creative commons
COMMONS DEED

저작자표시-비영리-변경금지 2.0 대한민국

이용자는 아래의 조건을 따르는 경우에 한하여 자유롭게

- 이 저작물을 복제, 배포, 전송, 전시, 공연 및 방송할 수 있습니다.

다음과 같은 조건을 따라야 합니다:

저작자표시. 귀하는 원저작자를 표시하여야 합니다.

비영리. 귀하는 이 저작물을 영리 목적으로 이용할 수 없습니다.

변경금지. 귀하는 이 저작물을 개작, 변형 또는 가공할 수 없습니다.

- 귀하는, 이 저작물의 재이용이나 배포의 경우, 이 저작물에 적용된 이용허락조건을 명확하게 나타내어야 합니다.
- 저작권자로부터 별도의 허가를 받으면 이러한 조건들은 적용되지 않습니다.

저작권법에 따른 이용자의 권리는 위의 내용에 의하여 영향을 받지 않습니다.

이것은 이용허락규약(Legal Code)을 이해하기 쉽게 요약한 것입니다.

Disclaimer

dCollection

연세대학교
YONSEI UNIVERSITY

Lateral wall integrity of the greater tuberosity is important for stability of osteoporotic proximal humerus fractures after plate fixation

Dohyun Kim

The Graduate School
Yonsei University
Department of Medicine

연세대학교
YONSEI UNIVERSITY

Lateral wall integrity of the greater tuberosity is important for stability of osteoporotic proximal humerus fractures after plate fixation

The Doctoral Dissertation Submitted
to the Department of Medicine
and the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy in Medical Science

Dohyun Kim

June 2024

연세대학교
YONSEI UNIVERSITY

This certifies that the Dissertation
of Dohyun Kim is approved.

Thesis Supervisor Yongmin Chun

Thesis Committee Member Yunrak Choi

Thesis Committee Member Min Jung

Thesis Committee Member Bong gun Lee

Thesis Committee Member Hun Mu Yang

The Graduate School
Yonsei University
June 2024

연세대학교
YONSEI UNIVERSITY

ACKNOWLEDGEMENTS

We would like to thank JH Kim, JH Bang, and T-J Ha from the Surgical Anatomy Education Center at the Yonsei University College of Medicine, Seoul, for their technical support.

First and foremost, I would like to express my deepest gratitude to my advisor, Professor Yongmin Chun. I am immensely grateful for your enthusiastic guidance throughout my PhD journey and for granting me the honor of submitting my medical research to prestigious journals. I will strive to repay your mentorship throughout my life. I would also like to extend my sincere thanks to Professor Yunrak Choi, the chairman of my dissertation committee and my mentor in hand surgery. Your endless support and guidance have been invaluable to me. To my parents, I am deeply thankful for nurturing me into the orthopedic surgeon I am today. Now that I am a father to a six-month-old daughter, I feel more profoundly the love and grace you have bestowed upon me. To my beloved wife, Yerim, thank you for your unwavering support during my experiments and the writing of my dissertation. I remember the nights you welcomed me home late, exhausted from long hours in the anatomy lab. Your comfort and encouragement meant the world to me. I love you. And to my six-month-old daughter, Jenna, it is with a special feeling that I mention your name for the first time in my PhD dissertation. I hope that your life will always be filled with happiness and peace. I love you.

연세대학교
YONSEI UNIVERSITY

TABLE OF CONTENTS

연세대학교
YONSEI UNIVERSITY

LIST OF FIGURES

연세대학교
YONSEI UNIVERSITY

LIST OF TABLES

연세대학교
YONSEI UNIVERSITY

ABSTRACT

Lateral wall integrity of the greater tuberosity is important for stability of osteoporotic proximal humerus fractures after plate fixation

Background: Previous studies assessing surgical fixation for osteoporotic proximal humerus fracture have primarily focused on medial calcar support. Here, we used a model for two-part surgical neck fracture of the osteoporotic proximal humerus to investigate how greater tuberosity (GT) lateral wall comminution affects biomechanical stability after fixation with a Proximal Humerus Internal Locking System (PHILOS) plate.

Methods: Ten matched pairs of cadaveric humeri (right and left) were assigned to either surgical neck fracture alone (SN group) or surgical neck fracture with GT lateral wall comminution (LW group) by block randomization, after simulating osteoporotic proximal humerus fracture. We then measured axial compression, torsional and varus bending stiffness, and single-load-to-failure for all plate–bone constructs.

Results: The LW group showed a significant decrease in all measures, including torsional stiffness (internal, $p = 0.007$; external, $p = 0.007$), axial compression stiffness ($p = 0.002$), and varus bending ($p = 0.007$). In addition, the mean single-load-to-failure of varus bending was 62% lower for the LW group versus the SN group ($p = 0.005$).

Conclusions: GT lateral wall comminution significantly compromises the stability of osteoporotic two-part humerus surgical neck fractures with plate–bone constructs.

Clinical Relevance: We show that GT lateral wall comminution significantly compromises the stability of osteoporotic proximal humeri with two-part surgical neck fractures fixed with a plate alone.

Key words : proximal humeral fracuture, cadaveric study, biomechanical study, humerus, greater tuberosity, philos, locking plate

연세대학교
YONSEI UNIVERSITY

1. INTRODUCTION

Proximal humerus fractures account for approximately 4–5% of all fractures and frequently occur in older adults with osteoporosis.[1] Although many proximal humerus fractures can be treated non-surgically, in some cases, open reduction and internal fixation (ORIF) surgery is preferred for achieving fracture stability and early mobilization of the shoulder.[2] In particular, internal fixation using a locking system for proximal humerus fracture has yielded satisfactory functional outcomes.[3,4,15] However, despite of the locking plate, reduction loss due to varus progression has been reported after fixation.[5,6,16,17] Moreover, if osteoporosis is combined with varus angulation or medial calcar comminution, it is difficult to avoid varus progression, even with a locking plate applied on the lateral part of the proximal humerus. Consequently, the medial calcar screw technique was introduced to augment stability after fixation.[7,10,11]

Tuberosity involvement in two-part fractures with non-displaced tuberosity and in three- or four-part fractures is common in proximal humerus fractures and is known to be a poor prognostic indicator for ORIF, especially in elderly patients with osteoporosis.[9] To promote strong fixation of the proximal fragment resulting from a surgical neck fracture, the locking plate screws should purchase the calcar bicortically, the lateral cortex of the greater tuberosity (GT), and the cancellous bone in the humeral head.[35] However, given that many elderly patients have poor cancellous bone quality within the humeral head due to osteoporosis combined with lateral wall comminution, biomechanical stability may be substantially compromised, even with medial calcar support. Consequently, early range of motion (ROM) exercises will be limited, potentially leading to suboptimal functional outcomes.

Previous studies have mainly focused on medial calcar support for osteoporotic proximal humerus fracture, and to our knowledge, none have assessed the significance of GT lateral wall integrity on biomechanical stability after fixation of osteoporotic proximal humerus fracture.[7,10,11] Therefore, in this study, we aimed to investigate how the presence of a comminuted versus an intact GT lateral wall affects the biomechanical properties of osteoporotic proximal humerus surgical neck fractures after locking-plate fixation. We hypothesized that the presence of a comminuted GT lateral wall would significantly impair biomechanical stability after fixation, even with medial calcar support.

연세대학교
YONSEI UNIVERSITY

2. MATERIALS AND METHODS

2.1 Specimen Preparation

Ten matched pairs of fresh-frozen cadaveric humeri (20 specimens) were used for this study. Specimens were obtained from subjects 75–103 years old (mean age = 84.4, standard deviation [SD] = 7.9), including seven males and three females. All humeri were macroscopically intact and showed no surgical wounds or old fractures. Cadaveric humeri were kept frozen at −20°C and thawed at room temperature for 24 hours before processing. All soft tissues associated with the humeri were removed.

Trabecular bone mineral density (BMD) of each humeral head was measured by quantitative computed tomography (qCT; LightSpeed VCT64, GE Healthcare, Milwaukee, WI, USA). After scanning the entire specimen, BMDs were determined from three parallel sections, each separated by 1.5-mm, at the largest transverse diameter of the humeral head (i.e., the axial plane perpendicular to the humeral shaft anatomical axis). A square-shaped region of interest was placed on the cross-sectional area of the bone slice, with each edge of the square touching the subcortical bone of the humeral head, measuring only cancellous bone. Final BMD values were obtained from the average of the three measurements.[18]
After qCT scans, paired humeri from each cadaveric sample were divided into two groups, as follows: 1) a two-part proximal humerus fracture group with surgical neck comminution fracture and no GT wall comminution (SN group) and 2) a two-part proximal humerus fracture group with both comminuted surgical neck fracture and GT wall comminution (LW group). Humeri within each pair were assigned to either the SN or LW group by block randomization.

For humerus fixation, we used the Proximal Humerus Internal Locking System (PHILOS; DePuy Synthes Inc., West Chester, PA, USA) plate. To simulate comminution of the surgical neck, we resected a 10-mm medially based wedge of bone from the humeral calcar with an oscillating saw, as described in previous simulation studies (Fig. 1A).[4,11] In brief, we positioned the superior border of the wedge perpendicular to the humeral shaft anatomical axis. Suture holes located between rows C and D (i.e., the calcar screws holes) of the plate were then used as landmarks when performing wedge resection, securing the near cortex for calcar screw insertion (Fig. 1B). For samples with GT lateral wall comminution, we resected the GT along the line connecting two dots located 5-mm apart from the plate on an axial plane toward the center of the humeral head. Because the proximal humerus has been reported to have a cortical thickness of up to 3.5 mm, we removed 5 mm of the GT wall where the plate was to be placed.[12] Due to the impossibility of achieving a complete reduction of all multi-fragmented greater tuberosities, we opted for the resection method, as previous studies that simulated comminution.[10,11,20,22]

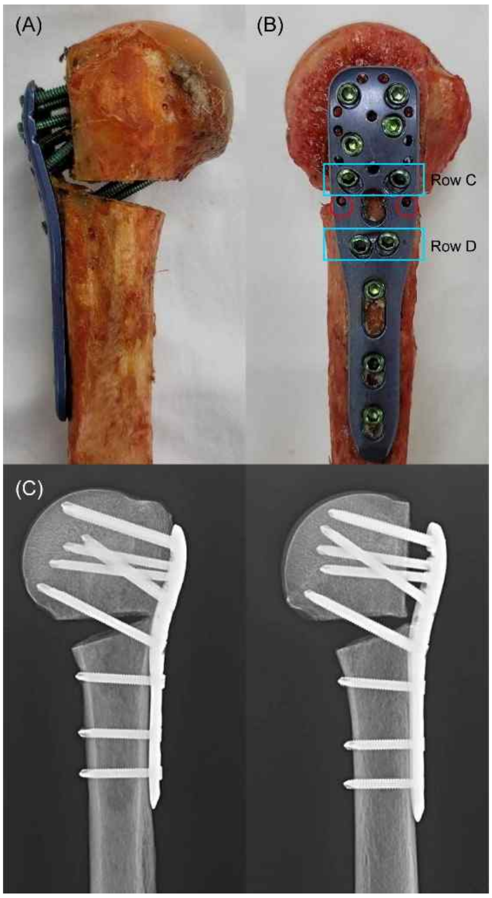

Figure 1. (A–B) Photograph showing the fracture model for the lateral wall (LW) comminution group (A). Wedge resection was performed through the line passing the suture holes of the plate, as indicated by the two circles between rows C and D (B). (C) Radiographs of the SN group (GT wall intact) and LW group (GT wall comminuted).

연세대학교
YONSEI UNIVERSITY

Screw fixation was performed from rows A to E, with the exception of row D, using 3.5-mm locking screws. A total of eight screw fixations were placed, with three locking screws used for fixation on the shaft region.13 After plate fixation, a radiograph was taken to confirm appropriate positioning of the plate and screws (Fig. 1C). We then resected the distal portion of each humerus 16.5 cm from the top of the humeral head, perpendicular to the humeral shaft axis. Proximal and distal potting was performed by placing a cadaveric humerus into a customized cuboid jig and securing it with unsaturated polyester resin (EC-304, Aekyung Chemical Co., Seoul, Korea). After the resin cures, it hardens into a rigid state. The proximal portion of the humerus attached to the plate was covered with clay before being coated with resin to ensure that the resin did not invade spaces between the resected bony surface and the plate/screw construct, as described previously.[19] The clay was then removed after the resin hardened. This procedure was necessary to eliminate unnecessary resistance and deliver pure mechanical force when performing the stability tests. This procedure was performed by a orthopaedic board-certified surgeon (K.D.H).

2.2 Biomechanical Testing

Biomechanical stability was assessed by performing four stiffness tests: torsional (internal/external) stiffness, axial compression, varus bending stiffness, and single-load-to-failure of varus bending. Torsional stiffness was measured using a torsional stiffness tester (DPTST; DYPHI, Seoul, Korea), and the other stiffness tests, including single-load-to-failure, were performed using an electrohydraulic materials test system (model 3366, Instron, Norwood, MA, USA).

We initially performed a non-destructive quasi-static torsional test, and load levels were selected based on a previous study.[14] Internal and external rotational torques were measured by rotating the humeral head at 0.2 Nm torque per second to ±3.5 Nm (Fig. 2A). A non-destructive axial compression test was then conducted up to a maximum force of 200 N at a rate of 0.1 mm/s (Fig. 2B). We next performed a varus bending stiffness test under four-point bending conditions, with a supporting span of 21 cm and a loading span of 13 cm. Bending tests were conducted to 3.5 Nm at 0.1 mm/s. The stiffness value was calculated as the slopes of the linear portions of the fifth force-displacement curves. Lastly, we used the varus bending setup to measure single-load-to-failure, with the point-of-failure identified as the abrupt

연세대학교
YONSEI UNIVERSITY

change in the force/displacement curve resulting from loss of fixation. Through a series of each experiment, we confirmed the elasticity of the force/displacement curve and ensured there was no loss of fixation before proceeding with the next experiment and final load to failure.

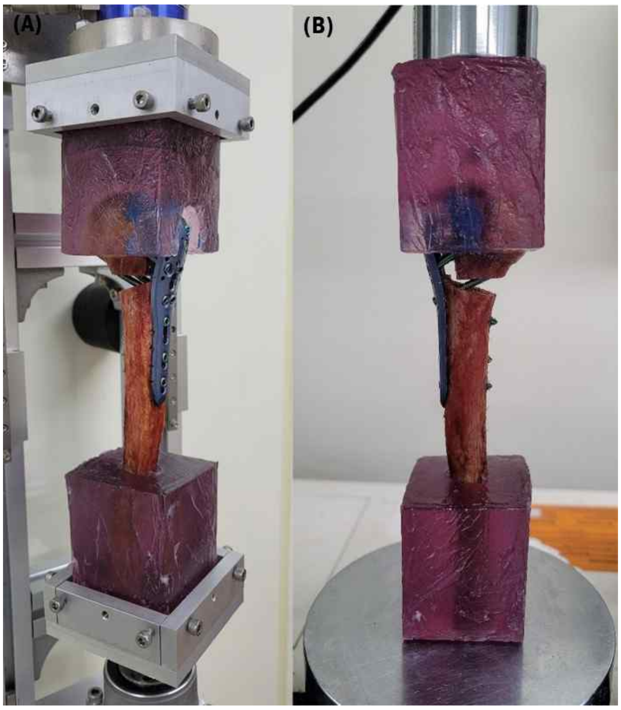

Figure 2. (A–B) Setup of the customized cuboid jig secured with unsaturated polyester resin used for torsional testing (A) and axial compression testing (B).

2.3 Sample Size and Statistical Analysis

As studies on this subject are lacking, sample size was calculated from the varus bending stiffness values measured in a pilot study performed with three paired humeri (six specimens). In this study, mean and SD varus bending stiffness values were 418.9 ± 67.6 N/mm for the SN group and 323.1 ± 71.2 N/mm for the LW group. Based on these data, we found that 20 specimens (10 per group) were required to provide 90% power at an α level of 0.05. The normal distribution of all variables was tested with the Shapiro-Wilk test. The paired t-test or Wilcoxon signed–rank test were used to identify significant differences in BMD and

연세대학교
YONSEI UNIVERSITY

mechanical performance values between the two groups. Statistical analyses were performed using IBM SPSS Statistics for Windows (v.25.0; IBM Corp.), and the cutoff for statistical significance was set at $p < 0.05$.

3. RESULTS

Given that the matched pairs of right and left humeri were block randomized, there were no differences in BMD between the SN (GT wall intact group) and LW groups (GT wall comminuted group). The LW group was impaired by 25.2% in internal torsional stiffness ($p = 0.007$) and by 19.6% in external torsional stiffness ($p = 0.007$) compared with the SN group. Compared with the SN group, axial compression stiffness was 43.2% lower ($p = 0.002$), mean varus stiffness was 26.1% lower ($p = 0.007$), and single-load-to-failure was 61.9% lower ($p = 0.005$) in the LW group (Table 1). Notably, varus bending, axial compression stiffness, torsional stiffness, and single-load-to-failure were significantly reduced in the LW group relative to the SN group.

Table 1. Bone mineral density (BMD) and results from stiffness and single-load-to-failure tests for the two groups examined in this study.

	SN group (n = 10)	LW group (n = 10)	p-value
BMD (mg/cm^3)	33.32 ± 12.5	34.10 ± 13.9	0.243
Stiffness in internal rotation (N/deg)	1.03 ± 0.11	0.77 ± 0.06	0.007
Stiffness in external rotation (N/deg)	0.92 ± 0.15	0.74 ± 0.09	0.007
Stiffness in axial compression (N/mm)	590.0 ± 69.3	335.1 ± 38.2	0.002
Stiffness in varus bending (N/mm)	435.9 ± 27.1	322.1 ± 26.5	0.007
Single-load-to-failure (N)	1121.7 ± 112.1	427.4 ± 51.8	0.005

SN group, GT lateral wall intact group; LW group, GT lateral wall comminution group.

All data except BMD are presented as the mean ± standard deviation.

연세대학교
YONSEI UNIVERSITY

4. DISCUSSION

In this study, we aimed to investigate the degree to which the presence of a comminuted versus an intact GT lateral wall comprises the biomechanical properties of osteoporotic proximal humeri with surgical neck fracture after locking-plate fixation. As we hypothesized, our results show that GT lateral wall comminution significantly compromises axial compression, torsional, varus bending stiffness, and single-load-to-failure of osteoporotic proximal humeri with two-part surgical neck fractures fixed with a plate. In particular, single-load-to-failure was nearly three-fold lower in the group with comminuted GT lateral walls.

Fixation failure and varus collapse are challenging issues in elderly patients with poor cancellous bone quality within the proximal humerus head. Consequently, medial calcar screw support was introduced to stabilize the plate–bone construct, particularly in patients with medial calcar comminution of the surgical neck. Previous studies have compared comminuted surgical neck fractures with and without calcar screws, reporting an approximately 34% reduction in axial stiffness[7,8] and a 20%–36% reduction in the single load failure of axial compression[11,33] in fractures without calcar screws compared to those with calcar screws. In the current study, GT lateral wall comminution reduced axial stiffness by 43% and single load to failure of varus bending by 61.9% in fractures, even with calcar support.

Critically, although GT lateral wall comminution is common in osteoporotic proximal humerus fractures, this issue has received little clinical attention. In the current study, we found that despite placement of medial column support for medial calcar comminution, the presence of GT lateral wall comminution significantly compromised biomechanical stability. Given that rotator cuffs and the deltoid muscle can place a varus bending force on the proximal humerus, decreased stability in patients with a comminuted GT lateral wall is likely to result in varus failure during the postoperative rehabilitation period.[24] Consequently, early ROM exercise is inevitably limited in these individuals.

Many Neer type II surgical neck fractures encountered in clinical and operative settings have concomitant GT lateral wall fractures—often a longitudinal fracture line just lateral to the bicipital groove—although there is no displacement. Undoubtedly, screws are introduced in close proximity to the fracture line on the lateral wall, raising concerns regarding stability, despite the use of a locking screw on the plate system. Fortunately, for patients with only one non-displaced longitudinal fracture on the GT lateral wall, this locking-plate system with medial calcar support appears to work well. However, the situation differs if lateral wall comminution is present. To avoid varus failure with a pullout locking plate and facilitate bone union, it appears necessary to either prolong the immobilization period with the affected arm placed under minimal varus load or include other augmentation, such as allogenous strut bone or calcium phosphate.[29,30,34]

Gardner et al.[25] first described the use of endosteal fibular strut bone augmentation to restore the medial column and add stability in osteoporotic proximal humeral surgical neck fractures with medial wall comminution. Subsequently, multiple clinical studies have reported favorable findings after endosteal fibular strut bone graft in patients with proximal humerus fractures. [26,27] Although a recent randomized controlled trial detected no added clinical benefit for fibular allograft in medial comminuted proximal humeral fractures[20], given our present findings, if proximal humerus fractures have concomitant GT wall comminution, the benefits of an endosteal fibular strut graft would be apparent in clinical trials.

This study has several limitations. First, due to the inherent nature of cadaver studies, there are inevitably differences compared to in-vivo setting. For instance, braided sutures for securing the multi-fragmented greater tuberosities during surgery were not simulated. Second, although the BMD values in the present study were low (33–34 mg/cm3) compared with previous similar studies investigating volumetric BMD in the proximal humerus, whether they are indeed osteoporotic could not be confirmed.[28] Third, when modeling a surgical neck wedge osteotomy, we used landmarks on the plate for placement of calcar screws to secure the near cortex of the humeral shaft in every model. Thus, the superior margin of the wedge is slightly different in each humerus. In addition, the bending tests were performed using the four-point bending method rather than the cantilever bending test, as was used in previous studies.[4,19,21,22] However, we note that with the four-point bending test, we can expect the same overall bending moment between loading spans, despite the cantilever bending test represents a more physiologic loading situation.[23] Fifth, because the axial loading test has been reported in previous studies, we included this parameter; however, this force does not seem to be physiologically relevant. Lastly, to simulate GT lateral wall comminution, we removed 5 mm from the GT lateral wall cortex. Prior studies have established methods for generating bone defects that simulate comminution in the humeral shaft or surgical neck. Here, we created GT defects in the same manner, as there are no published studies that describe a method for lateral wall comminution.

연세대학교
YONSEI UNIVERSITY

5. CONCLUSION

Our findings suggest that GT lateral wall comminution significantly compromises the stability of osteoporotic two-part humerus surgical neck fractures with plate–bone constructs.

연세대학교
YONSEI UNIVERSITY

References

1. Horak J, Nilsson BE. Epidemiology of fracture of the upper end of the humerus. Clin Orthop Relat Res. 1975;(112):250-253.
2. Howard L, Berdusco R, Momoli F, Pollock J, Liew A, Papp S, Lalonde KA, Gofton W, Ruggiero S, Lapner P. Open reduction internal fixation vs non-operative management in proximal humerus fractures: a prospective, randomized controlled trial protocol. BMC Musculoskelet Disord. 2018;19(1):299.
3. Koukakis A, Apostolou CD, Taneja T, Korres DS, Amini A. Fixation of proximal humerus fractures using the PHILOS plate: early experience. Clin Orthop Relat Res. 2006;442:115-120.
4. Edwards SL, Wilson NA, Zhang LQ, Flores S, Merk BR. Two-part surgical neck fractures of the proximal part of the humerus. A biomechanical evaluation of two fixation techniques. J Bone Joint Surg Am. 2006;88(10):2258-2264.
5. Laux CJ, Grubhofer F, Werner CML, Simmen HP, Osterhoff G. Current concepts in locking plate fixation of proximal humerus fractures. J Orthop Surg Res. 2017;12(1):137.
6. Agudelo J, Schürmann M, Stahel P, Helwig P, Morgan SJ, Zechel W, Bahrs C, Parekh A, Ziran B, Williams A, Smith W. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma. 2007;21(10):676-681.
7. Bai L, Fu Z, An S, Zhang P, Zhang D, Jiang B. Effect of Calcar Screw Use in Surgical Neck Fractures of the Proximal Humerus With Unstable Medial Support: A Biomechanical Study. J Orthop Trauma. 2014;28(8):452-457
8. Hasan AP, Phadnis J, Jaarsma RL, Bain GI. Fracture line morphology of complex proximal humeral fractures. J Shoulder Elbow Surg. 2017;26(10):e300-e308.
9. Robinson CM, Stirling PHC, Goudie EB, MacDonald DJ, Strelzow JA. Complications and Long-Term Outcomes of Open Reduction and Plate Fixation of Proximal Humeral Fractures. J Bone Joint Surg Am. 2019;101(23):2129-2139.
10. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. J Orthop Trauma. 2007;21(3):185-191
11. Ponce BA, Thompson KJ, Raghava P, Eberhardt AW, Tate JP, Volgas DA, Stannard JP.

연세대학교
YONSEI UNIVERSITY

The role of medial comminution and calcar restoration in varus collapse of proximal humeral fractures treated with locking plates. J Bone Joint Surg Am. 2013;95(16):e113(1-7).

12. Majed A, Thangarajah T, Southgate D, Reilly P, Bull A, Emery R. Cortical thickness analysis of the proximal humerus. Shoulder Elbow. 2019;11(2):87-93.
13. Fletcher JWA, Windolf M, Richards RG, Gueorguiev B, Varga P. Screw configuration in proximal humerus plating has a significant impact on fixation failure risk predicted by finite element models. J Shoulder Elbow Surg. 2019;28(9):1816-1823.
14. Hast MW, Chin M, Schmidt EC, Sanville J, Van Osten GK, Mehta S. Mechanical Effects of Bone Substitute and Far-Cortical Locking Techniques in 2-Part Proximal Humerus Fracture Reconstruction: A Cadaveric Study. J Orthop Trauma. 2020;34(4):199-205.
15. Faraj D, Kooistra BW, Vd Stappen WA, Werre AJ. Results of 131 consecutive operated patients with a displaced proximal humerus fracture: an analysis with more than two years follow-up. Eur J Orthop Surg Traumatol. 2011;21(1):7-12.
16. Agudelo J, Schürmann M, Stahel P, et al. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma. 2007;21(10):676-681.
17. Robinson CM, Wylie JR, Ray AG, Dempster NJ, Olabi B, Seah KT, Akhtar MA. Proximal humeral fractures with a severe varus deformity treated by fixation with a locking plate. J Bone Joint Surg Br. 2010;92(5):672-678.
18. Röderer G, Gebhard F, Krischak G, Wilke HJ, Claes L. Biomechanical in vitro assessment of fixed angle plating using a new concept of locking for the treatment of osteoporotic proximal humerus fractures. Int Orthop. 2011;35(4):535-541.
19. Donohue DM, Santoni BG, Stoops TK, Tanner G, Diaz MA, Mighell M. Biomechanical Comparison of 3 Inferiorly Directed Versus 3 Superiorly Directed Locking Screws on Stability in a 3-Part Proximal Humerus Fracture Model. J Orthop Trauma. 2018;32(6):306-312
20. Wang Q, Sheng N, Huang JT, Zhu H, Tuerxun M, Ruan Z, Shi T, Zhu Y, Zhang Y, Rui B, Wang L, Chen Y. Effect of Fibular Allograft Augmentation in Medial Column Comminuted Proximal Humeral Fractures: A Randomized Controlled Trial. J Bone Joint Surg Am. 2023;105(4):302-311.
21. Jabran A, Peach C, Zou Z, Ren L. Hybrid blade and locking plate fixation for proximal

연세대학교
YONSEI UNIVERSITY

humerus fractures: a comparative biomechanical analysis. Biomed Eng Online. 2018;17(1):10.

22. Siffri PC, Peindl RD, Coley ER, Norton J, Connor PM, Kellam JF. Biomechanical analysis of blade plate versus locking plate fixation for a proximal humerus fracture: comparison using cadaveric and synthetic humeri. J Orthop Trauma. 2006;20(8):547-554.
23. Hui Xue and H. Khawaja ,Analytical study of sandwich structures using Euler–Bernoulli beam equation, AIP Conference Proceedings 1798, 020076 (2017)
24. Chalmers CE, Wright DJ, Patel N, Hitchens H, McGarry M, Lee TQ, Scolaro JA. Muscular Forces Responsible for Proximal Humeral Deformity After Fracture. J Orthop Trauma. 2022;36(1):e18-e23.
25. Gardner MJ, Boraiah S, Helfet DL, Lorich DG. Indirect medial reduction and strut support of proximal humerus fractures using an endosteal implant. J Orthop Trauma. 2008;22(3):195-200.
26. Matassi F, Angeloni R, Carulli C, Civinini R, Di Bella L, Redl B, Innocenti M. Locking plate and fibular allograft augmentation in unstable fractures of proximal humerus. Injury. 2012;43(11):1939-1942.
27. Hinds RM, Garner MR, Tran WH, Lazaro LE, Dines JS, Lorich DG. Geriatric proximal humeral fracture patients show similar clinical outcomes to non-geriatric patients after osteosynthesis with endosteal fibular strut allograft augmentation. J Shoulder Elbow Surg. 2015;24(6):889-896.
28. Röderer G, Scola A, Schmölz W, Gebhard F, Windolf M, Hofmann-Fliri L. Biomechanical in vitro assessment of screw augmentation in locked plating of proximal humerus fractures. Injury. 2013;44(10):1327-1332.
29. Egol KA, Sugi MT, Ong CC, Montero N, Davidovitch R, Zuckerman JD. Fracture site augmentation with calcium phosphate cement reduces screw penetration after open reduction-internal fixation of proximal humeral fractures. J Shoulder Elbow Surg. 2012;21(6):741-748.
30. Kwon BK, Goertzen DJ, O'Brien PJ, Broekhuyse HM, Oxland TR. Biomechanical evaluation of proximal humeral fracture fixation supplemented with calcium phosphate cement. J Bone Joint Surg Am. 2002;84(6):951-961.
31. Katthagen JC, Schwarze M, Meyer-Kobbe J, Voigt C, Hurschler C, Lill H. Biomechanical

연세대학교
YONSEI UNIVERSITY

effects of calcar screws and bone block augmentation on medial support in locked plating of proximal humeral fractures. Clin Biomech (Bristol, Avon). 2014;29(7):735-41.

32. Erhardt JB, Stoffel K, Kampshoff J, Badur N, Yates P, Kuster MS. The position and number of screws influence screw perforation of the humeral head in modern locking plates: a cadaver study. J Orthop Trauma. 2012;26(10):e188-92.
33. Zhang X, Huang J, Zhao L, Luo Y, Mao H, Huang Y, Chen W, Chen Q, Cheng B. Inferomedial cortical bone contact and fixation with calcar screws on the dynamic and static mechanical stability of proximal humerus fractures. J Orthop Surg Res. 2019;14(1):1.
34. Raphael JS, Booker MR, Saing MH, Beaver AB, Marvil SC, Puglisi AS, Samuel SP. Locked Plate Fixation of Proximal Humerus Fractures Using Cannulated Subchondral Support Pegs. Shoulder & Elbow. 2013;5(3):178-182.
35. Mehta S, Chin M, Sanville J, Namdari S, Hast MW. Calcar screw position in proximal humerus fracture fixation: Don't miss high! Injury. 2018;49(3):624-629.

연세대학교
YONSEI UNIVERSITY

Abstract in Korean

근위 상완골 골절 금속판 고정시 대결절의 외측벽 무결성의 중요성

배경: 이전의 연구들은 골다공성 근위 상완 골 골절의 수술적 고정을 평가할 때 주로 내측 상완 거(calcar)에 대한 지지에 초점을 맞추었다. 하지만, 본 연구는 골다공증성 상완골의 이 분(2 part) 외과적 경부 골절모델을 사용하여 대 결절 외측벽의 분쇄골절이 금속판 고정 술 후 생체역학적 안정성에 어떤 영향을 미치는지 조사하였다.

방법: 골다공증성 상완 골 골절을 시뮬레이션 한 후, 우측과 좌측으로 구성된 총 열 쌍의 사체 상완골에 대해 블록 무작위 배정을 통해 수술 경부 골절만 있는 군(SN group), 수술 경부 골절과 대 결절 외측 벽 분쇄골절이 있는 군(LW group)으로 나누었다. 그 후 모든 금속판-사체 뼈 구조물에 대해 축성 압축(axial compression), 비틀림(torsional), 내반 휨(varus bending) 강성, 당일 하중 파괴 실험을 진행하였다.

결과: LW 군은 내 회전 비틀림 강성($p = 0.007$), 외 회전 비틀림 강성($p = 0.007$), 축성 압축 강성($p = 0.002$), 그리고 내반 휨 강성($p = 0.007$)를 포함한 모든 측정 항목에서 유의한 감소를 보였습니다. 또한, 내반 휨 평균 단일 하중 파괴 실험 결과는 LW군이 SN군에 비해 62% 낮았다. ($p = 0.005$)

결론: 대 결절 외측 벽 분쇄골절은 골다공성 이 분 근위 상완 골 골절 금속판-사체 뼈 구조물의 안정성을 상당히 저하시킨다.

핵심되는 말: 근위상완골, 사체 연구, 생체역학연구,상완골 골절, 대결절, 잠김 금속판