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ORIGINAL ARTICLE

Basic Study

Comminuted olecranon fracture fixation with pre-contoured plate: Comparison of composite and cadaver bones

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Abstract

AIM: To determine whether use of a precontoured olecranon plate provides adequate fixation to withstand supraphysiologic force in a comminuted olecranon fracture model.

METHODS: Five samples of fourth generation composite bones and five samples of fresh frozen human cadaveric left ulnae were utilized for this study. The cadaveric specimens underwent dual-energy X-ray absorptiometry (DEXA) scanning to quantify the bone quality. The composite and cadaveric bones were prepared by creating a comminuted olecranon fracture and fixed with a pre-contoured olecranon plate with locking screws. Construct stiffness and failure load were measured by subjecting specimens to cantilever bending moments until failure. Fracture site motion was measured with differential variable resistance transducer spanning the fracture. Statistical analysis was performed with two-tailed Mann-Whitney-U test with Monte Carlo Exact test.

RESULTS: There was a significant difference in fixation stiffness and strength between the composite bones and human cadaver bones. Failure modes differed in cadaveric and composite specimens. The load to failure for the composite bones (n = 5) and human cadaver bones (n = 5) specimens were 10.67 nm (range 9.40-11.91 nm) and 13.05 nm (range 12.59-15.38 nm) respectively. This difference was statistically significant

(P < 0.007, 97% power). Median stiffness for composite bones and human cadaver bones specimens were 5.69 nm/mm (range 4.69-6.80 nm/mm) and 7.55 nm/mm (range 6.31-7.72 nm/mm). There was a significant difference for stiffness (P < 0.033, 79% power) between composite bones and cadaveric bones. No correlation was found between the DEXA results and stiffness. All cadaveric specimens withstood the physiologic load anticipated postoperatively. Catastrophic failure occurred in all composite specimens. All failures resulted from composite bone failure at the distal screw site and not hardware failure. There were no catastrophic fracture failures in the cadaveric specimens. Failure of 4/5 cadaveric specimens was defined when a fracture gap of 2 mm was observed, but 1/5 cadaveric specimens failed due to a failure of the triceps mechanism. All failures occurred at forces greater than that expected in postoperative period prior to healing.

CONCLUSION: The pre-contoured olecranon plate provides adequate fixation to withstand physiologic force in a composite bone and cadaveric comminuted olecranon fracture model.

Key words: Composite bone; Fracture; Biomechanic; Cadaveric; Olecranon; Precontoured plate

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Core tip: Comminuted olecranon fractures present a clinical and surgical challenge. Fixation with traditional tension band constructs is difficult due to comminution involving the articular surface. We describe a method if achieving fixation using a precountoured olecranon plate. In our biomechanical model using composite bones as well as cadaveric specimen, this method of fixation provides fixation of comminuted olecranon fractures capable of withstanding the expected physiologic force in the early postoperative period.

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INTRODUCTION

Comminuted olecranon fractures are relatively common injuries. Most displaced fractures benefit from surgical treatment. These fractures, especially unstable injuries involving the coronoid process, are not amenable to tension band fixation and benefit from open reduction internal fixation with a plate. Zuelzer[1] first reported successful application of a hook plate in a comminuted olecranon fracture in his 1951 case report. Plate fixation is increasingly used to treat displaced olecranon fractures and therefore considered as the gold standard for treatment[2-6]. Reports on application of plate fixation for comminuted olecranon fractures have demonstrated variable results[2]. Reports of these contoured olecranon plating demonstrated to more positive results[5,7-10].

Biomechanical features of plate fixation including stiffness and strength have previously been reported, for comminuted olecranon fractures[11,12]. Despite recognized limitations, using bone substitute material makes it easier to answer some of the relevant research questions. Bone substitute materials are helpful in achieving more consistent test data than cadaveric bones due to human skeletal variability. Composite bones enable testing of several parameters at lower costs when compared to cadaveric specimen. Furthermore, the uniformity of composite bone specimens allows direct comparison of datasets.

The purpose of this study was twofold: (1) assess fixation of a comminuted intra-articular olecranon fracture with a locked pre-contoured plate in an *in-vitro* model; and (2) determine whether fourth generation composite bones are biomechanically comparable to human cadaveric bones under destructive loading conditions.

MATERIALS AND METHODS

Five samples of composite bone substitutes (Sawbones Cat#3426, large left ulna, fourth generation composite bone) per test group and five samples of fresh frozen human cadaveric left ulnas per test group were utilized for this study. A priori power analysis was performed to determine sample size. The five left fresh-frozen human cadaveric elbows were thawed prior to testing. These were five left male specimens with a mean age of 60.6 years (range 51-86 years). These specimens were subjected to dual-energy X-ray absorptiometry (DEXA) scanning to quantify the bone quality.

For the cadaveric bones, soft tissues were completely resected, with the exception of the triceps tendon. No evidence of previous injury or arthritis was found in any of the ulna cadaveric bones.

Specimens (fresh human, non-preserved) were received and stored at -20 ℃ prior to and following dissection. After hardware implantation, specimens were not refrozen and underwent mechanical testing.

The ulna was positioned in a custom cutting jig and locked into position with K-wires, prior to osteotomy creation[11], of a simulated comminuted fracture. A pre-contoured olecranon plate (Stryker Trauma AG, Selzach, Switzerland) was fixed onto the posterior aspect of the ulna with five VariAx 3.5 mm locking and two VariAx 3.5 mm non-locking screws (Figures 1 and 2). In each ulna (composite and human), the screw application was kept consistent with respect to length and configuration (Figure 1 and Table 1) with one at the olecranon tip, two through the olecranon, and four distal to the fracture (Figure 2). Screw length variability was dictated by the

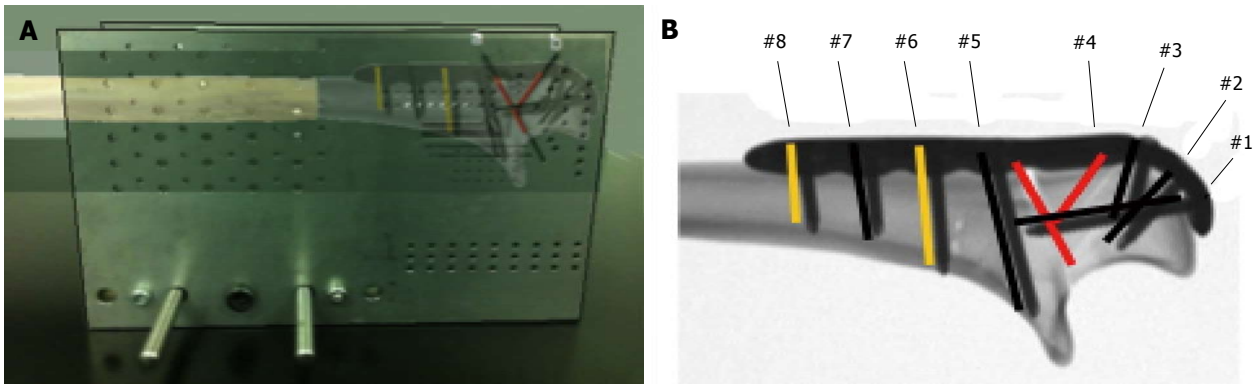

Figure 1 Custom osteotomy jig with plate and screw construct. A: Rendered photo of the jig used to create the comminuted olecranon fracture, with an overlay of the ulna, demonstrating the positioning of the bone in relation to the saw blade slots; B: A radiograph of the olecranon plate and screw construct in relation to the fracture. Screws placed in positions as indicated in Table 1.

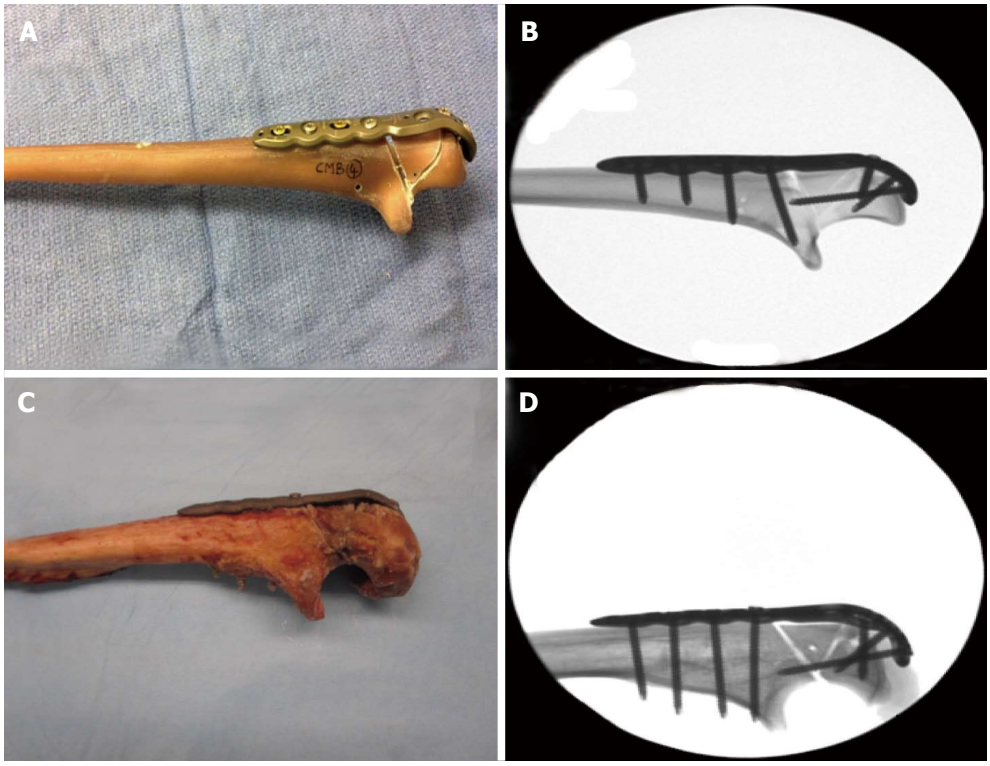

Figure 2 Fourth generation composite bone (A) and human cadaveric bone (C) with a comminuted olecranon fracture, fixed with a pre-contoured plate and screw construct, and lateral fluoroscopic radiographs of the composite bones (B) and human cadaveric ulna (D). The fracture is fixed with the olecranon plate and fixation screw.

anatomical variation of the human specimens. After fracture fixation with plate and screws, the K-wires were removed.

Tests were performed in a custom designed test apparatus (Figure 3) with the standardized osteotomy analogous to that described by Buijze *et al*[11] and Gordon *et al*[12] in their cadaveric models as well as others[13-15]. For cadaveric bones, the triceps tendons were fixed with a soft-tissue clamp, and the proximal ulna was also fixed with a bolt similar to the composite bones for more stability. For composite bones, the proximal ulna was fixed with an olecranon tip bolt only, simulating the attachment of the triceps tendon. Cantilever bending load was applied to the ulna with a lever-arm of 200 mm (measured from the elbow joint rotational axis to the point of load application). The starting position was 70° flexion[11], when the cantilever force was not in contact with the bone. A differential variable resistance transducer (DVRT; MicroStrain, United States), with a ± 1 μm accuracy, was attached across the bony fracture site (Figure 3). Fracture displacement, as determined by the DVRT, was recorded from the fracture site before, during, at, and after load to failure was achieved.

Force was applied at the rate of 1 mm/s (actuator speed) until each specimen failed catastrophically, determined both visually and *via* live data from the

Table 1 Screw types used

Plate hole number	#1	#2	#3	#4	#5	#6	#7	#8
Screw types used in composite bones L/NL/-	L	L	L	-	L	NL	L	NL
Screw types used in cadaveric bones L/NL/-	L	L	L	-	L	NL	L	NL

L: Locking; NL: Non-locking; -: None.

Table 2 Load to failure criterion of 2 mm gapping, displacement, stiffness and bone density per specimen

	Composite bones					Human cadaver bones				
	1	2	3	4	5	1	2	3	4	5
Load to failure criteria (nm)	11.91	9.40	10.97	10.67	9.64	15.10	12.59	13.05	13.02	15.38
Displacement (mm)	1.76	2.00	1.85	2.00	1.70	2.00	2.00	1.71	2.00	2.00
Stiffness (nm/mm)	6.80	4.69	5.95	5.33	5.69	7.55	6.31	7.62	6.52	7.72
Bone density (g/cm^2)	-	-	-	-	-	0.723	0.456	0.658	0.665	0.883
Failure mode	Distal fracture	Fracture gap	Distal fracture	Fracture gap	Distal fracture	Fracture gap	Fracture gap	Triceps failure	Fracture gap	Fracture gap

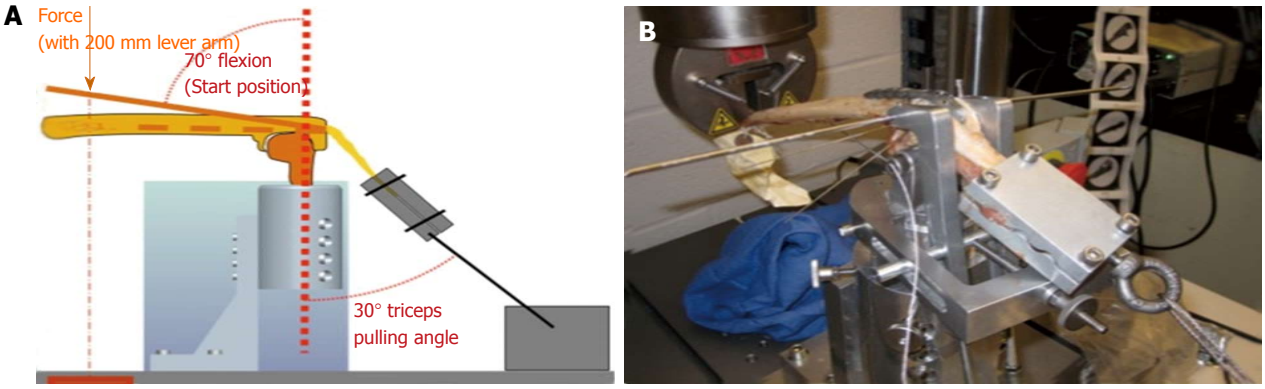

Figure 3 Custom mounting device. A: Pictorial representation of the test apparatus, demonstrating the ulna mounted on a potted distal humeral mould. The force was applied at 200 mm from the joint, and the triceps is clamped and retracted at a 30 degree angle; B: Photograph of the experimental setup, which includes the differential variable resistance transducer placed across the fracture site to measure fracture motion.

Instron graphic software. Failure load was recorded for each specimen and the mode of failure was noted. The load at ⩾ 2 mm displacement was obtained from the data files.

Statistical review of the data was performed by a biomedical statistician prior to submission and peer review. The results were statistically analyzed with two-tailed Mann-Whitney-U test a nonparametric measure of statistical dependence between these 2 variables (10000 samples) with statistical significance ascribed a value of $P < 0.05$. In addition, power was calculated (2-tailed, alpha = 0.05) where 80% was considered as sufficient power (IBM SPSS Sample Power 3).

The Kaplan-Meier survival function was estimated for load to failure results. The result plot estimated the cumulative survival at a certain load value (estimated survival rate at certain load application). The correlation between stiffness or failure load and bone mineral density was analyzed with a two-tailed Spearman's rank correlation coefficient.

RESULTS

Failure was defined as either a 2 mm fracture gap or complete failure (Figure 4). The load to failure for the composite bones ($n = 5$) and human cadaver bones ($n = 5$) specimens were 10.67 nm (range 9.40-11.91 nm) and 13.05 nm (range 12.59-15.38 nm) respectively (Figure 5 and Table 1). This difference was statistically significant ($P < 0.007$, 97% power). Median stiffness for composite bones and human cadaver bones specimens were 5.69 nm/mm (range 4.69-6.80 nm/mm) and 7.55 nm/mm (range 6.31-7.72 nm/mm). There was a significant difference for stiffness ($P < 0.033$, 79% power) between composite bones and cadaveric bones (Figure 5). Displacements for these specimens were

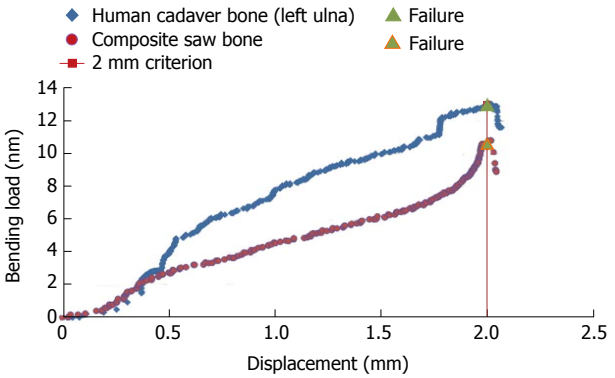

Figure 4 Sample graphs showing the force-displacement curve during destructive loading for composite bone and human cadaver bone specimens.

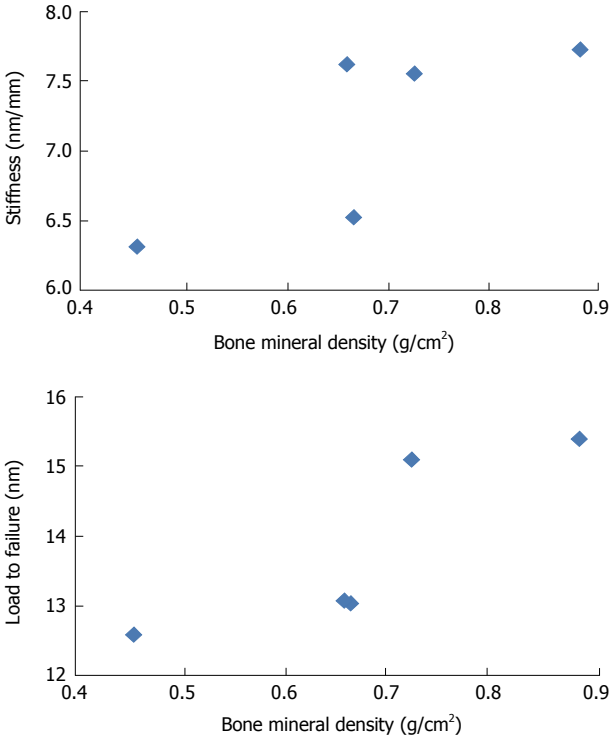

Figure 6 Bone mineral density in human cadaver bones (left ulnas), *n* = 5.

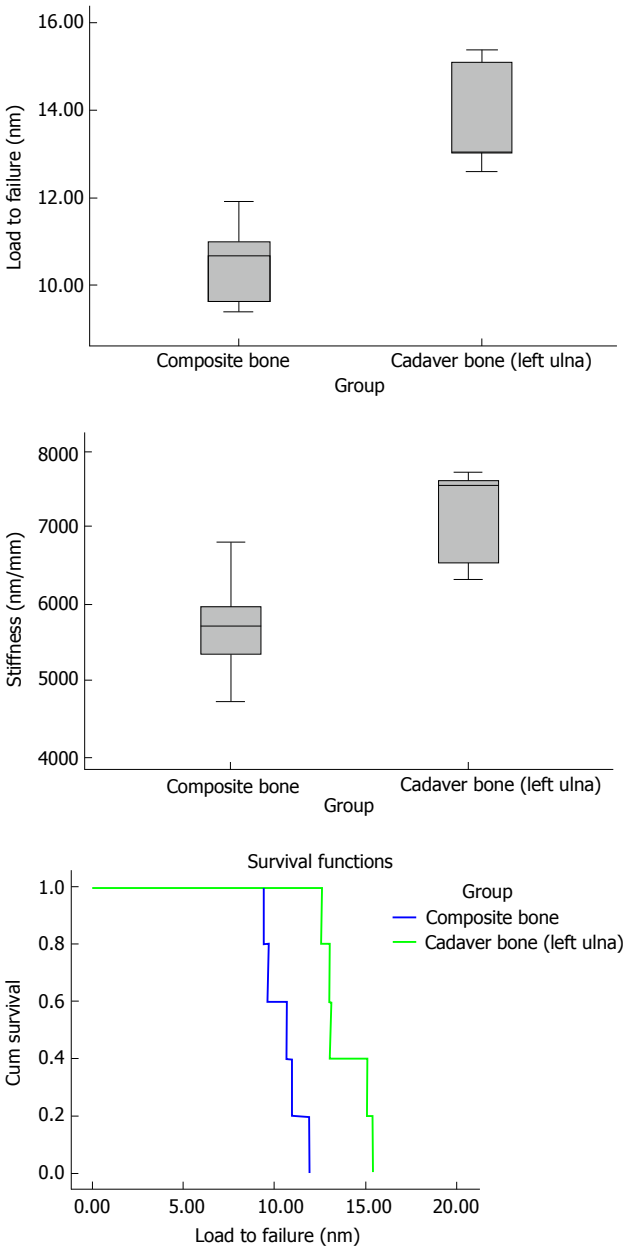

Figure 5 Load to failure criterion of 2 mm gapping, stiffness per specimen and survival function of specimens.

not compared, due to the 2 mm failure criterion. DEXA scans were used to assess cadaveric bone mineral density (Table 2 and Figure 6). Overall, the DEXA bone mineral density (BMD) for human cadaver specimens ranged from 0.456 to 0.883 g/cm^2, with a mean of 0.677 g/cm^2. BMD correlated with load to failure (P = 0.037), but did not correlate with stiffness (P = 0.188). Previous studies have shown that BMD significantly correlated with fracture loads in isolated human cadaveric pelvis[16] and femurs[17-19].

In the plated specimens, catastrophic failure occurred in 3/5 fourth generation composite bone specimens before the pre-defined 2 mm fracture gap was observed and in 2/5 cases when the fracture gap of 2 mm was observed. All complete failures (5/5) resulted from composite bone failure and not hardware failure. Failure occurred at the most distal screw.

There were no catastrophic fracture failures in the cadaveric specimens. Failure of 4/5 cadaveric specimens was defined when a fracture gap of 2 mm was observed, but 1/5 cadaveric specimens failed due to a failure of the triceps mechanism (the triceps tendon slipped in the soft-tissue clamp, and the augmentative trans-olecranon pin bent).

DISCUSSION

There were 2 primary objectives of this study. Firstly to ascertain whether there is acceptable fixation of a comminuted olecranon fracture with a pre-contoured locking plate and screw construct in an *in-vitro* model. Secondly to directly compare synthetic composite bones

Table 3 Comparison of the results from this study (composite synthetic fourth generation bones and cadaveric bones) with previous literature studies

	Load to failure	Stiffness
Gordon	30-34.5 nm	7-13 nm/mm
Buijze	4.5-27 nm	8.8-13.3 nm/mm
This study (cadaveric)	12.59-15.38 nm	7.55 nm/mm
This study (composite)	9.40-11.91 nm	5.69 nm/mm

to human cadaveric bones under conditions of destructive loading to determine the construct strength, representing the first time this comparison has been performed. Options for fixation of olecranon fractures include casting, external fixation, and internal fixation with intramedullary nails or plates[20]. Plate-and-screw fixation has proved to be the most reliable and successful strategy and is widely used. Clinical series have demonstrated excellent union rates with few complications[8,21-25]. Successful plate fixation of these fractures allows for early return to function of the upper extremity.

Gordon *et al*[12] reported that load to failure and mean stiffness values of olecranon fracture fixation was significantly greater with a posterior plate with long intramedullary screw than with dual-plated. However, no statistically significant increase in load to failure in stiffness was demonstrated when compared to posterior plates alone. Buijze *et al*[11] compared the stiffness and strength of locking compression plate fixation to one-third tubular plate fixation in a cadaveric comminuted olecranon fracture model with a standardized osteotomy. Stiffness and load to failure values from those two studies were similar to those found in the current investigation (Table 3).

Our study demonstrates that the pre-contoured olecranon is adequate when controlling the fracture position against physiologically relevant forces. Bone mineral density affected load to failure in our model and should be considered when evaluating the results of cadaveric biomechanical studies. In addition, when comparing composite bones to human cadaveric bones, with load to failure, stiffness, and fracture gapping of 2 mm as objective criteria, composite bones were found to be inferior in their mechanical properties. This latter finding has implications when interpreting studies which utilize fourth generation composite bones.

Cantilever forces were 9.40-11.91 nm (for composite bones) and 12.59-15.38 nm (for human cadaver bones) for the fracture sites which would be considerably greater than those experienced in normal activities after fracture fixation[11]. We conclude the following: (1) The pre-contoured plate and screw construct investigated in this model appears to withstand a force greater than the expected physiologic load in the postoperative prior to fracture consolidation. It appears to be a viable option for *in vivo* treatment of comminuted olecranon fractures; (2) Fourth generation composite bones are not a suitable model for olecranon fracture and plate stiffness testing, in a comminution model, since the interface stresses, at the distal extent of the plate was the site of failure in 5/5 tests, prior to failure loads seen in the cadaveric specimens; (3) Pre-contoured plate and screw constructs are more than adequate to control fracture displacement, when tested in a small cadaveric cohort, with pre-defined failure (fracture gapping of > 2 mm). None of the cadaveric specimens underwent catastrophic failure; and (4) The current study is with a pre-contoured plate with locking and non-locking screws, to stabilize a comminuted olecranon fracture, whereas prior relevant literature studies utilize dual plates, one-third tubular plates, and plate/intramedullary screw constructs. Hence direct comparisons of these study results should be considered carefully.

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COMMENTS

Background

Olecranon fractures are common injuries. Simple fractures are amenable to fixation with a tension band device. Comminuted olecranon fractures pose a unique treatment challenge because tension band devices fail when the cortex opposite of the fixation construct is not intact. A pre-contoured locking plate is an option in the armamentarium for treating this challenging fracture pattern.

Research frontiers

Previous biomechanical studies have evaluated various methods of fixation for comminuted olecranon fractures. However, the optimal plate and screw configuration is unclear.

Innovations and breakthroughs

To the authors' knowledge, no biomechanical study investigating this pre-contoured locking plate has been pursued. Further, no study has investigated behavior of cadaveric *vs* composite bone substitute in a comminuted olecranon fracture model.

Applications

This study highlights the efficacy of a unique option for comminuted olecranon fracture fixation. It also gives context to biomechanical studies performed using composite bone substitute. Variation of results in cadaveric *vs* composite biomechanical may be applicable to broader applications other than a comminuted olecranon fracture model.

Terminology

Sawbones-composite physiologic strength bone substitute.

Peer-review

The authors deal about an interesting topic, plating of comminuted olecranon fractures and fixation failure with cadaveric bones and composite bones. The article is well written.

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