A Biomechanical Comparison of Screw and Plate Fixations for Scaphoid Fractures

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Abstract

Background Headless screw fixation is the current gold standard of surgical repair for scaphoid fractures. However, maintaining reduction of certain types of scaphoid fractures is challenging with a compression screw. Plate fixation may offer superior fixation in some scaphoid fractures, particularly those with comminution, nonunion, segmental bony defects, and osteopenic or osteoporotic bone.

Purpose This study questions whether method of fixation is a determinant in load to failure in segmental scaphoid fractures, and whether any fixation provides a greater mechanical advantage in simulated normal versus osteoporotic bone.

Materials and Methods Polyurethane models were fashioned to simulate scaphoids with 3-mm segmental defects. Defects were bridged by one of three constructs: a locking plate, a nonlocking plate, or a headless compression screw. Three models for each fixation construct were tested for both simulated normal and osteoporotic bone density. Load to failure was recorded as the load at which the 3-mm segmental defect was closed.

Results Gap closure occurred in all trials. In simulated normal bone, there were no statistically significant differences in load to failure between fixation methods. In simulated osteoporotic bone, the locking plate had a 28% greater load to failure as compared with screw fixation.

Conclusion While biomechanical testing shows that plate and screw fixations are equivalent in normal density bone for fixation of a segmental scaphoid defect, locking plates are superior to screw fixation in simulated osteoporotic bone models.

Clinical Relevance Plate fixation may provide superior fixation for complex scaphoid fractures, particularly in osteopenic bone.

Keywords

- ▶ scaphoid
- ▶ nonunion
- ▶ biomechanical
- ▶ plate

The scaphoid is a key element of wrist stabilization and force transmission across the carpus.¹ Accordingly, scaphoid defects, such as those observed in scaphoid nonunion, lead to wrist instability and subsequent carpal collapse and osteoarthritis.^{1–3} Scaphoid nonunion after a fracture may occur for a variety of reasons, particularly rotational instability and ischemia due to the scaphoid's tenuous blood supply.^{4,5} Subsequent nonunion is also observed in up to 10% of scaphoid fractures treated acutely with headless compression screws.⁴ As the observed outcomes of untreated scaphoid nonunion include pain, disability, and arthritis, surgical management is recom-

mended.^{2,6,7} The current standard of surgical repair for scaphoid nonunion or segmental defect is the headless compression screw, typically with bone grafting.^{4,8} Although screw fixation remains the standard of care for scaphoid nonunion, there are inherent clinical problems with using screws: (1) screw monopolizing bone and consequently reducing the surface area for healing; (2) inability to use compression screws appropriately when there is limited bone to compress in a nonunion with segmental defect; and (3) intraoperative displacement of interposed bone graft during screw insertion.^{9,10}

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Plate fixation has received minimal attention since Huene and Huene described a 95% union rate using the Ender scaphoid-beaked plate in 1991.¹¹ Recently, plate fixation has been described as a surgical option when nonunion occurs after screw fixation, when a nonunion presentation is delayed >2 years, where there is bone loss, or where screw purchase is suboptimal with a segmental bone defect.¹² Some authors have suggested that scaphoid plating may provide superior fixation in cases of avascular necrosis of the proximal pole.¹² These plates act as bridging plates and may be fixed with either locking or nonlocking screws. The plate may improve fixation of a scaphoid fracture by resisting axial compression, rotation, and shear.¹² Axial collapse is the most frequent cause of failure in a collapsed scaphoid due to loss of cortical opposition with a segmental defect.^{13,14}

Scaphoid nonunion fixation is frequently augmented with bone grafting.^{4,8} Cancellous graft is the optimal graft choice because of its biologic properties.¹⁵ However, cancellous graft does not provide the structural integrity that cortical or corticocancellous grafts provide. For that reason, fixation for scaphoid nonunion must be structurally resilient if cancellous graft is to be used.

Consideration of bone quality is also important when choosing a method of fixation. Fixation is often more difficult in chronic scaphoid nonunion due to poor bone quality. Disuse osteoporosis is common in chronic scaphoid nonunion and adds an element of difficulty to fixation.^{16,17}

Given that fractures of the scaphoid presenting with nonunion or segmental defects are known to be difficult to fix with headless compression screws,^{9,13,18,19} the aim of this study is to determine whether method of fixation and bone quality act as determinants of load to failure in simulated scaphoid fixation.

Materials and Methods

Testing groups included polyurethane blocks (Sawbones, Vashon, Washington) with densities of 320 kg/m³ (20 lbs/ft³) and 160 kg/m³ (10 lbs/ft³) simulating normal density cancellous bone (252 kg/m³) and osteoporotic bone density (126 kg/m³), respectively.^{20,21} These groups were further divided into three fixation methods: plate fixation with either locking or nonlocking screws, and headless compression screw fixations. Three specimens were trialed in each of the six groups. The investigators used a power analysis with an α error of 0.05 and 80% power to estimate the number of specimens needed per group with a 20-N difference, and this difference was anticipated based on previous biomechanical studies using polyurethane.^{22,23}

To simulate a scaphoid, polyurethane blocks were cut to standardized dimensions of 8 cm length $\times$ 1.5 cm depth $\times$ 1 cm width. The longer length of the blocks compared with a scaphoid accommodates for biomechanical testing. The models were then contoured with a concavity radius of 0.5 cm mimicking a scaphoid's volar surface.

As scaphoid nonunion may lead to loss of contact between proximal and distal scaphoid poles, and as a 3- to 4-mm gap is typically filled with bone graft, a 3-mm gap was created in

the scaphoid models. This gap was bridged by either a headless screw or a volar plate with locking or nonlocking screws (Medartis AG, Basel, Switzerland).

For plate fixation, the plates were placed on the simulated volar contour of the polyurethane model, and screw holes were drilled according to manufacturing guidelines. With the use of a wooden prototype, a standardized 3-mm segmental cut was measured and created in the polyurethane to simulate a segmental defect. Afterward, the plate was replaced, and 6 $\times$ 9 mm locking or nonlocking screws were inserted.

For screw fixation, headless screws were predrilled according to the manufacturer's guidelines. A 3-mm segment of polyurethane was measured and removed from the center of the model prior to screw insertion, and this removed segment was then used as a spacer during screw insertion. Prior to insertion, the spacer was modified using a burr so that it would surround the screw on three sides. To preserve the 3-mm gap during screw insertion, the spacer was placed back in the gap while the screw was inserted. The spacer was removed after placement of the screw. Depth of the screw was standardized by a mark on the drill bit that would allow the drill bit and screw to glide through the polyurethane to a set distance. Each screw was inserted with a hand screwdriver to two-finger tightness by the same investigator. All screw threads were embedded in the polyurethane outside of the segmental defect.

The model with fixation was mounted on the load frame (TestResources Inc., Shakopee, MN) with the use of clamps, which were tightened to two-finger tightness (refer to ►Fig. 1). The model was clamped 1 cm from the segmental defect on either side, and oriented at a 45-degree angle relative to horizontal to simulate the scaphoid's normal

Fig. 1 Polyurethane model with plate fixation mounted on load frame.

position in a neutral wrist.^{1,24} This position allows for comparison to biomechanical trials conducted in previous studies.^{24,25} A 45-degree angle is also within the 30- to 60-degree range of documented radioscaphoid angles.²⁶

Clamps placed at either pole of this model transmit axial compression, which at a 45-degree angle recreates the dorsal to volar cantilever force. This bending force is described as the principal physiologic load that the scaphoid encounters from oblique loading by the trapezium, trapezoid, and capitate.^{1,24} This is the same mechanism that causes the “hump-back deformity” of a collapsed scaphoid.

Each model was loaded in compression at 0.125 mm/s until failure. Load to failure was defined as the load at which the 3-mm segmental defect was closed. To determine the point of failure, video recordings were analyzed to identify a time frame in which gap closure occurred. Within this time frame, the greatest load before a decreasing load represents the load to failure. For each trial, we recorded axial load and linear displacement of the compression platen.

Analysis of variance was used to test the null hypothesis, and post hoc *t*-tests were used to determine which groups were statistically different.

Results

Load to failure was achieved in all trials. All of the constructs fixed with plates failed by the plate initially bending, followed by gradual anterior translation of the simulated distal pole relative to the proximal pole. All of the screw constructs failed by screw cutout of the foam block.

Load to failure means ($n = 3$) in simulated normal bone were 125.6 ± 3.8 , 133.0 ± 11.3 , and 89.3 ± 37.3 N and in simulated osteoporotic bone ($n = 3$) were 52.3 ± 0.5 , 40.8 ± 3.9 , and 46.6 ± 2.7 N for locking plate, headless screw, and nonlocking plate, respectively.

In simulated normal bone, there were no statistically significant differences in load to failure between fixation methods (p -value = 0.56 for locking plate vs. screw; 0.38 for locking plate vs. nonlocking plate; and 0.32 for screw vs. nonlocking plate).

In simulated osteoporotic bone, the locking plate had a 28% greater load to failure as compared with screw fixation, and this difference was statistically significant (p -value < 0.05). Other differences between fixation methods in simulated osteoporotic bone were not statistically significant (p -value = 0.11 for locking plate vs. nonlocking plate and 0.29 for screw vs. nonlocking plate).

Discussion

This study reveals that in cases of scaphoid segmental defects, each method of fixation performs similarly in simulated normal bone, but that locking plate fixation is superior to screw fixation in simulated osteoporotic bone. The advantage of the locking plate observed in osteoporotic bone is thought to be due to the locking plate providing rotational stability and superior anchorage in osteoporotic bone compared with other methods of fixation.^{17,20}

It is important to consider the limitations of this study. As a biomechanical study with simulated bone, the clinical relevance of these results cannot be determined conclusively. The design of our study is validated in previous literature, and is consistent with the accepted mechanism of scaphoid loading.^{1,24,25} While polyurethane is an excellent bone simulator, it cannot entirely reflect the response of a scaphoid to deformity and loading, and the densities of our polyurethane models may not match those of scaphoid nonunion.

Other biomechanical studies have tested the compression screw's load to failure in both polyurethane models and cadaveric scaphoids. Our study includes load to failure data that is comparable to those of similar investigations, typically within 100 N of force, with differences likely due to variation in density, direction of applied force, and anatomic variance between models or specimens.^{22,23,25,26}

Scaphoid nonunion is often accompanied by a collapse deformity or segmental defect in bone.^{1,10} The authors believe that an ideal fixation device for scaphoid nonunion would provide both sufficient structural support and accommodate the use of biologically superior cancellous bone graft. The segmental gap in the polyurethane, bridged by only the screw or plate, simulates the scaphoid waist gap that would be without structural support from a graft postoperatively. This study demonstrates that even without the structural support of cortical-type graft, the plate can perform as well as the screw in preventing displacement of the scaphoid poles. Furthermore, while the screw crosses and disrupts potential space for grafting, the plate creates and stabilizes a gap in which to insert graft.

In further consideration of scaphoid nonunion, it is unlikely that these patients will possess normal bone density, due to disuse osteoporosis or poor bone quality.¹⁶ The results of this study are interpreted as locking plate fixation performing significantly better than screw fixation in simulated poor-quality bone. This suggests that in clinical conditions of nonunion, locking plates may be the more stable option.

To date, there are three published case series that provide clinical outcome data regarding plate fixation for scaphoid nonunion. Thirty-four cases of volar plate fixation of scaphoid nonunion with vascularized or iliac crest bone graft have been described among Dodds et al, Ghoneim, and Leixnering et al. Those authors report two failed union among these 34 cases.^{5,12,13}

For biomechanical reasons alone, the authors propose that locking plate fixation should be considered at least equivalent to screw fixation for scaphoid nonunion. Based on the superior performance of locking plates in simulated osteoporotic bone, and other clinical considerations, the authors believe that locking plate fixation merits consideration in cases of scaphoid nonunion with segmental defect.

Conflict of Interest

Dr. Scott Edwards is a consultant for Medartis. The other authors do not have any conflicts of interest.

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