# EXPERIMENTAL INVESTIGATIONS

# Biomechanical Aspects of Locking Reconstruction Plate Positioning in Osteosynthesis of Transverse Clavicle Fracture

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*Key words:* clavicle; fracture; biomechanics; osteosynthesis; locking plate.

*Summary.* The aim of this study was to evaluate and compare the biomechanical effects of locking reconstruction plate positioning on the osteosynthesis of clavicle midshaft simulated transverse fractures.

*Material and Methods.* Twelve synthetic clavicles with simulated midshaft transverse fractures were repaired with a 3.5-mm locking reconstruction plate in the anteroinferior or the superior position. The clavicles were randomly assigned to 2 groups (6 per group). Each repaired clavicle was tested in cantilever bending by using the universal testing machine. The maximal load and the displacement of the specimens at a load of 40 N were recorded for each group.

*Results.* The anteroinferior plating osteosynthesis with a 3.5-mm locking reconstruction plate could bear an average maximal load of 183.3 N (SD, 11.3); the corresponding load for the superior plating osteosynthesis with the identical implants was 444.8 N (SD, 102.3), and the mean displacement was 1.5 mm (SD, 0.5) and 0.7 mm (SD, 0.2), respectively.

*Conclusions.* The superior plating osteosynthesis of simulated midshaft transverse clavicle fractures with the 7-hole 3.5-mm locking reconstruction plate had a significantly higher bending (from top to bottom) load to failure in comparison with the anteroinferior plating osteosynthesis of the clavicle with the identical implants. Clavicles plated with the 7-hole 3.5-mm locking reconstruction plate at the superior aspect exhibited a significantly greater biomechanical stability at a load of 40 N than those plated at the anteroinferior aspect.

## Introduction

Clavicle fractures are common and account for 1% to 4% of adult fractures and about 40% of the shoulder girdle injuries (1–3). Fractures of the middle-third (midshaft) account for 60% to 97% of all clavicular fractures (1, 4–7). Surgery is recommended in case of the middle-third fractures of the clavicle under certain circumstances including open fractures and fractures with potential skin perforation or neurovascular injury, completely displaced fractures or with shortening by more than 2 cm, the floating shoulder, and polytrauma (8–13). However, the choice of methods for operative fixation of midshaft clavicle fractures is controversial, with wide geographic and institutional variations (8–13). The biomechanical data discovered in the experimental studies may allow orthopedic surgeons to make more definitive clinical decisions about the selection of implants and their application for the treatment of midshaft clavicle fractures (14–23).

The aim of this study was to evaluate and compare the biomechanical effects of locking reconstruction plate positioning on the osteosynthesis of simulated midshaft transverse clavicle fractures.

## Material and Methods

Twelve synthetic clavicles (Model #3308, Pacific Research Laboratories, Vashon Island, WA) with an identical transverse midshaft fracture created by the manufacturer were used.

The experienced orthopedic trauma surgeons performed the osteosynthesis of simulated clavicle fractures with a 7-hole 3.5-mm locking reconstruction plate (Changzhou Kanghui Medical Innovation Co., Ltd) and 3.5-mm self-tapping titanium locking screws (Changzhou Kanghui Medical Innovation Co., Ltd) according to the standard surgical technique. The plates were contoured to the clavicle using standard plate benders. Three screws were placed on each side of the fracture in all constructs. The length of the used screws was enough to fully pass through both cortices of the clavicle model.

The specimens were randomly assigned to 2 groups (n=6 per group). In the group 1 (anteroinferior), the plate was placed at the anteroinferior aspect of the synthetic clavicle (8). In the group 2 (superior), the plate was placed at the superior side of the clavicle model.

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The specimen was positioned by fixing the sternal end in the hole of the rectangular metal tube with acrylic cement (16). Each repaired clavicle was then tested in cantilever bending by using a universal testing machine (Tinius Olsen H25KT) (20). The support (wedge of metal) was put under the clavicle at the osteotomy site. In the group 1 (anteroinferior), the support was adjusted to be in contact with the plates (20) (Fig. 1). In the group 2 (superior), the wedge of metal was adjusted to be in contact with the inferior cortex of the clavicle model (20) (Fig. 2). The distance from the clamp of the clavicle to the support was 55 mm and from the support to the actuator 55 mm. A load from the testing machine (Tinius Olsen H25KT) was applied at a rate of 5 mm/min at the distal end of the clavicle and perpendicular to the axis of the specimen (16, 20). Loads were delivered until a structural failure, defined as a plate or clavicle breakage or bending to 25 mm of actuator displacement, occurred (14, 18). The maximal loads were recorded by the machine, and the displacement of the specimens at a load of 40 N was calculated for each group (18).

All the data were grouped by location of the locking reconstruction plate for descriptive statistics. The statistical analysis was performed by the Mann-Whitney *U* and Fisher exact tests. The level of significance to check the statistical hypothesis was set at 0.05.

### Results

The biomechanical effects of locking reconstruction plate positioning on the osteosynthesis of transverse clavicle fractures are described in Table. In the group 1, the anteroinferior plating osteosynthesis of the clavicle with locking reconstruction plates could bear an average maximal load of 183.3 N (SD, 11.3). In the group 2, the superior plating osteosynthesis of the clavicle with locking reconstruction plate could bear an average maximal load of 444.8 N (SD, 102.3). The superior plating osteosynthesis of simulated midshaft transverse clavicle fractures with the locking reconstruction plate had a significantly
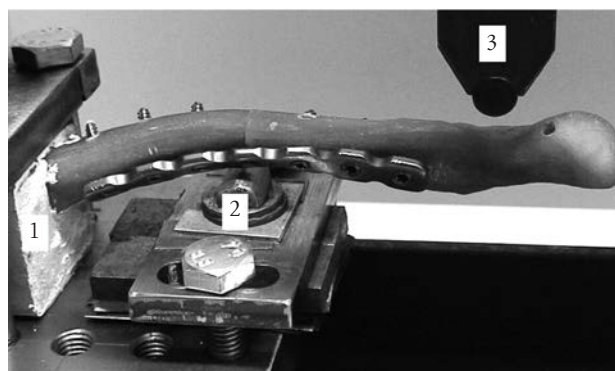


Fig. 1. The mechanical testing of the clavicle repaired by anteroinferior plating osteosynthesis

1, the rectangular metal tube, where the sternal end of the clavicle model was rigidly fixed with acrylic cement; 2, the support and 3, the actuator.
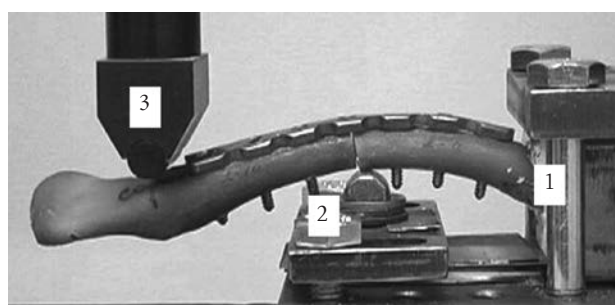


Fig. 2. The mechanical testing of the clavicle repaired by superior plating osteosynthesis

1, the rectangular metal tube, where the sternal end of the clavicle model was rigidly fixed with acrylic cement; 2, the support; and 3, the actuator.

higher bending load to failure in comparison with the same plate that was placed at the anteroinferior aspect of the clavicle model (*P*<0.05). All superior locking reconstruction plates failed due to clavicle sternal tip fracture through the most medial screw hole, whereas 83% of anterior-inferior locking reconstruction plates failed by plate bending (*P*<0.05) (Fig. 3). The mean displacement of the clavicles repaired with locking reconstruction plates, which were located on the anteroinferior surface of the bone, at a load of 40 N was 1.5 mm (SD, 0.5). The mean displacement of the clavicles repaired with the

*Table.* Biomechanical Effects of Locking Reconstruction Plate Location on the Osteosynthesis of Transverse Clavicular Fracture

| Specimen | Parameter | | | | | |
| | Anteroinferior Plating | | | Superior Plating | | |
| | Maximal Load, N | Displacement, mm | Failure Mode | Maximal Load, N | Displacement, mm | Failure Mode |
|---|---|---|---|---|---|---|
| 1 | 169.3 | 1.4 | LRP bent | 402.5 | 0.8 | Fracture |
| 2 | 170.0 | 2.4 | LRP bent | 564.0 | 0.8 | Fracture |
| 3 | 184.3 | 1.0 | LRP bent | 351.0 | 1.1 | Fracture |
| 4 | 196.8 | 1.6 | Fracture | 384.0 | 0.7 | Fracture |
| 5 | 190.0 | 1.1 | LRP bent | 585.8 | 0.5 | Fracture |
| 6 | 189.3 | 1.4 | LRP bent | 381.6 | 0.6 | Fracture |

LRP, locking reconstruction plate.
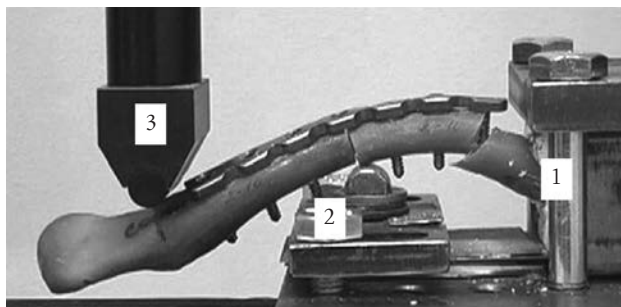
*Fig. 3.* The breakage of the repaired clavicle
1, the rectangular metal tube, where the sternal end of the clavicle model was rigidly fixed with acrylic cement; 2, the support; and 3, the actuator.

superior locking reconstruction plates at the same load was 0.7 mm (SD, 0.2). The location of implants had a significant impact on the stability of the osteosynthesis of simulated midshaft transverse clavicle fractures with locking reconstruction plates at a load of 40 N (*P*<0.05).

**Discussion**

Several biomechanical studies have been performed in order to elucidate the differences in biomechanical stability among different operative procedures and implants used for the fixation of clavicular fractures (14–23). Golish et al. in their study compared the biomechanical aspects of 7-hole 3.5-mm titanium dynamic compression plates (ACE/Depuy, Warsaw, IN, USA) contoured to the superior surface of osteotomized cadaveric clavicles versus intramedullary fixation with the Rockwood Pin (Depuy, Warsaw, IN, USA) in cyclic bending (19). They concluded that plate constructs were superior in showing less displacement at fixed loads and greater loads at fixed displacements (19). Harnroongroj and Vanadurongwan reported that the superior plating compression osteosynthesis of clavicle fractures without an inferior cortical defect with a 6-hole one-third tubular plate and 3.5-mm cortical screws provided more stability against the bending moment than the anterior plating with the same implants (16). Iannotti et al. tested human adult formalin-fixed osteotomized and plated clavicles in compression and torsion using superior versus anterior plating with 3.5-mm reconstruction plates, 3.5-mm limited contact dynamic compression plates, and 2.7-mm dynamic compression plates (14). They concluded that superior plating with 3.5-mm limited contact dynamic compression plates provided the best stiffness, rigidity, and strength (14). Goswami et al. in their study found no biomechanical differences between the tested 6-hole 3.5-mm stainless steel Synthes USA (West Chester, PA) limited-contact dynamic-compression plate and the 8-hole side-appropriate Acumed (Hillsboro, OR) nonlock-

ing clavicle plate, which were located on the superior surface of the fresh human adult cadaveric clavicles (15). Hamman et al. evaluated the biomechanical properties of unicortical locked clavicular superior plating with a 10-hole precontoured titanium clavicle plate (Acumed TM, Hillsboro, OR) against the nonlocked bicortical specimens (17). The authors reported that axial stiffness and axial load to failure of the locked unicortical versus nonlocked bicortical constructs were not statistically significantly different (17). The data of these studies facilitate to make a decision about our study purposes and design. The aim of our study was to evaluate and compare the biomechanical effects of locking reconstruction plate positioning on the osteosynthesis of simulated midshaft transverse clavicle fracture. The similar objectives were realized with different plate types and biomechanical test methods in the experiments performed by Celestre et al., Demirhan et al., and Partal et al. (20, 21, 23). In a study by Celestre et al., anterior-inferior plated synthetic clavicles with 8-hole 3.5-mm universal locking system locked contourable dual compression plates (CDCPs) (Zimmer Inc, Warsaw, IN) failed at a load of 170 N (SD, 9) (20). In our study, the anteroinferior plated synthetic clavicle with the 7-hole 3.5-mm reconstruction locking plate (Changzhou Kanghui Medical Innovation Co., Ltd) failed at a load of 183.3 N (SD, 11.3). Celestre et al. reported that the synthetic clavicles plated with the superior 8-hole 3.5-mm universal locking system locked CDCPs (Zimmer Inc, Warsaw, IN) failed at a load of 300 N (SD, 59) (20). In our experiments, the synthetic clavicle superiorly plated with the 7-hole 3.5-mm locking reconstruction plate (Changzhou Kanghui Medical Innovation Co., Ltd) failed at a load of 444.8 N (SD, 102.3). Partal et al. compared the stiffness of the anteroinferior and superior plating osteosynthesis of the simulated midshaft transverse clavicle fractures with a 3.5-mm pelvic reconstruction plate (Synthes, Paoli, PA) or a 3.5-mm locking pelvic reconstruction plate (Synthes, Paoli, PA) (23). Contrary to our data, they concluded that placing the plate anteroinferiorly on the clavicle provided a more stable construct in terms of bending rigidity with no detriment in axial and torsional stiffness compared with placing the plate superiorly (23). We think that this difference is likely to be a result of differences in the test setup. Demirhan et al. in their study compared the biomechanical aspects of the 6-hole locking compression plate (locking clavicle plate system; Acumed, Hillsboro, OR) contoured to the superior surface of osteotomized human adult formalin-fixed clavicles versus fixation with the dynamic compression plate (OrtoPro-Covision Medical, Carlton Ind, Park Carlton Nottinghamshire, UK) or the external fixator (Tasarımmed Ltd Sti-Mini LRS, Eyup, Istanbul, Turkey) in torsional

and 3-point bending loading tests (21). The authors reported that the mean failure load was 213.19 N (SD, 11.86) for the clavicles plated with the superior 6-hole locking compression plate (locking clavicle plate system; Acumed, Hillsboro, OR) (21). In our experiments, the synthetic clavicle superiorly plated with the 7-hole 3.5-mm locking reconstruction plate (Changzhou Kanghui Medical Innovation Co., Ltd) failed at a load of 444.8 N (SD, 102.3).

The data of our study and experiments of other researches suggest that the anterior–inferior locking plates failed at lower bending load in comparison with the locking plates positioned at the superior aspect of the clavicle model.

We hope that the biomechanical data derived from this experimental study may allow orthopedic surgeons to make more definitive clinical decisions about the selection of locking reconstruction plates and their application for the treatment of midshaft

claviclular fracture. However, the extrapolation of biomechanical data to the clinical setting should be done with caution.

## Conclusions

The superior plating osteosynthesis of simulated midshaft transverse clavicle fractures with a 7-hole 3.5-mm locking reconstruction plate had a significantly higher bending (from top to bottom) load to failure in comparison with the anteroinferior plating osteosynthesis of the clavicle with the identical implants. The clavicles plated at the superior aspect with the 7-hole 3.5-mm reconstruction locking plates exhibited a significantly greater biomechanical stability at a load of 40 N than those plated at the anteroinferior aspect.

## Statement of Conflict of Interest
The authors state no conflict of interest.

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