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How well do contoured superior midshaft clavicle plates fit the clavicle? A cadaveric study

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Background: Given the degree of variation in clavicular morphology, 4 clavicle plating systems were examined for their congruity as superior, midshaft, anatomic clavicle (SMAC) plates in a cadaveric study.
Methods: SMAC plates from 4 manufacturers were applied to 79 dry right human clavicles. Two systems offered multiple (4) variations of plates (MP), 1 offered two variations (TP), and 1 had a single plate (SP). Two examiners applied and clamped the best-fitting plate from each system onto each of the 79 clavicles and then graded them: 1, poor fit; 2, good fit; and 3, anatomic fit. Each examiner repeated the process to assess intraobserver and interobserver reliability. The scores were averaged to produce a final score for each system for each clavicle.
Results: The MP systems scored the highest (32%-37% anatomic, 54%-63% good, 5%-8% poor), followed by the TP system (30% anatomic, 53% good, 17% poor), and finally the SP system (9% anatomic, 59% good, 32% poor). Of note, clavicular length significantly correlated with a higher degree of conformity in all plating systems (Spearman rank correlation $P < .05$ for each system). In clavicles longer than 150 mm, the MP and TP systems performed identically, with the SP system close behind. Contouring of the plate is needed in 73% of cases overall.
Conclusion: Plating systems with multiple plate shape variations are more advantageous when dealing with smaller-sized clavicles, typically in females. However, when dealing with larger clavicles, there was no real difference.
Level of evidence: Basic Science; Surgical Technique Using Cadaver Specimens

Keywords: Clavicle; Trauma; Shoulder; Cadaveric; Fracture; Plate fixation

The human clavicle is highly variable within a given population,[1,5,9] being a 3-dimensional structure with a complex morphology. Variation exists not only in length and diameter but also in its cross-section and the degree of bowing.[1,9] There is also variation between males and females[9] as well as between the left and right clavicle in an individual,[5] with the left clavicle tending to be longer and the right thicker (thought to be due to hand dominance and stress loading[14]).

In traumatic injury, 80% of fractures occur in the middle third of the clavicle, 12% to 15% laterally and only 5% to 6% medially.[3,20] Although most fractures can be treated conservatively,[20,25] operative treatment should be considered in cases with gross displacement, soft-tissue interposition, shortening of greater than 2 cm, comminution, open fractures (or skin tenting), neurovascular involvement and associated

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scapula fractures.[7,15,19,25] Although plate and screw fixation is common,[7,15,25] fixation with an intramedullary device is also acceptable and provides similar midterm to long-term outcomes.[24] Intramedullary fixation will not be studied here.

Given the variation in clavicular anatomy, obtaining a suitable plate contour to provide a good fit for the clavicle is challenging. Plate options can include pelvic reconstruction plates, which are easy to bend into shape, but as a consequence are less rigid and can bend in situ.[6,18] Alternatively, thicker dynamic compression plates can be used, but they tend to be harder to bend and can cause issues with the overlying soft tissues.[18,23] Locking screws have been shown to increase the rigidity of the fixation.[12]

Contoured anatomic clavicle plates have been developed to reduce the need for excessive contouring and reduce hardware complications, yet still maintain a suitably rigid construct.[11,12] Several plating systems are commercially available, with large variations between the different systems.[2,4,10,21] The systems can be of stainless steel[4,10] or titanium[2,10,21] and have different shapes to fit anatomically the same region of the clavicle. One of the most notable variations is the number of plate variations available for each fracture location: for example, one system has up to 33 different dedicated clavicle plates to accommodate anatomic and fracture variations.[2]

Focusing on superior midshaft anatomic clavicle (SMAC) plates (because 80% of fractures involve the middle third of the clavicle), a plating system can contain from 1 plate variation[10] to 4 plate variations for the same plate length (in mm).[2,4] This clearly has implications in the cost of the plating system and the amount of stock that needs to be stored to be able to accommodate such systems. At a time where financial constraints are placing pressure on orthopedic interventions and the implants used, it is important to demonstrate the benefits of a potential cost increase.

There is little evidence in the literature to suggest how many plate variations are needed or when the multiple plate options become clinically useful. Anecdotally, several participants of this study have noted in practice that SMAC plates from various manufacturers do not fit some of the clavicles operated on. Our null hypothesis is that all plate systems perform equally regardless of the number of plate options. The aims of this study were to therefore to examine (1) how well different commercially available SMAC plates conform to a range of human clavicles, and (2) whether any factors, such as size of the clavicle, affect the congruity of the plating systems examined.

Materials and methods

Right-sided SMAC plating systems were obtained from 4 implant companies: Acumed (Hillsboro, OR, USA),[2] Arthrex (Naples, FL, USA),[4] DePuy Synthes (Warsaw, IN, USA)[10] and Stryker (Kalamazoo, MI, USA).[21] To ensure a fair comparison, SMAC plates of approximately 80 to 100 mm in length were selected because these were deemed to be the size most commonly used for simple fractures and longer plates were excluded. Acumed had a selection of plates for smaller patients, but by their own admission, these were not considered to be as rigid or strong. These plates were therefore excluded because they would not produce a mechanically comparable fixation. The plates used were 8-hole plates from Acumed, Stryker, and Arthrex and a 6-hole plate from DePuy Synthes. Acumed and Stryker used titanium, and DePuy Synthes and Arthrex used stainless steel plates.

The 4 plating systems were classified into 1 of 3 systems. Acumed and Arthrex were classed as providing multiplating systems (MP1 and MP2, respectively) consisting of 4 variations of 8-hole plates: straight, long, medium, and small. The Stryker system comprised two 8-hole plates (TP) with lesser and greater curvature. Finally DePuy Synthes offered a single 6-hole plate (SP).

The study used 79 right adult human clavicles of unknown provenance that were obtained from the University of Dundee's cadaveric collection. The specimens were skeletally mature, dry, denuded of soft tissues, and displayed no evidence of previous fractures or callus formation. The length of each clavicle and its diameter at the exact midpoint were recorded.

For each clavicle, the best fitting plate from each of the plating systems was selected and applied to the clavicle. All plates were sided and the ends, labelled medially and laterally, were placed in the correct orientation. Although the plates can often be flipped so that the medial end points laterally, we placed them in the correct orientation to standardize the testing. The plates were placed to cover a hypothetical fracture at the exact midpoint of the clavicle to ensure a minimum of 3 holes on either side of the fracture site. Plastic modelling clamps were used to secure the plate to the clavicle (Fig. 1). Plate-holding clamps, as used in the operating theater, were originally tried but rejected because we felt they ran the risk of damaging the older cadaveric specimens. The clamped plate and clavicle were then scored on the conformity of fit and the potential degree of plate bending that might be required for an anatomic fit.

The scoring system used was a simple 3-level clavicle congruence score (CCS). A score of 3 represented an "anatomic

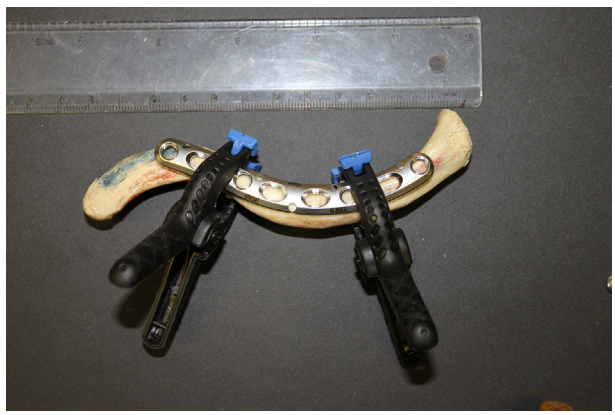

Figure 1 A superior middle clavicle plate attached to a clavicle via 2 plastic modeling clamps.