EXPERIMENTAL STUDY

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Biomechanical evaluation of different internal fixation methods for humerus shaft fractures with medial butterfly fragment

Mehmet Aykut TÜRKEN[1], Mehmet AKDEMİR[2], Bora UZUN[3], Mustafa ÖZKAN[4]

[1]*Department of Orthopedics and Traumatology, Bolu İzzet Baysal State Hospital, Bolu, Turkey;*
[2]*Department of Orthopedics and Traumatology, Turhal State Hospital, Tokat, Turkey;*
[3]*Department of Biomechanics, Faculty of Medicine, Dokuz Eylül University, İzmir, Turkey;*
[4]*Department of Orthopedics and Traumatology, Faculty of Medicine, Dokuz Eylül University, İzmir, Turkey*

Objective: The aim of this study was to compare the biomechanical strength of three fixation methods in humerus shaft fractures with medial butterfly fragment.

Methods: An AO 12B2 fracture with butterfly fragment was created in 21 synthetic cortical shell humeri. Humeri were divided into 3 groups which underwent bridge plating, antegrade intramedullary nailing or retrograde intramedullary nailing. Rotational and four-point bending test displacement curves were obtained.

Results: Mean displacement values in the torsion tests were 37.38 (range: 25.75 to 55.69) mm in the bridge plating group, 26.55 (range: 21.25 to 41.81) mm in the antegrade nailing group, and 33.23 (range: 27.50 to 46.45) mm in the retrograde nailing group. Mean displacement values in the four-point bending test were 3.27 (range: 2.54 to 3.73) mm in the bridge plating group, 3.17 (range: 2.69 to 3.55) mm in the antegrade nailing group, and 3.15 (range: 2.10 to 4.03) mm in the retrograde nailing group. No significant difference was found among the groups (p>0.05).

Conclusion: The biomechanical stability of bridge plating, antegrade intramedullary nailing and retrograde intramedullary nailing appears to be similar in the fixation of humerus shaft fractures with medial butterfly fragment.

Key words: Antegrade intramedullary nailing; bridge plating; humerus shaft fracture; medial butterfly fragment; retrograde intramedullary nailing.

Humeral shaft fractures comprise 1 to 3% of all fractures. Epidemiologic studies have demonstrated an incidence distribution with a small peak in the third decade for men and a larger peak in the seventh decade for women.[1,2] Most humeral shaft fractures are successfully managed through conservative treatment although surgery may be necessary in some cases. Plate and screws, intramedullary nailing and external fixation can all be used in surgical treatment.[3-7] However, the optimal choice is a subject of debate in terms of biomechanics, surgical planning and complications.[6]

The biomechanics of internal fracture fixation has grown in importance in recent years. Less rigid fixation promotes secondary bone healing with more callus for-

Correspondence: Mehmet Aykut Türken, MD. İzmir Üniversitesi Medical Park İzmir Hastanesi, Yeni Girne Blv. 1825 Sk., No: 12, Karşıyaka, İzmir, Turkey.

Tel: +90 533 - 644 88 66 e-mail: turken.aykut@gmail.com

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mation. Indirect reduction reduces surgical trauma. The use of bridge plating fixation with locking plates enables a better protection of the bone circulation.[1] As with all wounds, bone fracture healing depends on blood flow. Injury of the nutrient artery of the humerus during initial trauma or surgical intervention may impair fracture healing.[4]

The aim of this study was to compare the mechanical properties of the bridge plating and antegrade and retrograde intramedullary nailing fixation methods in a synthetic humeral shaft fracture model with a medial butterfly fragment.

Materials and methods

This study included 21 left plastic cortical shell humeri (Sawbones® model no: 1006; Sawbones AG, Malmö, Sweden). On each specimen, a butterfly fragment with a base of 40 mm was removed from the medial cortex in order to prepare an AO 12B2 fracture model. There was no bone contact between the main fracture fragments. Humeri were divided into three equal groups (n=7) and fixation with bridge plating, antegrade intramedullary nailing, and retrograde intramedullary nailing were performed (Fig. 1).

A 9x280 mm nail was used in all nailings and the nail was locked with two distal and two proximal screws (Figs. 2a and b). In the bridge plating group, a 4.5-mm wide 178-mm long humerus LC-DCP plate with 10 holes (Synthes) was fixed to the humerus to bridge the butterfly fragment with eight 20-mm locking screws (Fig. 2c).

Fig. 1. Examples of sawbones used in the study and shape of osteotomies. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

SHIMADZU Autograph AG-5kNG universal test instrument (Shimadzu Corp., Tokyo, Japan) was used as compression tool. In order to reduce contact friction during the test, the compression instrument was used on a fixation device with two height-adjustable arms of 180x15 mm and a base plate of 1000x600x12 mm (Fig. 3). The part containing bearings were connected to the compression tool with a roller system; the opposite site was kept stable. A 100x80 mm hole around which 4 8x1.5 mm pins were inserted was used to fix the bone.

The compression tool was calibrated during each experiment prior to loading. The torsion apparatus was

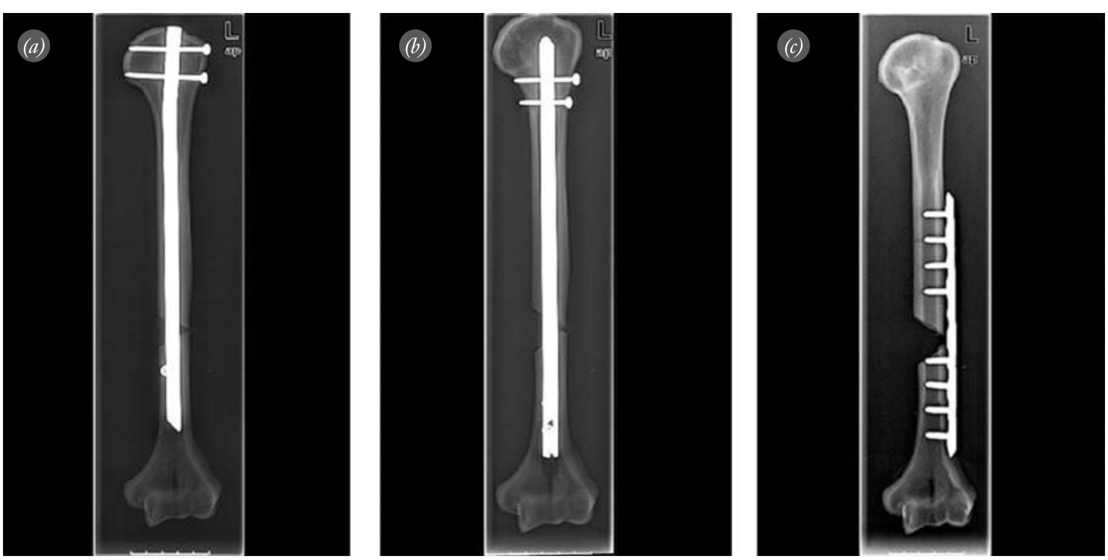

Fig. 2. Radiographic images of internal fixation modalities on the sawbones: **(a)** antegrade intramedullary, **(b)** retrograde intramedullary and **(c)** locked plate fixation.

Fig. 3. The apparatus adapted to the Shimadzu test machine. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

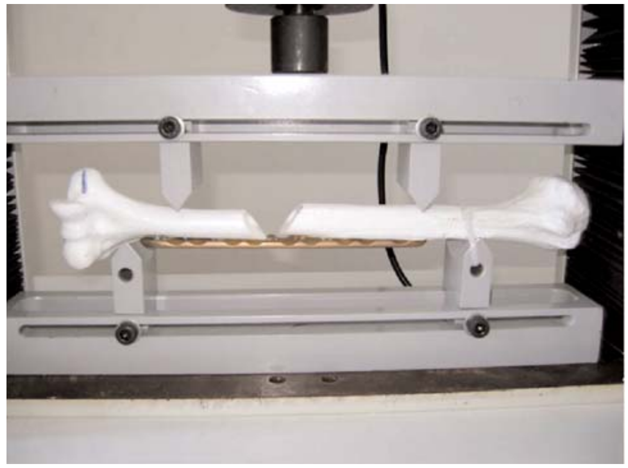

Fig. 4. The machine used for four-point bending. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

secured to the ground with a steel wire. The opposite direction of gravity loading was generated by connecting the torsion apparatus roller system to the compression tool with a steel wire. Attention was paid so that subjects were placed in the same direction with torsional rotation axis of the instrument. Constantly increasing loading was applied with the torsion tool until 320 N at a rate of 5 mm/min.

For four-part bending test, an instrument including two 450-mm parts, with two lower support points having wedge-shaped extensions and with two upper support points having sharp-shaped extensions that connected to the torsion tool, was designed so that subjects could lie on it (Fig. 4). Subjects were placed on this mechanism with a distance of 150 mm between the upper support points and 220 mm between the lower support points. Therefore, both sides were fixed with a distance of 35 mm between the upper and lower support points.[8] The contact of support points with the subjects presented the same equal plane. Four-part bending at a rate of 5 mm/min until 500 N in axial direction was applied to subjects in a mediolateral direction with the torsion tool. Therefore, loading (N) with a 500 N load and displacement (mm) curves were obtained.

Statistical analysis performed using SPSS for Windows v.11 (SPSS Inc., Chicago, IL, USA) software. The mean and (±) standard deviation values were calculated for bending and torsional measurement values. The Kruskal-Wallis variance analysis was used for intergroup comparison. Level of significance was set as $p<0.05$.

Results

Load-displacement (mm) curves were obtained from the torsion test. Displacement values below 360 N were transferred to the SPSS program and the minimum, maximum, average, and standard deviation values for the results were determined. As shown in Table 1, average displacement was 37.38 (range: 25.75 to 55.69) mm, 26.55 (range: 21.25 to 41.81) mm and 33.23 (range: 27.50 to 46.45) mm in the bridge plating, antegrade nailing and retrograde nailing groups, respectively. There was no statistically significant difference between 360 N torsional force applied to subjects and displacement values ($p=0.068$).

Load-displacement (mm) curves were obtained from the four-part bending test. Displacement values below 500 N were transferred to the SPSS program and the minimum, maximum, average, and standard deviation values were determined. As shown in Table 2, average displacement was 3.27 (range: 2.54 to 3.73) mm, 3.17 (range: 2.69 to 3.55) mm and 3.15 (range: 2.10 to 4.03)

Table 1. The minimum, maximum, average and standard deviation values for the results obtained from torsion test of the groups.

	n	Minimum	Maximum	Mean	Standard deviation	
Plate	7	25.7500	55.6875	37.376071	12.1467339	$\chi^2=5.565$ $p=0.068$
Antegrade	7	21.2500	41.8125	26.553571	7.3078180	
Retrograde	7	27.5000	46.4520	33.234214	6.5613844	

Table 2. The minimum, maximum, average and standard deviation values for the results obtained from four-part bending test of the groups.

	n	Minimum	Maximum	Mean	Standard deviation	
Plate	7	2.5400	3.7280	3.269429	0.4040585	χ^2=0.208 p=0.901
Antegrade	7	2.6880	3.5470	3.174143	0.32558443	
Retrograde	7	2.1010	4.0260	3.152143	0.7309048	

mm in the bridge plating, antegrade nailing and retrograde nailing groups, respectively. There was no statistically significant difference between the three groups in the four-part bending test (p=0.901).

Discussion

Humeral shaft fractures comprise 1 to 3% of all fractures.[1,2] The nonunion ratios of humeral shaft fractures vary between 10 and 15%.[4,8,9] In recent years, biological fixation methods have been reported to produce better results than those of rigid fixation with respect to healing for the internal fixation of long bone fractures.[9] In our study, we investigated the durability of minimally invasive internal fixation methods in humerus shaft fractures (AO classification 12B2) with medial butterfly fragment.

The primary nutrient arteries in the humerus enter from the medial border just below the middle of the shaft. A study conducted by Carroll demonstrated the existence of only one nutrient artery in 57 of 71 adult humeri.[10] Based on these anatomic findings, we created the butterfly segments away from the region in which the nutrient artery enters. Problems that occur during recovery in middle distal junction of humeral fractures may be due to injury of the nutrient artery during initial injury or surgical exposure of the butterfly fragments. Disturbing the blood supply of the butterfly fragment may impair the healing of this fragment on one or either side.[4,10]

Biomechanical testing mimicking loading of daily movement was performed to detect and compare the stability of different fixation methods. In these experiments, homogenous bone analogs that mimic human cadaver bones and their mechanical properties were used. The individual differences in bone mineral density may affect the results in tests with human cadaver bones. Lin et al. showed that the failure of the fixation in low loads was due to the bone itself in osteoporotic subjects while the failure in high loads was due to the implant in non-osteoporotic subjects.[11] In our study, the use of bone analog was found to be appropriate to ensure standardization between groups.

Experimental studies studying implant failure in the humerus have used different loadings.[12] Blum et al., evaluating the biomechanical properties of retrograde intramedullary nails in humeral shaft fractures, applied 450 N loading in the bending test and 8 Nm torque in torsional loading.[13] In our study, we applied 500 N in the four-part bending test and 9.6 Nm torque in torsional loading. As the load-to-failure measurement was beyond the scope of our study, we applied these physiological loads in order to avoid disrupting the structure of the bone implant.

Recent developments in internal fixation methods have resulted in less soft tissue damage. The purpose of biologic internal fixation is to ensure minimal soft tissue damage through indirect reduction, especially in segmental fractures.[14] In our study, the butterfly fragment was not fixed and moved off the bone-implant structure.

While first used in the treatment of subtrochanteric and distal femur fractures, minimal invasive plate fixation methods have then also been used in humerus fractures.[15-17] The application of this method is difficult in the humerus due to the location of the axillary nerve proximally and the radial nerve distally. This technique can be applied in fractures 6 cm below the deltoid insertion and above the trochlear fossa, which allows for the use of a minimum of three screws in the proximal and distal. The anterior approach has been recommended for this type of plating.[15-17] In long plates, torsional stress is distributed on the body of the plate with short fixations at both ends by bridging the fracture region.[18]

Perren[14] reported that locking plates used in minimal invasive plate osteosynthesis for external fixation protect the blood supply around the fracture site by providing minimal contact area on the bone surface. Locking plates do not have to fit the slope of the bone surface. Despite the ease of this technique, it does not allow to determine the size of necessary screws. Therefore, plates are fixed with screws holding only one cortex to keep the ends at the medullary canal. In our study, we applied fixation with screws holding only one cortex.

Livani and Belangero[15] applied bridge plating to 15 humerus shaft fractures using a minimally invasive technique. Five patients had AO Type A, seven Type B and four Type C fractures. The lower complication ratios and satisfied results showed that this approach can be used in the surgical treatment of humerus shaft fractures. The most important advantage of this technique is the stability that allows for early joint movement and minimal surgical damage. This treatment is not recommended in cases with radial nerve palsy where nerve exploration in necessary.

The humerus may be locked on both proximal and distal ends, setting an appropriate example for comparison of different screwing methods biomechanically. We used different screws from those used in the study conducted by Blum et al.[13] The most important difference in the humerus expert screw system is that distal locking screws can be locked in different directions at an angle of 22.5 degrees. This different angle allows for locking in anterolateral, anteromedial, and anteroposterior directions. Therefore, distal locking screws enables better fixation in the lateral supracondylar region.

In a randomized, prospective study, Chapman et al.[19] compared the clinical results of intramedullary nailing and plating in humeral shaft fractures. They reported no significant difference between both fixation methods with respect to recovery. Shoulder pain and stiffness were observed in patients treated with screws, while elbow pain and stiffness were observed in patients treated with plating.

In a study on humeral shaft fractures conducted by Lin et al.,[11] retrograde and antegrade nails were biomechanically compared. As a result, it was reported that nailing from the short segment to the long segment of a fracture provides a biomechanical advantage. The most important factor behind this advantage is nail-bone healing. In the same study, on osteotomy performed from 10 cm above the olecranon fossa on fracture models, there was no significant difference between nailings performed in antegrade and retrograde directions in different loadings. Fixing with a 5 cm screw at the distal fragment in antegrade nailing or at the proximal fragment in retrograde nailing provides adequate fixation. In our study, there was no significant difference between antegrade and retrograde nailing in different loadings.

Zimmerman et al.[20] biomechanically compared four different fixation methods in transverse fracture models at the middle of the humeral shaft. Torsion properties of the plated subjects were superior to those of elastic nails, and nails superior to plates. The plates used in their study had neutral properties and were fixed to the bone with six screws. We used four screws that can be fixed to the plate at both sides of the broken fragments in our study. This difference may explain the lack of significant difference between nails in the bending and torsion tests.

In the osteoporotic fracture model created by Gardner et al.[21] using locking and non-locking screws, the stability of fixation was evaluated under torsion loading. In osteoporotic unstable diaphyseal fracture models, locking plates were found to be superior to non-locking-screw fixation in torsion tests. The hybrid system created by using only one compression screw does not provide additional stability. However, compared to fully-locking systems, there is no significant difference with respect to stability. Locking screws are more expensive than non-locking screws. Torsion properties of hybrid structures show similar biomechanical properties as the locking screw-plate combination. It can be said that locking plates with a hybrid combination of locking and non-locking screws can be used in the fracture treatment of patients with low bone quality. In our study, the determination of similar displacement values between plates fixed with knocked screws and locking intramedullary nails in torsion loadings may be due to the use of locking screws in plates.

In their biomechanical study, Chen et al.[22] compared axial loading of plating and intramedullary screwing methods in the fixation of 1.5-cm defects created in humeral shafts. There was no significant difference between both fixation methods in physiological loadings. Bone implant structure deteriorated at a much higher value in the group with intramedullary screws. It was reported that this may create an advantage in multiple trauma patients requiring partial loading after operation.

In our study, we performed torsion and mediolateral four-part bending tests to mimic the frequent exposure to this two-directional force of the humerus in daily living. Different biomechanical studies have discussed different loading properties.[8,12,16,23] By applying both bending and torsion tests to different fixation methods, we were able to study the formation of natural humerus loading and determine appropriate fixation methods.

In conclusion, there is no significant biomechanical difference between intramedullary nailing and plating methods for the fixation of 12B2 humerus shaft fractures. The surgeon's experience, patient's general condition, and fracture type will determine the method to be used.

Conflicts of Interest: No conflicts declared.

References

1. Ekholm R, Adami J, Tidermark J, Hansson K, Törnkvist H, Ponzer S. Fractures of the shaft of the humerus. An epidemiological study of 401 fractures. J Bone Joint Surg Br 2006;88:1469-73.
2. Tytherleigh-Strong G, Walls N, McQueen MM. The epidemiology of humeral shaft fractures. J Bone Joint Surg Br 1998;80:249-53.

3. Castellá FB, Garcia FB, Berry EM, Perelló EB, Sánchez-Alepuz E, Gabarda R. Nonunion of the humeral shaft: long lateral butterfly fracture – a nonunion predictive pattern? Clin Orthop Relat Res 2004;(424):227-30.
4. Jupiter JB, von Deck M. Ununited humeral diaphyses. J Shoulder Elbow Surg 1998;7:644-53.
5. Klenerman L. Fractures of the shaft of the humerus. J Bone Joint Surg Br 1966;48:105-11.
6. Modabber MR, Jupiter JB. Operative management of diaphyseal fractures of the humerus. Plate versus nail. Clin Orthop Relat Res 1998;(347):93-104.
7. Zagorski JB, Latta LL, Zych GA, Finnieston AR. Diaphyseal fractures of the humerus. Treatment with prefabricated braces. J Bone Joint Surg Am 1988;70:607-10.
8. Blum J, Karagül G, Sternstein W, Rommens PM. Bending and torsional stiffness in cadaver humeri fixed with a self-locking expandable or interlocking nail system: a mechanical study. J Orthop Trauma 2005;19:535-42.
9. Corley FG, Williams GR, Pearce JC, Rockwood CA Jr. The management of nonunions of the humerus. Instr Course Lect 1990;39:277-88.
10. Carroll SE. A study of the nutrient foramina of the humeral diaphysis. J Bone Joint Surg Br 1963;45-B:176-81.
11. Lin J, Inoue N, Valdevit A, Hang YS, Hou SM, Chao EY. Biomechanical comparison of antegrade and retrograde nailing of humeral shaft fracture. Clin Orthop Relat Res 1998;(351):203-13.
12. Ulian V, Mazzer N, Barbieri CH, Moro CA. Primary stabilization of humeral shaft fractures: an experimental study of different osteosynthesis methods. Acta Ortop Bras 2008;16:8-12.
13. Blum J, Machemer H, Baumgart F, Schlegel U, Wahl D, Rommens PM. Biomechanical comparison of bending and torsional properties in retrograde intramedullary nailing of humeral shaft fractures. J Orthop Trauma 1999;13:344-50.
14. Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. J Bone Joint Surg Br 2002;84:1093-110.
15. Livani B, Belangero WD. Bridging plate osteosynthesis of humeral shaft fractures. Injury 2004;35:587-95.
16. O'Toole RV, Andersen RC, Vesnovsky O, Alexander M, Topoleski LD, Nascone JW, et al. Are locking screws advantageous with plate fixation of humeral shaft fractures? A biomechanical analysis of synthetic and cadaveric bone. J Orthop Trauma 2008;22:709-15.
17. Zhiquan A, Bingfang Z, Yeming W, Chi Z, Peiyan H. Minimally invasive plating osteosynthesis (MIPO) of middle and distal third humeral shaft fractures. J Orthop Trauma 2007;21:628-33.
18. Apivatthakakul T, Arpornchayanon O, Bavornratanavech S. Minimally invasive plate osteosynthesis (MIPO) of the humeral shaft fracture. Is it possible? A cadaveric study and preliminary report. Injury 2005;36:530-8.
19. Chapman JR, Henley MB, Agel J, Benca PJ. Randomized prospective study of humeral shaft fracture fixation: intramedullary nails versus plates. J Orthop Trauma 2000;14:162-6.
20. Zimmerman MC, Waite AM, Deehan M, Tovey J, Oppenheim W. A biomechanical analysis of four humeral fracture fixation systems. J Orthop Trauma 1994;8:233-9.
21. Gardner MJ, Griffith MH, Demetrakopoulos D, Brophy RH, Grose A, Helfet DL, et al. Hybrid locked plating of osteoporotic fractures of the humerus. J Bone Joint Surg Am 2006;88:1962-7.
22. Chen AL, Joseph TN, Wolinksy PR, Tejwani NC, Kummer FJ, Egol KA, et al. Fixation stability of comminuted humeral shaft fractures: locked intramedullary nailing versus plate fixation. J Trauma 2002;53:733-7.
23. Maher SA, Meyers K, Borens O, Suk M, Grose A, Wright TM. Biomechanical evaluation of an expandable nail for the fixation of midshaft fractures. J Trauma 2007;63:103-7.