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The effects of screw orientation in severely osteoporotic bone: A comparison with locked plating

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ABSTRACT

Background: Techniques such as varying screw insertion angles and the use of locked plating have been shown to improve the strength of fixation in bone. The effects of these methods is less clearly understood in bone of exceedingly poor quality.
Methods: Forty plate-bone constructs were assembled and divided into four groups of ten. Perpendicularly placed screws were placed in one group, convergently placed crossing screws were placed in a second group, an oblique end screw was placed in a third group, and a fourth group utilized perpendicularly placed locking screws in a locking plate. All test subjects were mounted and loaded in cantilever bending to the point of failure. Stiffness, initial load to failure, and maximal load tolerated were all analyzed.
Findings: All four groups demonstrated evidence of failure at similar loads (21.8–26.1 N). The locked group was able to tolerate significantly higher loads overall (37.3 N, $P = .044$). All three non-locked groups demonstrated similar failure patterns and load to failure. Locking constructs demonstrated a distinctly different failure pattern. No significant differences were detected with regard to screw orientation and load to failure. The group with an oblique end screw was significantly less stiff than the other three constructs ($P = .017$).
Interpretation: In a severely osteoporotic model, failure in cantilever bending at low forces will take place regardless of fixation methods used. The mechanism of failure is different in locked constructs compared to traditional constructs. The added benefit of oblique screw placement observed in healthy bone is not observed in osteoporotic bone.

1. Introduction

Fracture fixation with plate and screw constructs has been the trademark of orthopaedic surgeons for decades. Prior to the introduction of locked plating in the 1990s, conventional plating was used almost exclusively as the method of choice for open fracture fixation. Since its advent, locked plating has significantly aided in the treatment of many fracture patterns, particularly those involving the long bone metaphysis. Improved construct stability and fracture healing potential with locked plating has been suggested (Fulkerson et al., 2006; Stoffel et al., 2007) in fracture settings that include severe comminution or osteoporotic bone. The improved stability of locked plating in the osteoporotic setting, however, has recently come into question, as recent studies (Egol et al., 2004; Gardner et al., 2004; Minihane et al., 2006) have failed to uniformly support its superiority over conventional plates.

Variables improving strength of fixation with conventional plates in normal bone has been extensively studied as well. Factors shown to improve fixation strength include greater spacing of screws (DeCoster et al., 1990), increasing the major diameter of the screw (Chapman et al., 1996), optimizing thread pitch (Conrad et al., 2005), increasing the number of threads in contact with the bone (Asnis et al., 1996) and use of longer plates (Tornkvist et al., 1996). Recent literature (Stoffel et al., 2004; Robert et al., 2003; Friedman et al., 1994; Nasson et al., 2001; Kuzhupilly et al., 2002) has additionally shown an advantage in construct fixation strength with screws placed obliquely into conventional plates. The effect of screw orientation is less understood in osteoporotic bone.

In this study we propose to explore two factors affecting plate and screw construct stability in a severely osteoporotic bone model: screw orientation and use of locking screws. We investigate the belief that locked plating affords superior strength, regardless of the degree of osteoporosis. We also explore the enhancing effect of varying screw insertion angles in bone of exceptionally poor quality. We hypothesize that locked plating will offer superior strength of fixation to conventional screws even in minimally

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dense bone. We also believe that varying the insertion angles of screws will show a greater stability enhancing effect in bone of exceedingly poor quality. We believe that the added stability of varying screw insertion angles will rival the fixation strength of locking screws.

2. Methods

Forty synthetic plate-bone models were constructed and divided into four groups of ten. The synthetic bone medium used was a very low density open cell polyurethane model (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA, model 1522-505) designed to mimic severely osteoporotic bone (5.5 pounds per cubic foot). The bone samples were cut from five commercially available blocks from a single lot into 40 smaller blocks 40 mm × 40 mm × 60 mm. The synthetic polyurethane bone material was as closely matched as possible in strength, density, and physical properties to severely osteoporotic metaphyseal bone to facilitate failure at lower forces by pullout rather than hardware failure. Our model was not designed to mimic a clinical setting but rather explore biomechanical relationships and therefore a cortex was not utilized. By using a synthetic bone medium, we hoped to minimize the amount of the structural variability documented in human bone (Kennedy and Carter, 1985). Groups 1, 2, and 3 utilized non-locking dynamic compression plates (DCP Synthes, West Chester, Pennsylvania, USA) while group 4 utilized locking plates and screws (LCP Synthes, West Chester, Pennsylvania, USA). Group 1 (perpendicular group) had two screws placed perpendicularly in a traditional fashion. Group 2 (convergent group) had two screws placed in a convergent pattern at 30° from a perpendicular to the plate. Group 3 (oblique group) had an obliquely placed end screw at 30° and a perpendicularly placed proximal screw. Group 4 (locked group) had locking screws placed perpendicularly. Fig. 1 demonstrates the screw configurations used by the various groups.

All plates and screws used were 3.5 mm screws and six hole 3.5 mm plates. All screws were placed in the 1 and 3 position in the plates. Screws that were placed at a 30° angle in groups 2 and 3 were 36 mm and those placed in a perpendicular fashion were 34 mm to ensure that an equal number of threads in contact with the bone were equivalent in each sample and among groups. A jig was constructed by local machinists to consistently insert the screws at appropriate angles and was used in all four groups. All holes were drilled to 2.5 mm and tapping was unnecessary in bone of this quality.

All constructs were then mounted onto a MTS 858 Mini Bionix servo-hydraulic test system (MTS Systems Corp, Eden Prairie, MN, USA) by using a specially designed mount as demonstrated in Fig. 2. Force–displacement curves were generated for all forty constructs as they were loaded in gap closing cantilever bending at 1 mm/s to the point of failure. Despite small load to failures, all loads were within the detection limit of the load cell used. All forces were applied at a loading point 3.5 cm from the fulcrum. Failure was observed at two points on the force–displacement curve. Initial failure was defined as the first sharp decline in force as detected by the load cell. The maximum load tolerated was defined as the largest force observed on the force–displacement curve by the construct prior to failure as some constructs demonstrated multiple points of initial sub catastrophic failure. Stiffness was also calculated in each sample as the linear portion of the force–displacement curve prior to initial failure.

Due to small sample size, non-parametric statistical methods were used which included the Kruskall Wallace test for significant differences among all four groups. Statistical methods exploring relationships between two specific groups utilized a Mann Whitney U test. Significance was defined as $P < .05$. A power analysis was performed prior to the study which revealed that 10 samples in each group would give 93% power, acceptable by statistical standards. All statistical calculations were analyzed using SPSS software (SPSS Inc., Chicago, IL, USA).

3. Results

Results are displayed in Table 1. Failure was defined as a sudden sharp decrease in force on a load displacement curve. All samples experienced failure under relatively small loads (15–55 N) as anticipated given the low density of the bone used. Specimens were inspected after loading and in each sample failure was observed by screw pullout. There were no samples in which breakage of the plates or screws occurred. In the perpendicular group, screws sheared vertically out of the bone, leaving two small bone defects where the screws had been inserted. In the oblique group, the oblique end screw initially sheared rotationally through the bone and

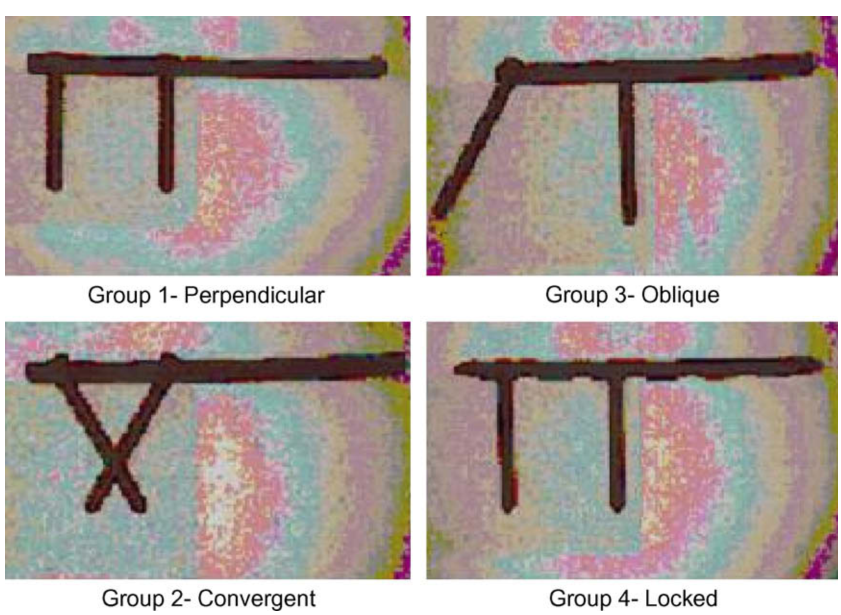

Fig. 1. Radiographic depictions of the screw configurations tested in synthetic bone.