With application of an anterior load, the dual-plate construct was significantly more rigid than an anterior plate, but was less rigid than a superior plate. The exact opposite was found when a superior load was applied. The authors concluded that single-plate constructs were least rigid when loaded parallel to the narrow dimension of the plate. Consequently, orthogonal plates may be better suited to resist multiplanar bending forces than a single plate[13]. This might be especially true in segmental or more comminuted clavicle fractures. Prasarn et al.[13] used a transverse osteotomy (corresponding to a clinically less common fracture pattern), whereas, in our model and that of Ziegler et al.[21], an inferior butterfly fragment was created. A systematic review of biomechanical studies on the surgical fixation of midshaft clavicle fractures stated that, for segmental or comminuted fractures, anterior plating was stiffer than superior plating in cantilever bending[22]. This finding was consistent with our results and the study by Ziegler et al.[21]. These findings support why we found that the 2 dual-plating constructs with a superior 2.4-mm plate combined with the more rigid 2.7-mm plate placed anteriorly are stiffer in cantilever bending when compared with the 2 opposite dual-plating constructs, and especially when compared with the single 3.5-mm superior plate.

In a biomechanical study, Boyce et al.[19], using an inferior butterfly fragment in synthetic clavicles (n = 15), compared single superior plating (8-hole stainless steel 3.5-mm LCP with 6 locking screws), combination plating (an additional 10-hole titanium 2.8-mm LCP placed anteriorly and 9 locking screws), and dual mini-fragment plates (2 of the latter 2.8-mm plates placed superiorly and anteriorly, 18 locking screws). Not surprisingly, combination plating was the stiffest construct in torsion and cantilever bending. However, in terms of reducing implant prominence, this construct is likely suboptimal. Similar to the current study and that of Ziegler et al.[21], Boyce et al. found that the location of failure in the majority of the single-plate constructs was at the fracture site. For numerous dual-plating constructs, they reported failure at the most lateral screw. Therefore, they recommended staggering the dual plates to minimize the stress riser created at the ends of the plates. However, for dual plating in both the current study and that of Ziegler et al.[21],

TABLE VI Bending Load to Failure with Superior Loading by Plate Configuration Group

Groups	Bending Load to Failure* *(N/mm)*	Significance†
3.5-mm LCP superiorly	254.75 ± 20.84 (192.56 to 325.20)	NS
3.5-mm LCP anteriorly	341.00 ± 55.74 (187.95 to 542.75)	NS
2.7-mm LCP superiorly and 2.4-mm Adaptation plate anteriorly	306.00 ± 15.99 (250.44 to 352.21)	NS
2.7-mm Adaptation plate superiorly and 2.4-mm LCP anteriorly	252.75 ± 26.84 (182.84 to 353.70)	NS
2.4-mm LCP superiorly and 2.7-mm Adaptation plate anteriorly	383.25 ± 40.59 (254.07 to 512.43)	NS
2.4-mm Adaptation plate superiorly and 2.7-mm LCP anteriorly	337.75 ± 23.53 (266.25 to 415.99)	NS

*The values are given as the mean and the standard error of the mean, with the 95% CI in parentheses. †NS = nonsignificant. Configurations are not significantly different from one another.

TABLE VII Location of Failure by Plate Configuration Group

Groups	Fracture at Interfragmentary Screw	Fracture at Bone-Screw Interface			
		First Screw Medial	Second Screw Medial	First Screw Lateral	Second Screw Lateral
3.5-mm LCP superiorly	2	2			
3.5-mm LCP anteriorly	4				
2.7-mm LCP superiorly and 2.4-mm Adaptation plate anteriorly		2		1	1
2.7-mm Adaptation plate superiorly and 2.4-mm LCP anteriorly		3		1	
2.4-mm LCP superiorly and 2.7-mm Adaptation plate anteriorly			1	2	1
2.4-mm Adaptation plate superiorly and 2.7-mm LCP anteriorly		1		3	

most failures occurred in either the first medial screw or the first lateral screw. This difference can be explained by the difference in surgical technique (18 locking screws compared with 8 standard screws). This difference is further illustrated by a recent finite element analysis (superior and anterior plating with a 6-hole, titanium, 3.5-mm LCP and 6 standard screws compared with dual plating with two 6-hole, 2.7-mm LCP and 8 standard screws). In this model, the concentration of stress found in the superior and anteroinferior single-plate constructs was located near the fracture gap in cantilever bending, axial compression, and axial torsion. In contrast, the force in the dual-plate construct was more equally distributed[20]. In terms of construct stability, dual plating exhibited the highest stiffness and the least micromotion in their models[20]. If a construct is too rigid, this could lead to stress-shielding and the clavicle might fracture at the periphery, as depicted by the study of Boyce et al.[19]. Ensuring that the dual plates are of different lengths could also reduce stress concentrations at the end of the plate-screw constructs. Additionally, a too-rigid construct might predispose to higher nonunion rates. However, a systematic review and meta-analysis described excellent union rates for dual plating (99.5%) and no significant differences were observed among all surgical fixation types[8]. It seems that dual plating is biomechanically superior for fixation of midshaft clavicle fractures when compared with a single superior plate. Dual plating had biomechanical properties similar to those of a single plate placed anteriorly, although it appears that orthogonal plates may be better suited to resist multiplanar bending and rotational forces, especially in more comminuted or segmental fractures, and therefore might better endure early weight-bearing.

The current study had several limitations. Although our biomechanical study had the largest number of specimens (n = 24), the limited number of clavicles per group (n = 4) made it possible to detect only large effects (leading to a potential type-II error). However, it is more than adequate to test for biomechanical noninferiority by applying nonparametric testing. Cadaveric clavicles were used, whereas synthetic clavicles provide a more consistent material and specimen size for biomechanical testing of the different configurations. However, by using human bone, the results are more realistic and clinically applicable. Our specimens were from patients older than those who would likely undergo surgical fixation. Although this does not warrant the use of locking screws[22], it does increase the risk of poorer fixation in osteopenic bone and might amplify clinical differences. However, a priori random allocation, with stratification by BMC, ensured homogenous groups and minimized the effect of bone quality on our biomechanical outcomes.

Dual-plating configurations using mini-fragment plates were biomechanically superior for the fixation of midshaft clavicle fractures when compared with a single, superior, 3.5-mm plate and had biomechanical properties similar to those of a 3.5-mm plate placed anteriorly. It is therefore a viable treatment option, especially given that the use of these lower-profile implants could substantially reduce implant removal rates. With the exception of axial stiffness, no significant differences were found when the different dual-plating constructs were compared with each other. However, placing a 2.4-mm plate superiorly, in combination with a 2.7-mm plate anteriorly, seems to be the most rigid construct given its biomechanical superiority in cantilever bending over the 3.5-mm plate placed superiorly. ■

NOTE: The authors thank Ifaz Haider, Maria Beketskaia, Rohit Bansal, and W. Brent Edwards.

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