

Biomechanical comparison between double-plate fixation and posterior plate fixation for comminuted olecranon fracture using two triceps screws in synthetic bone model

Yohan Lee, MD^{a,b}, Bong Wan Cho, MD^c, Min Bom Kim, MD, PhD^{a,d}, Young Ho Lee, MD, PhD^{a,d,*} 

Abstract

Background: Although preventing triceps fragment displacement is essential for treating an olecranon fracture, we frequently encounter situations in which only a few screws can be fixed to the triceps fragment. The aim of this study was to compare the stability of double-plate fixation and posterior plate fixation for olecranon fractures when the triceps fragment was small and only 2 screws could be inserted.

Methods: A composite ulna model was used to simulate olecranon fracture. Four groups were formed consisting of double-plate and posterior plates with cortical and locking screws. The cyclic loading test was conducted for 500 cyclic loads of 5 to 50 N on a specimen to measure micromotion and displacement of the gap caused by light exercise. The load-to-failure test was performed by applying a load until fixation loss, defined as when the fracture gap increased by 2 mm or more or catastrophic failure occurred, to measure the maximum load.

Results: Eight samples per group were tested through the pilot study. All groups were stable with a micromotion of <0.5 mm. However, the mean micromotion showed significant differences between the 4 groups ($P < .001$, Table 1). In the mean micromotion during exercise, posterior plating with cortical screws was the most stable (0.09 ± 0.02 mm) while double-plating with cortical screws was the most unstable (0.42 ± 0.11 mm). At the maximum load, posterior plating with locking screws was the strongest (205.3 ± 2.8 N) while double-plating with cortical screws was the weakest (143.3 ± 27.1 N). There was no significant difference in displacement after light exercise between the groups.

Conclusions: This study showed that when 2 triceps screws were used, both groups were stable during light exercise, but posterior-plating was stronger than double-plating.

Abbreviations: DC = double plate-cortical screw, DL = double plate-locking screw, PC = posterior plate-cortical screw, PL = posterior plate-locking screw.

Keywords: biomechanical phenomena, bone plates, comminuted/surgery, fractures, olecranon process/surgery

1. Introduction

Olecranon fractures are common, accounting for 10% of all upper extremity fractures.^[1] Fracture patterns vary from non-displaced simple to comminuted fractures with dislocation.^[2] The

triceps fragment receives significant tension force in any olecranon fracture (Fig. 1).^[3,4] When tension force is applied to the triceps fragment, rotational displacement occurs because the trochlea acts as an obstacle. For the extensor mechanism,

Editor: Atul Dwivedi.

This study was supported by a trauma research fund (No. 15-62420) of Seoul National University Hospital.

This study protocol was approved by the institution's IRB (No. 07-2020-294 of Seoul National University Boramae Hospital).

Informed consent was waived.

The raw data is provided as Supplemental Information.

The authors have no conflicts of interest to disclose.

Supplemental Digital Content is available for this article.

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

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How to cite this article: Lee Y, Cho BW, Kim MB, Lee YH. Biomechanical comparison between double-plate fixation and posterior plate fixation for comminuted olecranon fracture using two triceps screws in synthetic bone model. *Medicine* 2022;101:1(e28313).

Received: 23 May 2021 / Received in final form: 5 November 2021 / Accepted: 27 November 2021

<http://dx.doi.org/10.1097/MD.00000000000028313>

Table 1
Mean gapping and displacement in the cyclic loading test.

Group	Gapping during the test (range)	Displacement after the test	
		Anterior cortex (range)	Posterior cortex (range)
Double-cortical	0.42 ± 0.11 (0.25–0.58) [*]	0.02 ± 0.18 (–0.78–0.31)	0.14 ± 0.14 (–0.13–0.16) [†]
Double-locking	0.17 ± 0.03 (0.12–0.21) [*]	0.05 ± 0.10 (–0.16–0.16)	0.08 ± 0.14 (–0.17–0.11)
Posterior-cortical	0.09 ± 0.02 (0.05–0.12) [*]	0.03 ± 0.13 (–0.37–0.22)	0.03 ± 0.19 (–0.14–0.28)
Posterior-locking	0.12 ± 0.04 (0.07–0.17) [*]	0.04 ± 0.10 (–0.12–0.22)	–0.03 ± 0.22 (–0.44–0.20)

The values are presented as the mean ± standard deviation, with ranges in parentheses.

All values are in mm.

^{*}Significant difference between groups ($P < .05$).

[†]Significant difference in the gap before and after the test ($P = .023$).

preventing this displacement is essential for treating an olecranon fracture.^[5,6]

Plate fixation has been recommended for treating comminuted olecranon fractures.^[7] A posterior plate is traditionally used for olecranon fractures with clinically favorable results.^[8] However, problems such as irritation and infection related to implant prominences have been raised.^[9,10] Hardware-related symptoms from posterior plates reached 67%.^[10] To solve the posterior plate problems, lateral plate fixation was proposed,^[11] and low-profile double-plate fixation to both lateral sides was developed.^[12]

Previous studies have reported that double-plating had biomechanical stability similar to posterior plating for olecranon fractures.^[12–15] However, the previous tests could not be fully applied in practice. Previous studies were performed in a setting where enough screws, 3 or more, could be inserted into the triceps fragment. Still, we frequently encounter situations in which only a few screws can be fixed to the triceps fragment. For comminuted olecranon fractures, it is recommended to add another fixation method such as interfragmentary screws to the plating.^[5,16,17] The additional fixation method can vary depending upon the surgeon's preference, and the plating is the basis for comminuted

olecranon fracture surgery. Furthermore, more severe comminution makes the size of the triceps fragment smaller. It is possible to fix the triceps fragment with only a few screws when there is interference by the interfragmentary construct and when the triceps fragments are too small.

As the number of the triceps fragment screws decreases, the plate position's influence on stability can vary. To the best of our knowledge, no studies have investigated the stability of plates with fewer than 3 triceps screws. Therefore, the objective of this study was to compare the stability of a double-plate and a posterior plate for olecranon fractures with a small triceps fragment fixed with only 2 screws.

2. Materials and methods

2.1. Specimen preparation

This study was approved by the institution's Institutional Review Board (No. 07-2020-294 of Seoul National University Boramae Hospital). This was a biomechanical study using a fourth-generation composite ulna model (Sawbones, Pacific Research Laboratories, Vashon, WA). Plates using this study have been

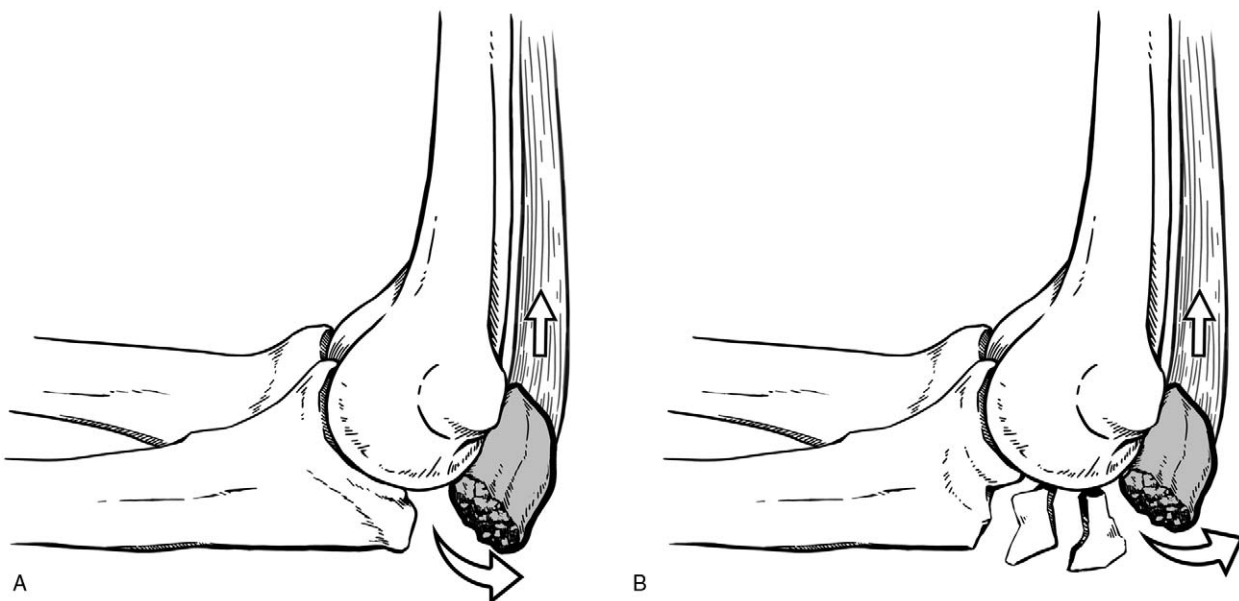


Figure 1. The triceps fragment that receives tension force becomes a rotational displacement by the trochlea.

commercially used in clinical practice for olecranon fractures, including 1.8-mm double plates and 4.0-mm posterior plates (Arix elbow system, Jeil Medical, Seoul, South Korea). To determine the effect of the screw on stability, the composition of the triceps screws was divided into cortical and locking groups. The locking screw has angular stability, which reduces plate's influence. In contrast, the cortical screw compresses the fragment onto the plate, so the plate position has a significant effect on the stability.^[18] Four groups were formed consisting of double-plate and posterior plates with cortical and locking screws: the double plate-cortical screw (DC) group, the double plate-locking screw (DL) group, the posterior plate-cortical screw (PC) group, and the posterior plate-locking screw (PL) group.

A comminuted fracture was made by removing a 5-mm bone block from an area 1-cm distal to the olecranon tip.^[11] The plate position for each specimen was made the same using a customized frame. A fixed angle drill guide was used as much as possible when drilling the cortical/locking screw hole. The diameter of the theoretical and locking screws, called triceps screws, inserted into the triceps fragment was the same at 2.8 mm. At the ulnar shaft, the posterior plate was fixed with 5, 3.5-mm screws and the double plate was fixed with 8, 2.8-mm screws. The shaft fixation of each plate was sufficient. It did not affect the biomechanical test results. An additional 3.5-mm screw, called a load screw, was inserted independently of the plate. The load screw applies a force to the triceps fragment. The prepared specimens are presented in Figure 2.

2.2. Testing setup

The test setup was modified based on methods in previous studies.^[14,15,19–22] The mechanical testing machine was an Instron E3000 (Instron Engineering Corporation, Norwood, MA). All specimens were fixed on a hollow cylindrical fixture customized for this study (Fig. 3). The elbow joint angle was fixed at 90°. The load was applied to the load screw in the direction of 90° of the ulna axis. For each specimen, the distance from the rotational axis to the load cell was made the same. The same distance equalized the length of the lever arm and the ratio of the

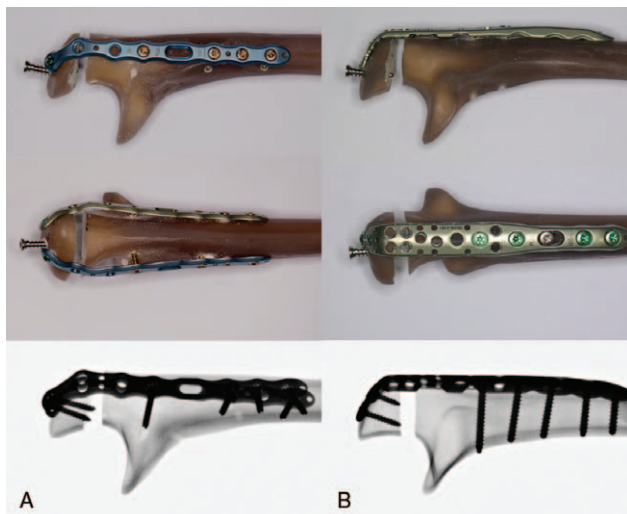


Figure 2. Specimens simulated for a comminuted olecranon fracture with retained implants. (A) Double plate. (B) Posterior plate.

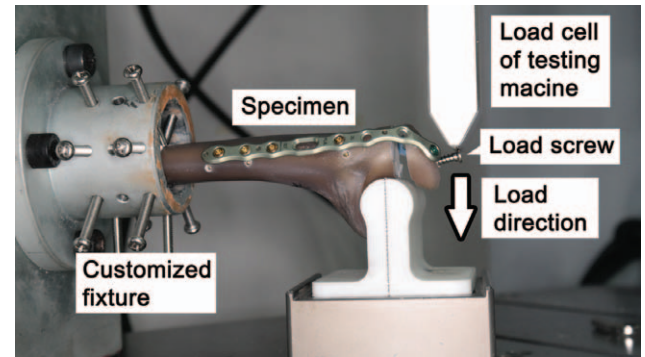


Figure 3. A vertical load applied to the triceps fragment to simulate a triceps pull.

load cell's moving distance to fracture displacement. To simplify the measurement, the load cell's moving distance was assumed to be an approximation of the micromotion during the tests. Fixation loss was defined as an increase of 2 mm or more in the moving distance of the load cell or when a catastrophic failure occurred.

2.3. Cyclic loading test

The cyclic loading test aimed to measure the stability during light exercise of the elbow. A light exercise force was assumed to be 5 N to 50 N.^[14,23] Thus, a force of 5 N to 50 N was applied to a specimen 500 times at a frequency of 1 Hz. During the experiment, the average moving distance of the load cell was regarded as the micromotion during exercise. The difference in gap distance at the anterior and posterior cortex before and after the test was assumed to be the displacement after exercise. The gap distance was measured using a digital caliper (Mitutoyo, Neuss, Germany).

2.4. Load-to-failure test

A load-to-failure test was performed on the same specimen after the cyclic loading test to measure the maximum load until fixation loss. The load was increased 1 mm/min from 0 N.

2.5. Statistical analysis

Sample size analysis was performed using G*power (Version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany).^[24] A pilot study of the load-to-failure test with 3 samples in each group revealed that the average maximum load was DC 146 N, DL 173 N, PC 186 N, and PL 205 N. The standard deviation of the PL group used as the reference was 2 N. With an α setting of 0.05 and 80% power, the appropriate sample size was 8 per group.

For statistical analysis of result, R (Version 3.6.3, R Foundation for Statistical Computing, Vienna, Austria) and Rex (Version 3.5.0, RexSoft Inc., Seoul, South Korea) software were used. The Kruskal–Wallis test was used to compare variables between the 4 groups and Dunn–Bonferroni method was used for the posthoc test. The Wilcoxon signed-rank test was used to compare gaps before and after a cyclic loading test. A P -value of $<.05$ was regarded as statistically significant.

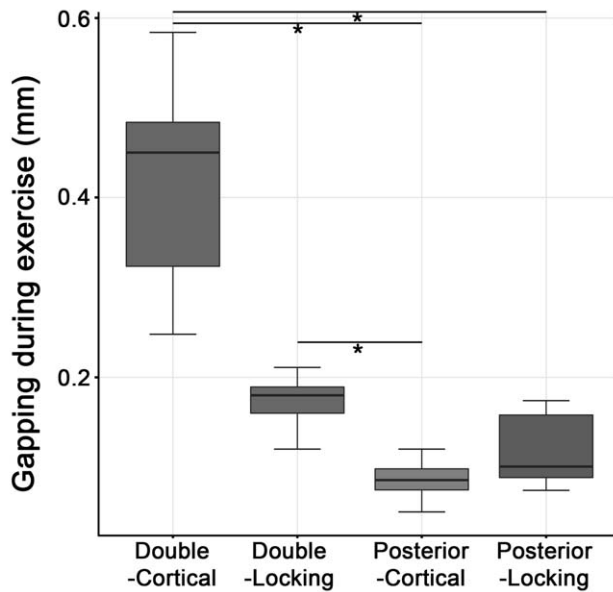


Figure 4. Gapping during exercise in the 4 groups.

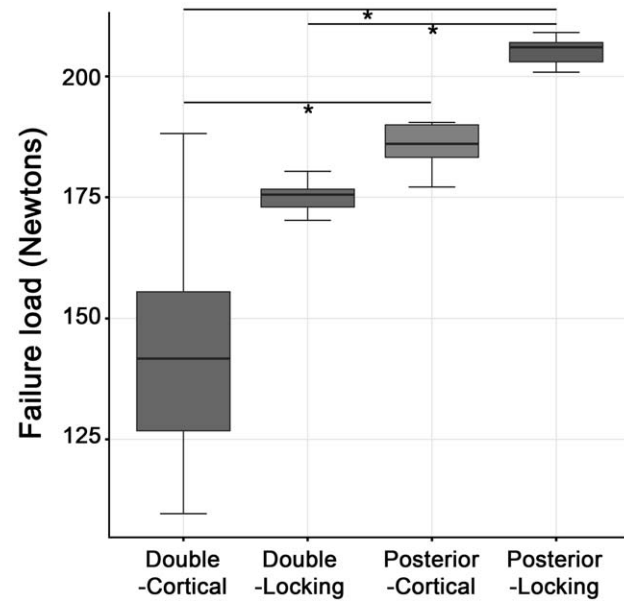


Figure 5. Maximum load in the 4 groups.

3. Results

3.1. Cyclic loading test

All groups were stable with a micromotion of <0.5 mm. However, the mean micromotion showed significant differences between the 4 groups ($P < .001$, Table 1). The difference in stability increased when the triceps fragment was compressed onto a plate using a cortex screw. The PC group was the most stable, whereas the DC group was the most unstable. The mean micromotion was significantly different for the DC group vs the PC group ($P < .001$), the DC group vs the PL group ($P = .002$), and the DL group vs the PC group ($P = .04$) (Fig. 4). When comparing the gap difference before and after the test, only the posterior cortex of the DC group showed a statistically significant difference ($P = .023$). The displacement after the cyclic loading test was not significantly different between the 4 groups (anterior cortex, $P = .931$; posterior cortex, $P = .316$).

3.2. Load-to-failure test

The maximum load was significantly different between the 4 groups ($P < .001$). The maximum load was the strongest for the PL group and weakest for the DC group (Table 2). There was a significant difference in the maximum load in the DC group vs the

PC group ($P = .03$), the DC group vs the PL group ($P < .001$), and the DL group vs the PL group ($P = .002$) (Fig. 5).

4. Discussion

Handling triceps fragments in olecranon fractures is essential to maintaining the extensor mechanism. The number of triceps screws is important when affixing the triceps fragment. Intramedullary screws, so-called home run screws, can also enhance stability. Three or more triceps screws and intramedullary screws provide sufficient stability to hold triceps fragments, reducing the effect of the plate position. Gordon et al^[12] reported that posterior plating with intramedullary screws had the highest maximum load and that simple posterior plating and double-plating had similar stability. They used 3 cancellous screws for posterior plating and 4 cancellous screws for double-plating on the triceps. Wegmann et al^[13] reported that there was no difference in reduction quality between posterior plating with 5 cortical triceps screws, posterior plating with 4 locking triceps screws, and double plating with 6 locking triceps screws in Monteggia-like proximal ulnar fractures. Hackl et al^[14] reported that double-plating had superior or similar stability to posterior plating in micromotion between 25 N and 80 N using 4 cortical triceps screws including intramedullary screws. Hoelscher-Doht et al^[15] concluded that when using 4 locking triceps screws, the low-profile double-plate had a comparable maximum load to the posterior plate. Wagner et al^[25] reported that posterior plating with 3 locking triceps screws and double-plating with 4 locking triceps screws had similar stability when intramedullary screws were used in a study using an osteoporotic olecranon cadaver.

In comminuted olecranon fractures, plating-only is frequently impossible for appropriate fixation and bony union. To fix fragments or bone grafts, a variety of fixation methods can be used in addition to plating (eg, interfragmentary screws or cerclage wiring).^[16,17,5,2] If composite fixation is performed or the triceps fragment is too small, sufficient screw insertion into the triceps fragment cannot be achieved. In the past, when the

Table 2

Mean maximum load in load-to-failure test.

	Maximum load (range)
Double-cortical	143.3 ± 27.1 (109.6–188.2)*
Double-locking	175.1 ± 3.3 (170.2–180.4)*
Posterior-cortical	185.5 ± 5.0 (177.1–190.5)*
Posterior-locking†	205.3 ± 2.8 (200.9–209.1)*

The values are presented as the mean ± standard deviation, with ranges in parentheses.

All values are in N.

* Significant difference between groups ($P < .05$).

† Two out of eight had a catastrophic failure.

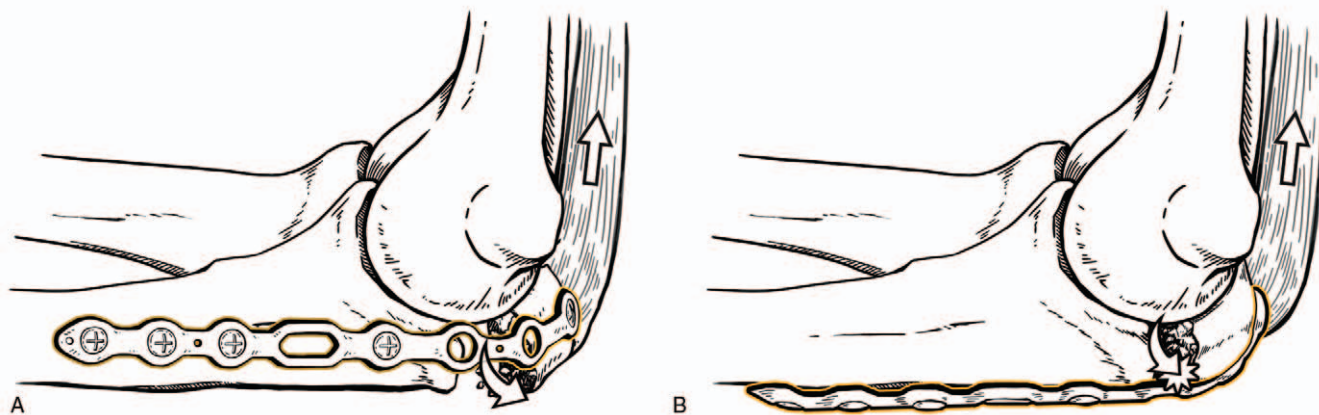


Figure 6. Effect of plate position on the rotational displacement of the triceps fragment. (A) A double-plate fixation can prevent distraction forces. However, its effects on rotational displacement are limited. (B) A posterior plate can effectively fix the triceps fragment against distraction and rotational forces.

triceps fragment was small, fragment excision and triceps advancement were recommended for low-demand patients and triceps fragments with <50% articulation.^[26] However, Bell et al^[27] demonstrated that small triceps pieces contributed to coronal stability. Since then, methods of handling small triceps fragments and extensors have been studied. Izzi and Athwal^[5] recommended off-loading triceps sutures to augment plating when the triceps fragment is small. Wild et al^[17] reported a median improvement of 48% in the maximum strength when suture augmentation was performed in addition to plate fixation. Our study showed that both groups were stable during light exercise, but that posterior plating was more stable than double-plating when the number of triceps screws was 2. This is because a plate posteriorly located blocks the rotational displacement of the triceps fragment better than a double-plate when the triceps screws are insufficient (Fig. 6).

The double-plate was proposed because of problems with the posterior plate, but it seems that the double-plate does not completely replace the posterior plate. In 2 retrospective studies led by Ellwein et al,^[28,29] a total of 126 patients were analyzed and reported no statistical difference in clinical outcomes, including implant-related irritation, between double and posterior plates. Morwood et al^[16] recommended additional fixation,

such as a lateral plate and cerclage wiring after posterior plating for an olecranon fracture with sagittal split fragments. Our results suggest a posterior plate rather than a double-plate for small triceps fragments. In summary, studies including our study suggest that double-plating can be used as an alternative to posterior plating in less comminuted olecranon fractures, but it is not recommended when comminution is severe.

This study had several limitations. First, the statistical power was weak because the number of specimens was small. The results would be more precise if a larger number of specimens were used because parametric analysis would be possible. Second, the results of this study could be influenced by plate design. The double plate was a 1.8-mm-thick low-profile plate and the posterior plate was 4.0-mm thick. Different results may occur for other plate designs depending upon the manufacturer. The third limitation was the method of applying pressure using a load screw. We applied force directly to the triceps fragment using a load screw to remove interference caused by the polyester band or steel wire used in previous studies. However, catastrophic failure occurred in 2 of 8 specimens in the PL group in the load-to-failure test. In the catastrophic failure specimens, the triceps fragment could not withstand the load applied to the load screw within the triceps fragment (Fig. 7). The load at the time of the catastrophic failure of 2 specimens was 202.9 N and 209.1 N as shown in the Supplemental Digital Content, <http://links.lww.com/MD2/A777>. These results were higher than the average of the other groups, so there was little influence on the statistical analysis. Our study setup using load screws is not suitable for biomechanical experiments with large loads above 200N.

5. Conclusion

This study showed that when 2 triceps screws were used, both groups were stable during light exercise, but posterior-plating was stronger than double-plating.

Author contributions

Conceptualization: Yohan Lee.

Data curation: Yohan Lee.

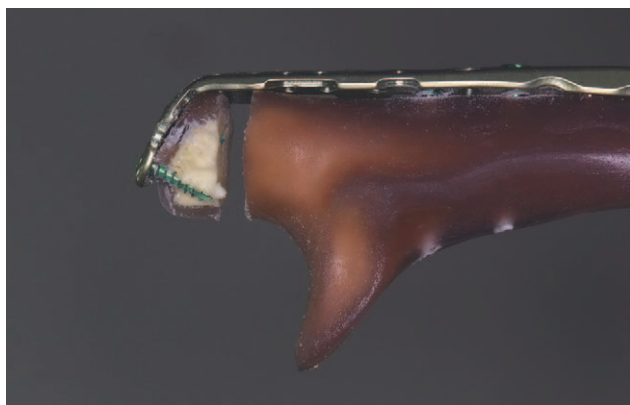


Figure 7. Catastrophic failure occurred at the load screw site in the PL group.

Formal analysis: Yohan Lee.

Funding acquisition: Young Ho Lee.

Methodology: Yohan Lee, Bong Wan Cho, Min Bom Kim, Young Ho Lee.

Software: Yohan Lee.

Supervision: Bong Wan Cho, Min Bom Kim.

Visualization: Yohan Lee.

Writing – original draft: Yohan Lee.

Writing – review & editing: Yohan Lee, Bong Wan Cho, Min Bom Kim, Young Ho Lee.

References

- [1] Rommens P, Kuchle R, Schneider R, et al. Olecranon fractures in adults: factors influencing outcome. *Injury* 2004;35:1149–57.
- [2] Hak DJ, Golladay GJ. Olecranon fractures: treatment options. *J Am Acad Orthop Surg* 2000;8:266–75.
- [3] Lindeman RW, Morris R, Weatherby P, et al. Effect of elbow position on load to failure in olecranon fracture fixation: a biomechanical cadaveric study. *J Orthop Trauma* 2019;33:256–60.
- [4] Newman SDS, Mauffrey C, Krikler S. Olecranon fractures. *Injury* 2009;40:575–81.
- [5] Izzi J, Athwal GS. An off-loading triceps suture for augmentation of plate fixation in comminuted osteoporotic fractures of the olecranon. *J Orthop Trauma* 2012;26:59–61.
- [6] Anderson ML, Larson AN, Merten SM, et al. Congruent elbow plate fixation of olecranon fractures. *J Orthop Trauma* 2007;21:386–93.
- [7] Rouleau DM, Sandman E, van Riet R, et al. Management of fractures of the proximal ulna. *J Am Acad Orthop Surg* 2013;21:149–60.
- [8] Bailey CS, MacDermid J, Patterson SD, et al. Outcome of plate fixation of olecranon fractures. *J Orthop Trauma* 2001;15:542–8.
- [9] Lawrence TM, Ahmadi S, Morrey BF, et al. Wound complications after distal humerus fracture fixation: incidence, risk factors, and outcome. *J Shoulder Elbow Surg* 2014;23:258–64.
- [10] De Giacomo AF, Tornetta PIII, Sinicrope BJ, et al. Outcomes after plating of olecranon fractures: a multicenter evaluation. *Injury* 2016;47:1466–71.
- [11] King GJW, Lammens PN, Milne AD, et al. Plate fixation of comminuted olecranon fractures: an in vitro biomechanical study. *J Shoulder Elbow Surg* 1996;5:437–41.
- [12] Gordon MJ, Budoff JE, Yeh ML, et al. Comminuted olecranon fractures: a comparison of plating methods. *J Shoulder Elbow Surg* 2006;15:94–9.
- [13] Wegmann K, Engel K, Skouras E, et al. Reconstruction of Monteggia-like proximal ulna fractures using different fixation devices: a biomechanical study. *Injury* 2016;47:1636–41.
- [14] Hackl M, Mayer K, Weber M, et al. Plate osteosynthesis of proximal ulna fractures – a biomechanical micromotion analysis. *J Hand Surg Am* 2017;42:834.
- [15] Hoelscher-Doht S, Kladny A, Paul M, et al. Low-profile double plating versus dorsal LCP in stabilization of the olecranon fractures. *Arch Orthop Trauma Surg* 2020;141:245–51.
- [16] Morwood MP, Ruch DS, Leversedge FJ, et al. Olecranon fractures with sagittal splits treated with dual fixation. *J Hand Surg Am* 2015;40:711–5.
- [17] Wild JR, Askam BM, Margolis DS, et al. Biomechanical evaluation of suture-augmented locking plate fixation for proximal third fractures of the olecranon. *J Orthop Trauma* 2012;26:533–8.
- [18] Miller DL, Goswami T. A review of locking compression plate biomechanics and their advantages as internal fixators in fracture healing. *Clin Biomech* 2007;22:1049–62.
- [19] Hamilton DA Jr, Reilly D, Wipf F, et al. Comminuted olecranon fracture fixation with pre-contoured plate: comparison of composite and cadaver bones. *World J Orthop* 2015;6:705.
- [20] Fantry A, Sobel A, Capito N, et al. Biomechanical assessment of locking plate fixation of comminuted proximal olecranon fractures. *J Orthop Trauma* 2018;32:e445–50.
- [21] Kozin SH, Berglund LJ, Cooney WP, et al. Biomechanical analysis of tension band fixation for olecranon fracture treatment. *J Shoulder Elbow Surg* 1996;5:442–8.
- [22] Wilson J, Bajwa A, Kamath V, et al. Biomechanical comparison of interfragmentary compression in transverse fractures of the olecranon. *J Bone Joint Surg Br* 2011;93:245–50.
- [23] Hutchinson DT, Horwitz DS, Ha G, et al. Cyclic loading of olecranon fracture fixation constructs. *J Bone Joint Surg Am* 2003;85:831–7.
- [24] Faul F, Erdfelder E, Lang A-G, et al. G* Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39:175–91.
- [25] Wagner FC, Jaeger M, Friebis C, et al. Low-profile double plating of unstable osteoporotic olecranon fractures: a biomechanical comparative study. *J Shoulder Elbow Surg* 2021;30:1519–26.
- [26] Inhofe PD, Howard TC. The treatment of olecranon fractures by excision of fragments and repair of the extensor mechanism: historical review and report of 12 fractures. *Orthopedics* 1993;16:1313–7.
- [27] Bell TH, Ferreira LM, McDonald CP, et al. Contribution of the olecranon to elbow stability: an in vitro biomechanical study. *J Bone Joint Surg Am* 2010;92:949–57.
- [28] Ellwein A, Argiropoulos K, DeyHazra R-O, et al. Clinical evaluation of double-plate osteosynthesis for olecranon fractures: a retrospective case-control study. *Orthop Traumatol Surg Res* 2019;105:1601–6.
- [29] Ellwein A, Lill H, Warnhoff M, Hackl M, et al. Can low-profile double-plate osteosynthesis for olecranon fractures reduce implant removal? A retrospective multicenter study. *J Shoulder Elbow Surg* 2020;29:1275–81.