Research Article

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Journal of Clinical & Experimental Orthopaedics
ISSN 2471-8416

2018
Vol.4 No.1:56

DOI: 10.4172/2471-8416.100056

Evaluating Periarticular Screw Margins for Locking Plate Osteosynthesis

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Received date: March 4, 2018; **Accepted date:** April 3, 2018; **Published date:** April 7, 2018

Citation: Akinleye SD, Sadeghpour R, Culbertson MD, Garofolo-Gonzalez G, Choueka J (2018) Evaluating Periarticular Screw Margins for Locking Plate Osteosynthesis of Proximal Humerus Fractures. J Clin Exp Orthop Vol 4.No1:56.

Abstract

Introduction: The purpose of this study was to determine whether placing screws farther from the articular cortex could achieve comparable levels of purchase to the more deeply buried configurations currently recommended (between 5 and 8 mm from the articular surface), thus lowering the risk of screw cutout.

Methods: Locking screws were inserted into synthetic composite models of osteoporotic bone at depths corresponding to 8, 11 and 14 mm from the articular surface of an anatomic reference model and subjected to mechanical testing. This protocol was then recapitulated in 24 paired cadaveric humeral specimens to assess the forces required to dislodge screws at depths of 8 and 14 mm from the articular surfaces.

Results: The average pullout strengths of screws positioned 8, 11 and 14 mm from the articular surface in the synthetic bone composites were 145.64, 140.31 and 140.36 N respectively, demonstrating no significant difference. Pullout testing was performed with screw depths of 8 and 14 mm from the articular surfaces in 24 paired proximal humerus samples. The mean pullout strength of screws 8 and 14 mm from the articular surface were 23.92 and 21.79 N respectively ($p=0.37$).

Conclusion: This study demonstrates no significant difference in locking screw purchase up to 14 mm of the articular margin. Increasing the periarticular distance of locking screws can help confer strength and stability to the implant, while simultaneously mitigating the risk of screw cutout.

Clinical relevance: Biomechanical study comparing screw purchase of varying periarticular margins to decrease risk of screw cutout without sacrificing fixation.

Keywords: PHILOS; Periarticular screw; Periarticular distance; Screw cutout; Proximal humerus fracture; Proximal humerus fixation; Varus collapse

Introduction

Proximal humerus fractures are a common orthopaedic injury, representing 4-5% of all upper extremity fractures, and comprising the third most common fracture type in people 65 years of age and above [1]. Most proximal humerus fractures can be managed non-operatively; however, complex and unstable fracture patterns frequently require surgical intervention [2,3].

Locking plate systems have emerged as the gold standard for treating these complex fractures. This modality offers multiple locking screws oriented in different directions to optimize resistance to fracture displacement; these plates provide particularly secure fixation in osteoporotic bone [4]. The locking proximal humerus plate and screws behave as a single unit, with stability achieved at the screw-bone interface [1,5]. This construct can compensate for lesser bone quality by achieving fixation without relying on the friction between plate and bone required in conventional plate fixation. Previous work confirms that the angular stability inherent to locked plate fixation is beneficial in osteoporotic bone [6,7].

Despite the advantages conferred by periarticular locking plates, outcome studies have found complication rates as high as 36%. Some of these complications include loss of fixation, impingement, and intra-articular screw penetration [6,8]. Varus collapse of the proximal humerus followed by screw cutout and intraarticular penetration of screws through the subchondral bone of the humeral head **(Figure 1)**, account for the vast majority of locking plate failures [1,5-7,9-11]. Some authors attribute the high complication rates to surgical technique, positing that exceptional vigilance is required when estimating the appropriate number and length of screws used for fixation [8,9]. Previous biomechanical cadaver studies suggest that screw pullout strength increases substantially when screws are positioned such that the tips reside in subchondral bone; these results guide current practice to target screw purchase between 5 and 8 mm from the articular margin [8,12,13]. However, high rates of screw perforation suggests that a greater interval between the screw and the subchondral bone may be necessary to mitigate the risk of screw advancement and injury to the articular surface.

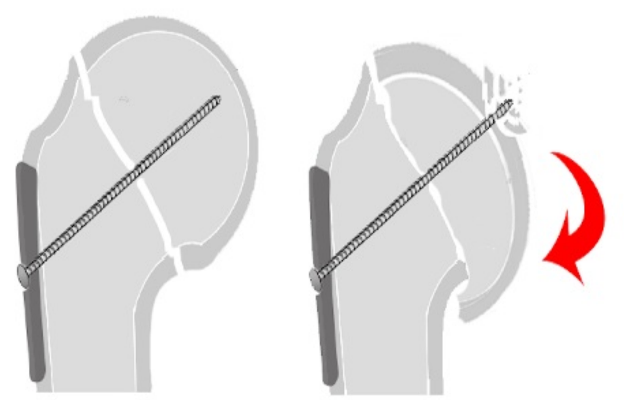

Figure 1: Illustration depicting varus collapse of proximal humerus open reduction internal fixation.

In this study, we tested screw pullout strength at increased distances from the articular margin of the proximal humerus in order to establish whether larger periarticular screw margins can strike a balance between maintaining adequate screw purchase and limiting the risk of screw cutout. We hypothesized that there would be no significant difference in screw purchase at the farther articular margins.

Materials and Methods

The Depuy Synthes PHILOS (Proximal Humerus Internal Locking System) system (PHILOS locking plate-60 mm, Locking screws-3.5 mm) was utilized for these tests. The technique guide, which states that the locking screws should be inserted 5-8 mm from the articular surface to engage subchondral bone [12], was used as a reference to establish the periarticular distances tested in our study.

Three different screw placement depths were examined **(Figure 2)**:

(1) Condition 1 (Control): Screws tips reside 8 mm from the articular surface, the maximum recommended distance for screw placement as described by the hardware manufacturer [12].

(2) Condition 2: Screw tips were placed 3 mm farther from the articular margin than the control, or 11 mm from the articular surface.

(3) Condition 3: Screw tips were placed 6 mm farther from the articular margin than the control, or 14 mm from the articular surface.

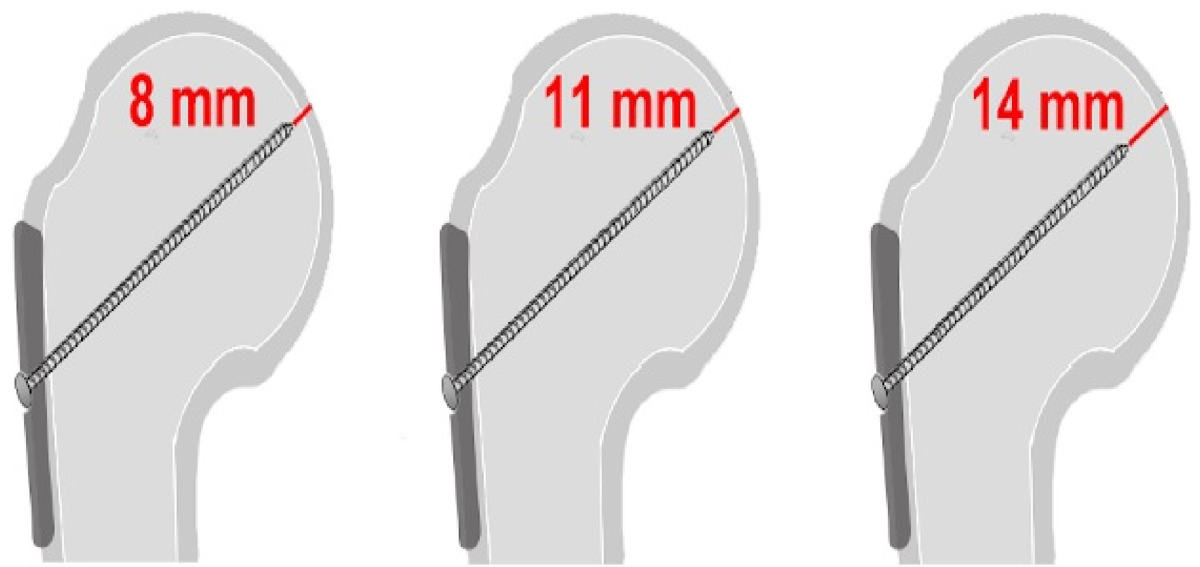

Figure 2: Three different periarticular screw margins studied.

Synthetic foam bone composite

The first arm of experimental testing involved testing the force differential required for screw disengagement at different placement depths in a synthetic substrate designed to model osteoporotic bone. A rigid foam substrate (30 pcf open cell foam block, model 1522-525, Sawbones, Vashon Island WA) model with porosity comparable to that of osteoporotic trabecular bone was used to test screw pullout at burial depths equivalent to 8 mm, 11 mm and 14 mm from the joint surface. We utilized a fourth generation composite proximal humerus (Sawbones), to establish the burial depth the 60 mm screws would be subjected to when inserted through the right proximal hole of the PHILOS locking plate which is referenced as section A [1,12], or screw hole # 1 [13].

Thus, when inserted into the composite, the screws 8 mm from the articular surface had 43 mm of the screw implanted into the material, whereas the 11 mm and 14 mm joint distances had 40 mm and 37 mm of the screws buried, respectively. This testing paradigm was employed to provide interspecimen consistency and examine the fixation properties of the hardware with respect to the implanted screw length independent of bone quality or anatomic variations usually encountered in cadaveric specimens. Twelve screws at each of the three different periarticular screw lengths were implanted in composite blocks to produce a total of 36 testing samples.

Figure 3: Testing apparatus for screw pullout of synthetic bone composite.

To test the distraction force necessary to effect screw pullout, the synthetic bone blocks were affixed to 4" long ½" diameter steel carriage bolts (Hillman SteelWorks, Cincinnati, OH) with epoxy resin to allow for screw action grip fixation of the construct to an Instron mechanical testing apparatus (Model 5967 Instron, Norwood, MA). The screw head was then grasped with a mechanical wedge action grip fitted with vee-faces **(Figure 3)**. A constant distraction displacement of 10 mm/min was then applied to the screw. Load to failure with screw disengagement form the synthetic bone composite was recorded for the 12 specimens in each of the three conditions. Mean pullout force values were calculated for each depth group. Comparisons between the three conditions carried out via one-way ANOVA using JMP statistical software (Version 9, SAS).

Cadaveric specimens

Figure 4: Testing apparatus for screw pullout of cadaveric specimen.

The second arm of experimental testing was carried out on twenty-four paired fresh-frozen cadaveric proximal humerus samples from 12 donors. These tests were done to establish whether findings in natural bone specimens would recapitulate results observed in the composite bone models. Inclusion criteria for the cadaveric specimens comprised donors with available bilateral proximal humeri that were ≥ 50 years of age, in order to capture the osteopenic/osteoporotic bone quality found in the majority of patients subject to proximal humerus fixation. Donors with a history of fracture or surgical intervention involving the proximal humerus on either side were excluded. Given, the matched proximal humeri, only two conditions could be compared in this phase of testing. We elected to compare the control depth (8 mm) *vs.* the farthest screw from the articular surface that showed no significant difference in screw engagement in the first arm of the study (14 mm).

Screw fixation in the cadaveric specimens was performed in accordance with the manufacturer's surgical guidelines in order to stimulate the angulation and location of the screws as they would occur during a normal surgical fixation. Thus, the PHILOS locking plate (temporarily stabilized by 1.6 mm Kirschner wires) was positioned 2-4 mm lateral to the intertubercular groove of the humerus and 5-7 mm below the tip of the greater tuberosity

[12]. The outer sleeve was assembled into the right proximal screw hole of section A, followed by advancement of the drill through the articular surface of the proximal humerus in each specimen. Depending on the condition tested, a premeasured spacing insert corresponding to the appropriate distance from the articular cartilage was inserted through the hole present on the articular surface. The 60 mm screw was then advanced through the lateral cortex until it contacted the spacing insert at the correct periarticular depth.

Once each of the 12 specimen pairs had screws buried at 8 mm and 14 mm from their paired proximal humeri, humeral samples were affixed to carriage bolts with epoxy resin and affixed to the Instron testing apparatus. Screw pullout strength was then assessed under the same distraction protocol as was used with the synthetic bone models **(Figure 4)**. Subsequent analyses were also carried out in the same fashion as with the synthetic bone composites.

Results

Within the synthetic bone composite, mean forces required to disengage screws at depths of 8 mm, 11 mm, and 14 mm from the articular surface, were 145.64 N (95% CI: 121.31–169.97), 140.31 N (95% CI: 113.10–167.52), and 140.36 N (95% CI: 126.30–154.41) respectively **(Figure 5)**. Pairwise t-test comparisons of the mean pullout force for each of the screw groups yielded no significant differences (8 mm *vs.* 11 mm, p=0.7157; 8 mm *vs.* 14 mm, p=0.7181; 11 mm *vs.* 14 mm, p=0.9975).

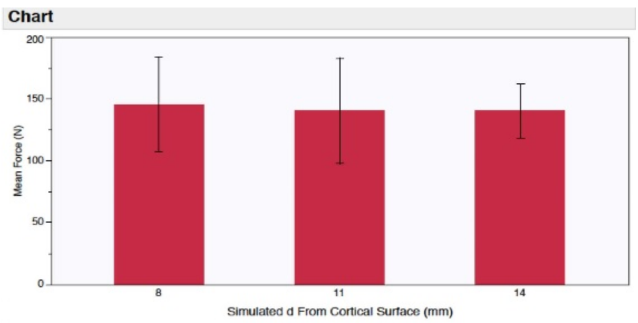

Figure 5: Mean forces required to disengage screws from synthetic osteoporotic bone at three different periarticular distances.

In the cadaveric proximal humeri, testing the mean screw pullout forces of the 8 mm and 14 mm depths **(Figure 6)** showed that screws 8 mm from the articular surface disengaged at a mean force of 23.92 N (95% CI: 16.65–31.18), while the mean pullout force for screws 14 mm from the articular surface was 21.79 N (95% CI: 11.59–31.99). There was no significant difference in the force required to disengage the screws between the two depth groups (p=0.37).

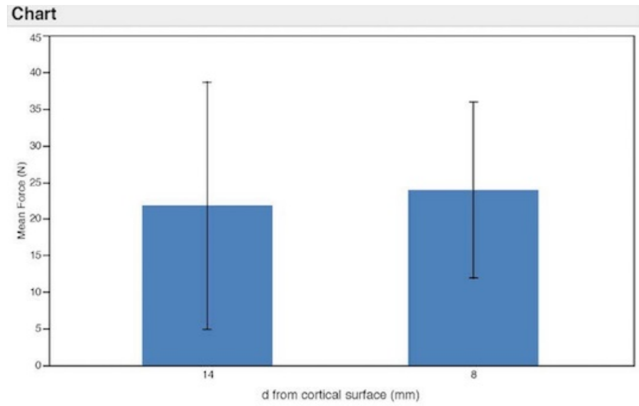

Figure 6: Mean forces required to disengage screws from matched cadavers at two different periarticular distances.

Discussion

Operative treatment of comminuted proximal humerus fractures can be particularly challenging in osteoporotic patients [14]. Locking plates are commonly used to treat these complex fractures, as the fixed angled screws act as struts to prevent subsequent displacement of the humeral head [6]. Screw perforation is the most frequently reported implant specific complication, with some studies yielding rates as high as 23% [6,7,15]. The elderly are at a particularly heightened risk for this complication due to their compromised bone quality.

Primary screw cutout is a manifestation of intra-articular penetration at the time of operation, often due to improper surgical technique, in which screws are malpositioned due to suboptimal utilization of intraoperative fluoroscopy [4,9,15-18]. Egol et al. maintained that vigilance must be taken to approximate appropriate screw length in order to prevent articular penetration [9].

Secondary screw cutout occurs following fracture collapse of the humeral head into varus, allowing the fixed screws to become prominent and penetrate the joint [1,5-7,9-11,15]. When the rotator cuff fires, a varus moment is applied against the rigid locking plate construct; the high resultant stress causes the tips of the screws to cut through the cancellous bone [15,19,20]. The sequelae of this type of failure are often severe, as it usually necessitates reoperation to prevent significant damage to the glenohumeral joint that can lead to permanent loss of function [9,21]. In addition to cartilage destruction, one study documented injury to the axillary artery with intra-articular screw penetration [8,22].

Numerous studies have demonstrated that a medial column buttress of the proximal humerus fixation is critical in preventing varus deformation and subsequent implant failure [1,6,15,23,24]. However, achieving adequate screw purchase by positioning screw tips in close proximity to the subchondral bone has been advocated as well [3,4,8]. Some authors argue that adequate screw purchase, 5-8 mm from the articular margin, should be the surgical goal in order to avert secondary screw cutout [5,8,13,25].

By contrast, some authors advocate for the use of shorter screws, in order to mitigate the risk of this unwanted complication. Richitti et al. shortened their locking PHILOS screws up to 10 mm from subchondral bone and reported no cases of hardware failure or screw penetration, despite 5 out of their series of 54 shoulders progressing to varus malunion [26]. Namdari et al. was even more conservative, advocating for proximal humerus screw depths 1-2 cm from the articular margin. They argued that subchondral screw purchase should be maintained for fixations within load bearing joints such as the proximal femur, rather than the proximal humerus. In their series of 53 proximal humeri, in which their shortened locking screws were used in conjunction with suture fixation to the rotator cuff, there were 2 instances of asymptomatic varus malunion and no cases of screw cutout [11]. These two studies documented the utility of avoiding secondary screw cutout, despite varus displacement of the humeral head, by shortening screws with respect to the articular margin. Screw location also dictates fixation, as multiple biomechanical studies [3,4,8,15,27] have demonstrated that the most superior and medial aspect of the humeral head contains the densest bone mass, and facilitates a greater amount of screw purchase in comparison to screws buried in the margins. These findings lead Frich et al. to conclude that convergent or parallel locking screws aimed at the center of the humeral head provide a more optimal fixation construct than divergent screws aimed toward the periphery [4].

In this study, we found no significant difference in the pullout force required to dislodge locking screws 8 mm, 11 mm and 14 mm from the articular margin. Interestingly, the marginal increase in the interval from the subchondral plate did not lead to a substantial drop off in the containment of the screw bone interface. Frich et al. measured the subchondral plate to be approximately 0.6 mm with a linear decrease in bone penetration strength with each millimeter below the plate. In fact, the measured strength of trabecular bone 5 mm from the subchondral plate was only decreased by 25%, whereas the bone strength a distance of 7-8 mm below the dense articular margin was decreased by 50% [6]. This precipitous change in the bone strength with respect to the periarticular margin of the proximal humerus was not supported by our cadaveric results, as the marginal decrease in screw depth showed no significant change in screw purchase.

One limitation of this study was the use of screw pullout to assess purchase in locking screws. In-vivo, this is a less common method of failure; as the screws are locked into the plate, locking plate constructs tend to fail as a complete “monoblock” rather than as failures of individual components. Furthermore, our study did not take into account deforming forces from the rotator cuff, which normally contribute to implant failure. Future studies would be better suited to test load-failure of the entire locking screw plate construct, in order to better replicate the clinical scenario. Nevertheless, this study does address the stability contribution of individual screw purchase of the PHILOS locking screws with respect to the distance from the articular margin.

Conclusion

In summary, this biomechanical study supports the notion that shorter screws can be used in proximal humerus osteosynthesis to mitigate the risk of screw penetration without substantially weakening the strength and stability of the construct. The relatively high and costly complication rates associated with screw penetration challenge the current recommendations of subchondral screw depths <1 cm. This study provides evidence for surgeons to position their locking screws approximately 10-14 mm from the articular margin of the humeral head in order to both maintain adequate screw purchase and decrease the risk screw cutout. Even if subsequent varus displacement of the proximal humerus should occur, shorter locking screws may circumvent the significant morbidity associated with screw infiltration of, and subsequent damage to, the glenohumeral joint.

Conflict of Interest

All co-authors declare that they have no conflict of interest.

Funding

Maimonides Research and Development Foundation Grant; #49837.

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