ARTICLE IN PRESS

J Shoulder Elbow Surg (2017) ■■, ■■–■■

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ORIGINAL ARTICLE

Biomechanical comparison of three different plate configurations for comminuted clavicle midshaft fracture fixation

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Background: The aim of this study was to compare the fixation rigidity of anterior, anterosuperior, and superior plates in the treatment of comminuted midshaft clavicle fractures.

Methods: Six-hole titanium alloy plates were produced according to anatomic features of fourth-generation artificial clavicle models for anterior (group I; n = 14), anterosuperior (group II; n = 14), and superior (group III; n = 14) fixation. After plate fixation, 5-mm segments were resected from the middle third of each clavicle to create comminuted fracture models. Half the models from each group were tested under rotational forces; the other half were tested under 3-point bending forces. Failure modes, stiffness values, and failure loads were recorded.

Results: All models fractured at the level of the distalmost screw during the failure torque, whereas several failure modes were observed in 3-point bending tests. The mean stiffness values of groups I to III were 636 ± 78, 767 ± 72, and 745 ± 214 N · mm/deg ($P = .171$), respectively, for the torsional tests and 38 ± 5, 20 ± 3, and 13 ± 2 N/mm, respectively, for the bending tests ($P < .001$ for group I vs. groups II and III; $P = .015$ for group II vs. group III). The mean failure torque values of groups I to III were 8248 ± 2325, 12,638 ± 1749, and 10,643 ± 1838 N · mm ($P = .02$ for group I vs. II), respectively, and the mean failure loads were 409 ± 81, 360 ± 122, and 271 ± 87 N, respectively ($P = .108$).

Conclusions: In the surgical treatment of comminuted midshaft clavicle fractures, the fixation strength of anterosuperior plating was greater than that of anterior plating under rotational forces and similar to that of superior plating.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Clavicle; spiral clavicle plate; plating; biomechanical; comminuted; anterior clavicle plate

Clavicle fractures represent 2%-5% of adult fractures and about 44% of shoulder fractures, and 80% of clavicle fractures are in the midshaft region.[4,14,16,18,21] Most clavicle fractures are treated conservatively; relative operative indications are accompanying neurovascular injuries, multiple trauma, floating shoulder, 100% displacement, skin irritation by fragments due to laceration of the fascia, comminuted fractures, and

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https://doi.org/10.1016/j.jse.2017.06.034

>2 cm of shortening.[1,15,21,25] In these fractures, functional impairment and cosmetic problems may be due to malunion or nonunion, which is seen in 30% of patients.[9,25]

The recommended surgical treatment is open reduction with plate-screw fixation because it yields rigid fixation and early mobility.[9,13] Studies have shown the biomechanical superiority of superior plating over anterior plating and of locking screw fixation over unlocking screws.[2,17,20] Moreover, superiorly placed plates are usually more superficial and can be easily palpated under the skin.[3,8] Anterosuperior spiral plating results in less skin irritation compared with superior plating and has stable fixation strength against rotational forces on the clavicle.[6,8]

We hypothesized that the fixation strength of anterosuperior spiral plates is superior to that of anterior and superior plates in the treatment of comminuted, displaced clavicle midshaft fractures, especially under rotational loads. This biomechanical study compared the stiffness and failure loads of superior, anterosuperior, and anterior clavicle plates under rotational and bending forces in midshaft comminuted clavicle fracture models.

Materials and methods

For each plate configuration, a power analysis based on $\alpha = .05$ and 80% power indicated that 14 samples were required. Therefore, 42 fourth-generation, identical, polyurethane, large, left clavicle models (Sawbones Europe, Malmö, Sweden) were divided into 3 groups of 14 models each: group I, anterior plate; group II, anterosuperior spiral plate; and group III, superior plate. Half the models from each group were subjected to torsional loads and the other half to 3-point bending loads. Custom-made 3.5-mm locking plates (Ilerimed, Istanbul, Turkey) were made from titanium, aluminum, and vanadium alloy (Ti-6Al-4V) based on original 3-dimensional drawings and the anatomic features of the artificial clavicles (Siemens Unigraphics NX, Siemens PLM software, Munich, Germany). The respective lengths, widths, and thicknesses were 117, 11, and 3 mm for the anterior plates (Fig. 1, *A*); 115, 11, and 3 mm for the anterosuperior plates (Fig. 1, *B*); and 115, 11, and 3 mm for the superior plates (Fig. 1, *C*). All plates had 6 holes, and the distance between 2 holes was 15 mm. There was no hole in the middle 50 mm of each plate to decrease the risk of plate fracture and to increase its rigidity because a previous study found that the stresses were highest at the level of the defect and the 2 screws closest to the defect.[10] The plates were fixed to the models using six 3.5-mm locking bicortical screws. To model a comminuted fracture, a 5-mm defect was created in the middle of each clavicle corresponding to the center of the hole-free area of the plates (Fig. 2).

Each end of the clavicle for torsional tests and only the sternal end for bending tests were encrusted into plastic molds filled with polyester cement. For the torsion tests, the sternal end of the clavicle was fixed to the test device, and the force was placed on the acromial end of the clavicle in clockwise direction to simulate real physiologic biomechanical torsion (Fig. 3).

In the 3-point bending tests, the medial end of the clavicle was fixed to the test machine to prevent rotation during loading, and a support was placed under the clavicle at the midpoint between the defect and the medial screw (Fig. 4). Force was exerted vertically through the lateral end of the clavicle.

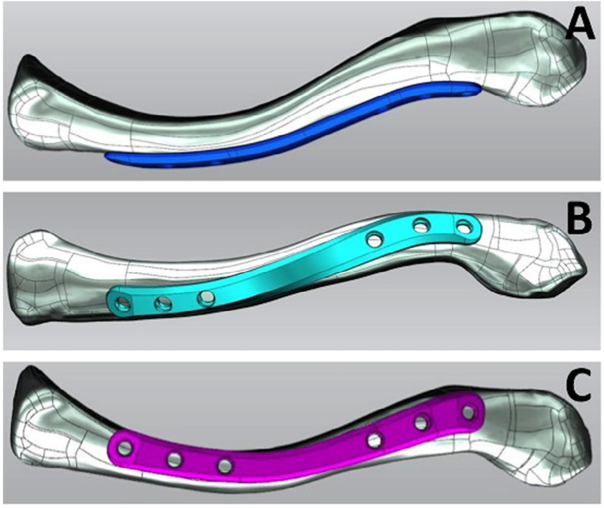

Figure 1 Three-dimensional drawings of the original Sawbones clavicle models and anterior (**A**), anterosuperior (**B**), and superior (**C**) custom-made plates.

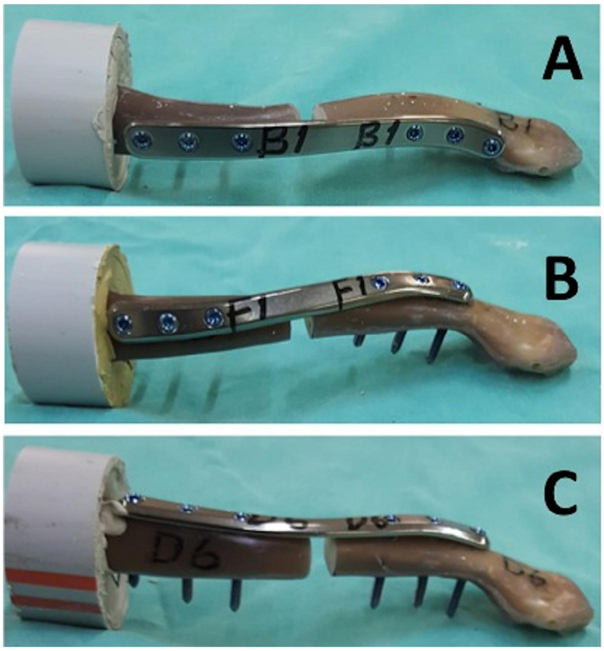

Figure 2 Application of the anterior (**A**), anterosuperior (**B**), and superior (**C**) plates and 5 mm of defect to simulate comminuted fracture models.

The load and torque were recorded by an MTS axial/torsional load cell (2500 N/25 N • m; MTS Systems Corporation, Eden Prairie, MN, USA) located on a fixed support for the torsion tests and on an application support for the bending tests at 0.5 Hz. During cyclical loading, an 80 N force was applied, which is 18% of the force that fractured the original Sawbones clavicle. The linear and angular displacements were recorded using the standard transducers of the MTS 858. Torsional and 3-point bending forces were applied to each specimen for 500 cycles in all subgroups. Load displacement data were collected and recorded initially (after 10 cycles) and after 100, 200, 300, 400, and 500 cycles. The bending and torsional stiffness values