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Calcar screw position in proximal humerus fracture fixation: Don't miss high!

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ABSTRACT

Introduction: In locked plate fixation of proximal humerus fractures, the calcar is an important anchor point for screws providing much-needed medial column support. Most locking plate implants utilize a fixed-trajectory locking screw to achieve this goal. Consequently, adjustments of plate location to account for patient-specific anatomy may result in a screw position outside of the calcar. To date, little is known about the consequences of "missing" the calcar during plate positioning. This study sought to characterize the biomechanics associated with proximal and distal placement of locking plates in a two-part fracture model.
Materials and methods: This experiment was performed twice, first with elderly cadaveric specimens and again with osteoporotic sawbones. Two-part fractures were simulated and specimens were divided to represent proximal, neutral, and distal plate placements. Non-destructive torsional and axial compression tests were performed prior to an axial fatigue test and a ramp to failure. Torsional stiffness, axial stiffness, humeral head displacement and stiffness during fatigue testing, and ultimate load were compared between groups.
Results: Cadavers: Proximal implant placement led to trends of decreased mechanical properties, but there were no significant differences found between groups. Sawbones: Distal placement increased torsional stiffness in both directions ($p = 0.003$, $p = 0.034$) and axial stiffness ($p = 0.018$) when compared to proximal placement. Distal placement also increased torsional stiffness in external rotation ($p = 0.020$), increased axial stiffness ($p = 0.024$), decreased humeral head displacement during fatigue testing, and increased stiffness during fatigue testing when compared to neutral placement.
Discussion: The distal and neutral groups had similar mechanical properties in many cadaveric comparisons while the proximal group trended towards decreased construct stiffness.
Results: from the Sawbones model were more definitive and provided further evidence that proximal calcar screw placements are undesirable and distal implant placement may provide improved construct stability.
Conclusion: Successful proximal humerus fracture reconstruction is inherent upon anatomic fracture reduction coupled with medial column support. Results from this experiment suggest that missing the calcar proximally is deleterious to fixation strength, while it is safe, and perhaps even desirable, to aim slightly distal to the intended target.

Introduction

Proximal humerus fractures, accounting for over 5% of the fractures in adults [1,2], are the third most common fractures in the elderly [3–5], and are expected to increase 3-fold in the next 30 years [6]. Open reduction and internal fixation (ORIF) is an attractive option for the repair of proximal humerus fractures because it restores native anatomy and allows for early return of function. The recent advent of locking plates in proximal humerus fracture ORIF has improved outcomes [7,8]. Despite the benefits of locking plate fixation, humeral head collapse, fixation failure, and hardware-related complications have led to poor outcome rates between 27% and 59% in some studies [9–12].

Optimization of proximal humerus locking plate design is an avidly researched topic. Previous studies have sought to improve

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fixation by introducing extra screws or blades into the humeral head [13,14] or by injecting calcium phosphate cement into the cancellous bone [15,16]. The added value of using fibular strut augmentation [13,17,18] and polyaxial screws [19–23] has also been explored. While these studies are valuable, they often utilize additional materials during implantation, which ultimately increases time in the operating room and imposes an additional financial burden.

Several studies have focused on the use of the calcar as an anchor point for screws that are intended to provide medial column support, a technique that has been shown to provide resistance to humeral head collapse [13,24–26]. In many implant designs, humeral head screws have a fixed trajectory relative to the plate. Because the plate and locked screws have a predefined geometry, proximal or distal adjustments of plates may ultimately result in screw purchase outside of the calcar. To date, little is known about the biomechanical consequences of "missing" the calcar during implantation.

The purpose of this study was to characterize the biomechanics of a locked plate construct when the implant is aligned neutrally, distally, and proximally. The goal was to provide surgeons with guidelines for implant placement if optimal calcar screw position is not readily achieved. We hypothesized that missing the calcar by 8 mm in either direction would lead to undesirable changes in fixation strength of the repaired construct. Similarly, we also hypothesized that missing the calcar would lead to increased migration of the humeral head during cyclic testing and decreased failure strength.

Materials and methods

This study was first performed with cadaveric specimens and repeated with Sawbones models. Twelve matched pairs of fresh-frozen cadaveric arm specimens from 8 females and 4 males (average age 78.6 years, range 66 to 96 years) were assigned to the following groups: cadaveric neutral (CN, n = 8); cadaveric proximal (CP, n = 8); and cadaveric distal (CD, n = 8) (Fig. 1). Nine left osteoporotic humerus Sawbones models (#1028-130, Pacific Research Laboratories, Vashon Island, WA) were also used. Specimens were assigned the following groups: Sawbones neutral (SN; n = 3), Sawbones distal (SD; n = 3), and Sawbones proximal (SP; n = 3).

The number of cadaveric samples used was based on results from a previous study that quantified the biomechanics of proximal humeri with and without calcar screws [24]. We hypothesized that missing the calcar would decrease the previously reported axial stiffness (278.5 N/mm) by at least 25%,

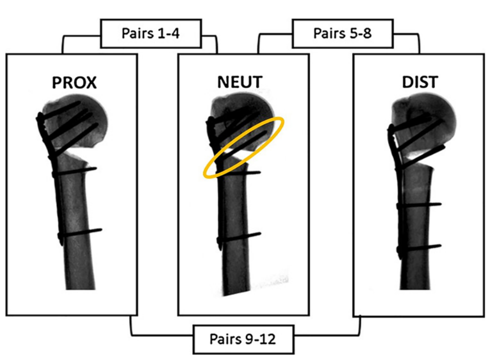

Fig. 1. A schematic of the distribution of matched pairs between the proximal, neutral, and distal groups for cadaveric testing. Fluoroscopic images represent how changes in plate placement affect screw purchase into the calcar (circled in yellow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

while the standard deviation would remain similar to the previous values (40 N/mm). Therefore, the following input parameters were used in an a priori ANOVA sample size analysis: expected difference in mean between groups = 69.6, standard deviation = 40, number of groups = 3, desired power = 0.8, and $\alpha = 0.05$.

Specimen preparation

Cadaveric specimens were stored at −20 °C and thawed overnight prior to implantation. The humerus was disarticulated from the shoulder joint and transected at the midshaft. In order to simulate an unstable two-part fracture, a defined 30° transverse wedge osteotomy was created with an oscillating saw for all specimens (Fig. 1).

All implantation procedures were performed with a single locking plate design (LCP Proximal Humerus, DePuy Synthes, West Chester, PA). Neutrally aligned plates were positioned according to manufacturer guidelines and care was taken to ensure that pilot holes were drilled directly into the calcar, approximately 3 mm superior to the outer cortex. Drills were left in the specimens and fluoroscopy was used to ensure proper implant placement prior to insertion of screws. The same procedure was used to create proximally and distally placed implants with 8 mm offsets.

Final implantation was achieved with a predefined set of 3.5 mm screws (two 36 mm cortex, two 36 mm locking, two 44 mm locking, and two 48 mm locking). For the cadaveric specimens, screws sizes were selected in a manner to optimize length without violating the articular surface. For the Sawbones models, the screw pattern was kept constant across all specimens. Distal humeri were potted into polycarbonate cylinders filled with rigid epoxy resin (Bondo, 3 M, Maplewood, MN). Cadaveric specimens were refrigerated for no more than 48 h prior to biomechanical testing.

Biomechanical testing

The methods used in this experiment were based on previously published protocols that also sought to characterize the biomechanics of proximal humerus implants [13,27]. All testing was performed in a universal testing frame (TA Instruments Electro-Force 3550, Eden Prairie, MN) equipped with a 15 kN/49 Nm load/torque cell.

First, a non-destructive torsional stiffness test was performed (Fig. 2A). The humeral head was gripped by blunt screws and custom-built aluminum jigs were connected to universal joints so torsion about the long axis of the bone was isolated. Internal and external torques were applied to the humeral head under displacement control at a constant speed of 0.1°/s. Torque limits were set ±3.5 Nm for the cadaveric specimens and ±1.5 Nm for the Sawbones models. The cadaveric torque limits were chosen based on previous estimations of in-vivo measurements during activities of daily living [28] which also falls within the range of torques applied during similar experiments [13,29,30]. The limits were lower for the Sawbones experiment because 3.5 Nm created unrealistically high amounts of angular displacement between the humeral head and shaft. Each specimen was cycled 4 times, and the mean torsional stiffness from the last three cycles was determined by calculating the average slope of the linear portions of torque-angular displacement curves during loading.

Next, a battery of nondestructive quasi-static compression tests were performed. The specimens were mounted to a rotating vice and tested at 0°, 20° abduction, and 20° adduction positions (Fig. 2B–D). An aluminum-backed Delryn plate acted as an articulating surface for the humeral head and was coated in petroleum jelly to minimize shear forces. Triangle waveforms were used to impose compressive loads between 15 and 200 N under