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ORIGINAL ARTICLE

The evaluation of a *de novo* biplanar distal humerus plate: A biomechanical study

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ABSTRACT

Objectives: The aim of this study was to compare the stability of a novel biplanar distal humerus plate with the single- and double-columns J-plating techniques.

Materials and methods: Eighteen sawbones humera were divided into three groups. In Groups 1, 2 and 3, biplanar plate, single lateral J-plate and double J-plate, were used, respectively. Transverse osteotomies at the upper portion of the olecranon fossa were made. Blocks of 10-mm was removed from each sample. Axial, torsional, and extensional stiffness of each group were measured.

Results: The mean axial stiffness values in Groups 1, 2, and 3 were 64.80±6.75, 33.70±5.71, and 171.48±9.53 N/mm, respectively. Group 1 demonstrated a statistically significant difference compared to Group 2 (p=0.032), whereas Group 3 showed a statistically significant difference compared to Groups 1 and 2 (p=0.025 and p=0.014, respectively). The mean torsional stiffness values of Groups 1, 2, and 3 were 0.23±0.01, 0.14±0.008, and 0.30±0.007 N/degree, respectively. Groups 1 and 3 demonstrated a statistically significant difference compared to Group 2 (p=0.042 and p=0.028, respectively). No statistically significant difference was detected between Groups 1 and 3 (p=0.27). The mean extensional bending stiffness values of Groups 1, 2 and 3 were 2.64±0.31, 1.17±0.13, and 3.2±0.1 N/mm, respectively. Group 1 demonstrated a statistically significant difference compared to Group 2 (p=0.041). There was no statistically significant difference between Groups 1 and 3 (p=0.083).

Conclusion: Biplanar plate allows applying enough numbers of long sagittal screws and offers more biomechanical stability than lateral column J-plate and in some aspects strong as dual J-plating in torsional and bending tests.

Keywords: Biomechanical study, biplanar plate, extraarticular distal humerus fractures, stability.

Distal humerus shaft fractures are accepted to be challenging in nature and relatively carry a high complication rate regarding union and elbow contracture. Therefore, open reduction and stable internal fixation is considered the gold-standard treatment of choice to allow early mobilization, thereby avoiding the unforgiving elbow joint contracture.[1,2] Several biomechanical studies have been conducted to assess the most stable and secure fixation method of distal extraarticular humerus fracture which may allow early mobilization and decreases the relatively high rate of complications including nonunion, elbow joint contracture, and implant failure.[3-5] Stable plating system selection is considered difficult due to the unique osseous morphology, neurovascular anatomy and the complex muscle trajectory working upon the distal humerus and elbow joint. Therefore, single plate has been considered suitable for some fracture patterns, whereas other types of fractures may require two or more plates to obtain stable and secure fixation.[6]

The specifically designed anatomical J-plate was used for extraarticular distal humerus fractures. This plate is pre-contoured 3.5-mm limited contact

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dynamic compression plate (LC-DCP), allows an increased number of screw fixation at the distal fragment compared to the standard straight 3.5-mm plate.[7] Despite of the common use of a single-column fixation of extraarticular distal one-third humerus fractures particularly AO Foundation and. Orthopaedic Trauma Association (AO/OTA) type A2 and A3 fracture patterns, the limits and absolute indications are still not well defined.[7,8] For more stability, the AO group recommends the use of double plating technique, particularly in AO/OTA type A3 fractures. However, dual platting increases the stability at the purchase of more soft tissue stripping around the fracture site.[9,10]

In the present study, we aimed to biomechanically assess the stability and stiffness of a novel biplanar posterolateral anatomical distal humerus plate and compare it with the conventional single-column J-plate and double anatomical J-plate fixation techniques.

MATERIALS AND METHODS

Specimens

Eighteen right with an accurate anatomical morphology and identical geometry, adult-sized humera (Composite humerus Sawbones 4th generation, Malmö, Sweden), were used to accomplish this biomechanical study. Artificial humera were used to unify the mechanical properties and bone geometry to assure standardization of cortical bone strength for biomechanical testing. Humera specimens were divided into three groups with six samples in each group. In Group 1, biplanar (posterolateral) plate was used, in Group 2, a single lateral anatomical J-plate was used, and in Group 3, double (medial and lateral) anatomical J-plate was used. A transverse osteotomy was performed in all bone samples at the same level, just at the level of the upper portion of the olecranon fossa with a surgical reciprocating saw. Bone block of 10-mm was removed from each bone sample as described by different studies.[3,11]

Implants application and configuration

Three-plate configurations were used, the biplanar posterolateral plate, anatomical J-plate and double anatomical J-plate.

Biplanar (posterolateral locking) plate is a plate designed to offer fixation in different plans, the lateral and the posterior plans. It is a fixed angle titanium locking plate (TIPSAN Tıbbi Aletler, Izmir, Türkiye) which can be used for a definitive fracture fixation of extraarticular distal humerus fractures, particularly AO/OTA type A2 and A3 fracture types (Figure 1). This plate is composed of three parts, the proximal part which settles directly upon the posterior surface of the distal humerus and it is composed of a locking plate with holes suitable for locking 3.5-mm screw fixation. Whereas the distal anatomical part settles directly on the lateral aspect of the humerus with three holes suitable for locking 3.5-mm screw fixation and another two non-locking holes on the proximal distal connecting angle to provide multidirectional fixation. Three locking 3.5-mm bicortical screws were placed bicortically at the proximal part of the plate and another three locking screws were placed bicortically at the distal plate segment at the condylar area of the distal humerus, whereas the two screw holes at the connecting angle were kept empty (Figure 2). The second group humera were fixed with a lateral 6-hole J-plate, whereas the third group humera were fixed with a double (medial and lateral) 6-hole J-plate (TIPSAN Tıbbi Aletler, Izmir, Türkiye) (Figure 3a, b). Using the same standard surgical technique for plating, specimens were plated by a single orthopedic surgeon. Three bicortical locking 3.5-mm screws were proximally and three locking 3.5-mm screws were distally fixed in all samples. The study was conducted at Dokuz Eylul University, Faculty of Medicine, Department of biomechanics. Biomechanical tests were accomplished using the

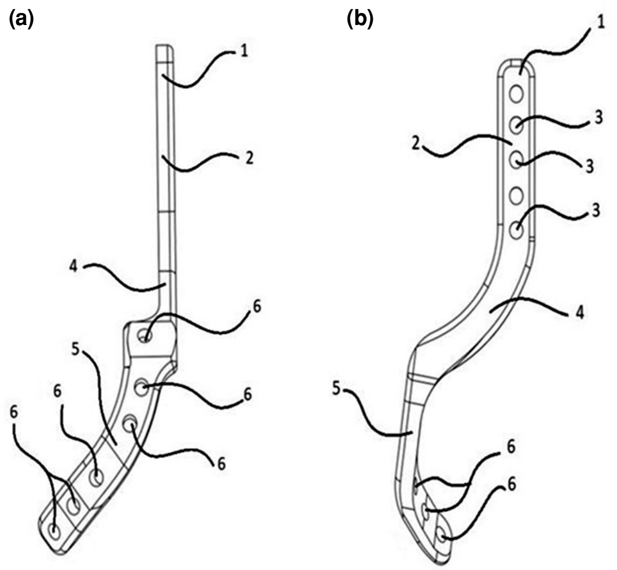

FIGURE 1. The biplanar (posterolateral) plate, **(a)** lateral, **(b)** anterior views. 1; the posterior portion of the plate. 2; 3.5-mm locking DCP design of the posterior plate portion. 3; Holes suitable for 3.5-mm locking screws. 4; the connecting fixed angle. 5; the lateral portion of the plate. 6; Screw holes suitable for 3.5-mm locking screws of the lateral plate portion.
DCP: Dynamic compression plate.

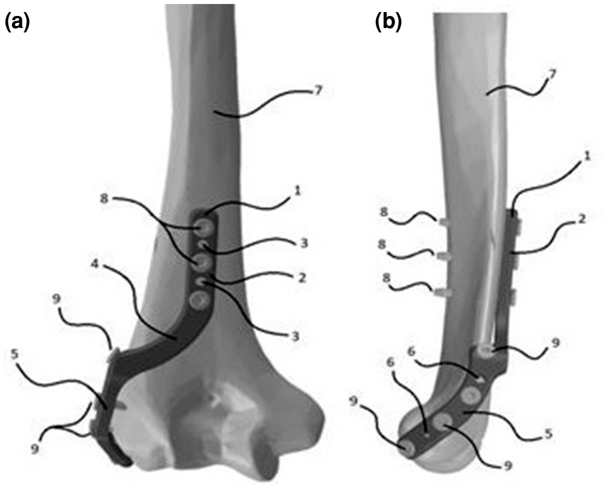

FIGURE 2. (a, b) Anterior and lateral views of the biplanar plate humerus construct. 1; Biplanar plate posterior portion. 2; 3.5 locking DCP design of the posterior plate portion. 3; Holes suitable for 3.5-mm locking screws. 4; The fixed connecting plate angle. 5; The lateral portion of the plate. 6; 3.5-mm locking DCP design of the lateral plate portion. 7; Distal diaphysis of humerus. 8,9; 3.5-mm locking screws.
DCP: Dynamic compression plate.

test machine (AG-IS 10 kN, Shimadzu, Kyoto, Japan). The distal humerus in all samples was fixed through a special anatomical apparatus to fit the distal morphology the condylar area, whereas the proximal area was fixed to the load cell of the test machine. In all trials, the gap changes in torsional forces, axial forces and bending angles were recorded both in unloaded and loaded conditions.

Under the axial load, the whole plate-bone model was tested. Applying 250 N for 5000 cycles at 3 Hz, the gap strain and displacement were recorded.[12]

Using the servo sync torque machine (SQM132, 245 Nm 100 rpm, ELSIM Elektroteknik A.S, Istanbul, Türkiye), the torsion tests were conducted by using a maximum moment in both directions of 4.5 Nm with the displacement control mode. The velocity of the test was 0.3°/sec, where the premoment was 0 Nm. The testing cycles were applied from 0 to 4.5 Nm. The degree of angle deformation versus torque values was recorded.[13,14]

A three-point bending model was designed to assess the distribution of the load encountered by the distal humerus on sagittal plane and extensional stability.[15] In each test, a maximum load of 250 N at 10-mm/min was applied. Displacement versus load values was recorded. To ensure the test accuracy, bending and torsion tests were repeated three times for each specimen.

The mean load displacement of axial, torsional and bending stiffness of the three bone plate configurations are demonstrated in Figure 4.

Statistical analysis

Statistical analysis was performed using the SPSS version 15.0 software (SPSS Inc., Chicago, IL, USA). Descriptive data were expressed in mean ± standard deviation (SD). The Mann-Whitney U test was used to compare between the results of the applied forces. A p value of <0.05 was considered statistically significant.

RESULTS

The mean stiffness values of the three groups are demonstrated in (Table I). The mean axial stiffness values in Groups 1, 2, and 3 were 64.80±6.75, 33.70±5.71, 171.48±9.53 N/mm, respectively

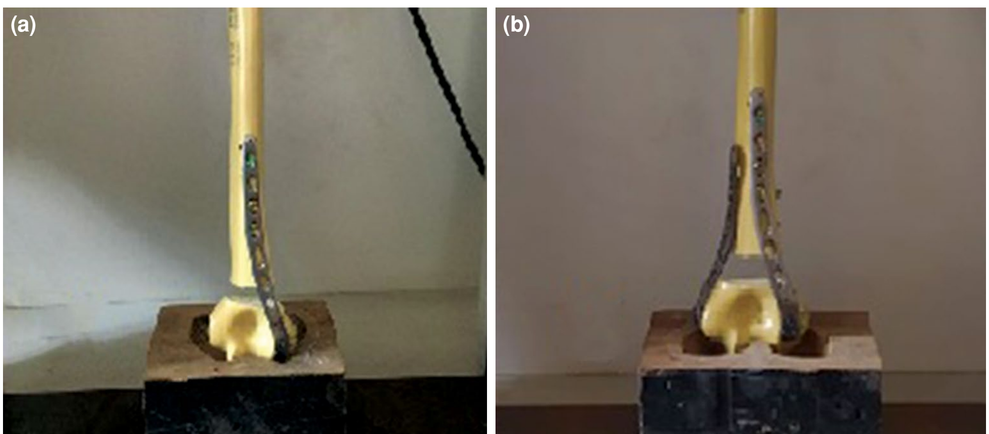

FIGURE 3. (a) Lateral column fixation with a single J-plate. **(b)** Dual column fixation with a double J-plate.

TABLE I
The mean stiffness values of the three groups involved in the study

	Mean axial stiffness (N/mm)	Mean torsional stiffness (N/degree)	Mean bending stiffness (N/mm)
Groups	Mean±SD	Mean±SD	Mean±SD
Group 1	64.80±6.75	0.23±0.01	2.64±0.31
Group 2	33.70±5.71	0.14±0.008	1.83±0.16
Group 3	171.48±9.53	0.30±0.007	3.17±0.13

SD: Standard deviation.

(Figure 5a). Group 1 demonstrated a statistically significant difference compared to Group 2 (p=0.032). However, Group 3 showed a statistically significant difference compared to Group 1 and Group 2 (p=0.025 and p=0.014, respectively).

The mean torsional stiffness values of Groups 1, 2, and 3 were 0.23±0.01, 0.14±0.008, and 0.30±0.007 N/degree, respectively (Figure 5b). Groups 1 and 3 demonstrated statistically significant values compared to Group 2 (p=0.042 and p=0.028, respectively). However, there was no statistically significant difference between Group 1 and Group 3 (p=0.27).

The mean extensional bending stiffness values of Groups 1, 2, and 3 were 2.64±0.31, 1.83±0.16, and 3.17±0.13 N/mm, respectively (Figure 5c). Group 1 demonstrated a statistically significant difference compared to Group 2 (p=0.041), while there was no statistically significant difference between Group 1 and Group 3 (p=0.083).

DISCUSSION

Open reduction and stable internal fixation of distal humerus fractures allow early extremity motion and reduce the risk of elbow joint contracture. Unilateral column fixation requires less aggressive soft tissue dissection. Although both medial and lateral column fixation techniques provide more mechanical stability, it provides more tissue disruption and thus delays the opportunity of early bone healing.[6,7]

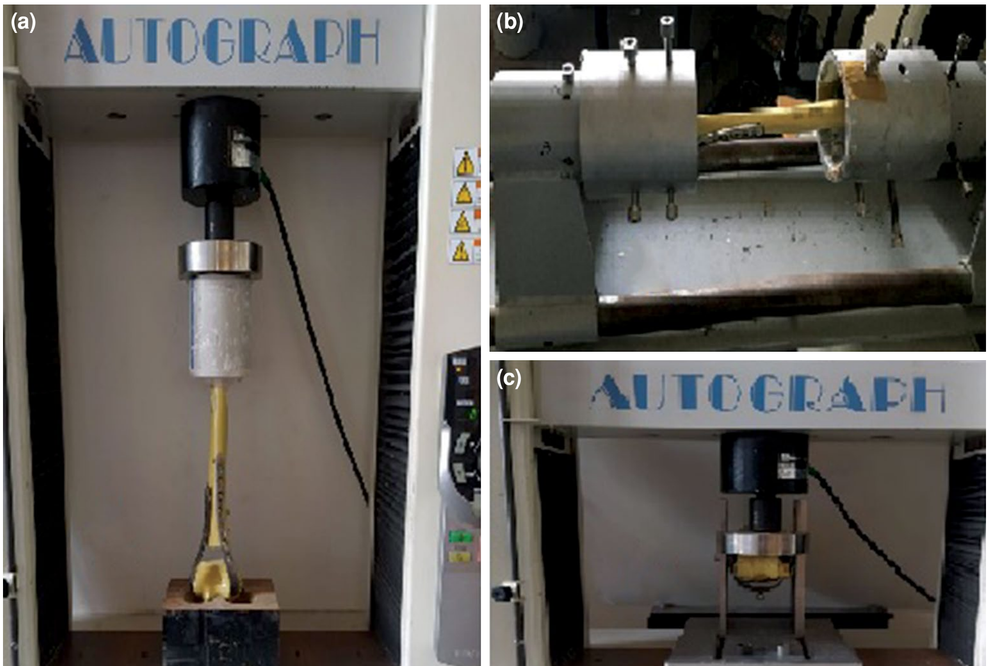

FIGURE 4. The set-up of the trial, prepared to assess the load displacement measures of axial, torsional and bending stiffness of the three plate-bone constructs.

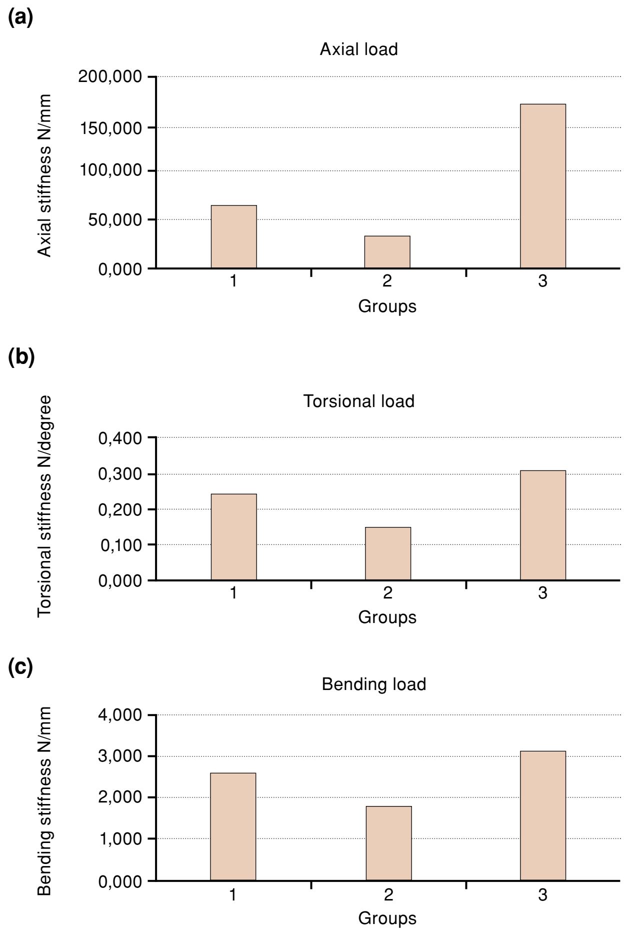

FIGURE 5. (a-c) The mean load displacement Bar Graphs of the three groups involved in the study.

Dual column fixation has been traditionally the standard surgical method of reconstruction for extraarticular distal humerus fractures, particularly the most unstable type AO/OTA type A3, to provide a secure fixation of the distal short humerus segment to achieve stable fixation, thereby promoting early mobilization and union.[16,17]

Several plating designs have been biomechanically studied and compared in the literature. Self and Ilyas[18] demonstrated that 90°/90° plate construction design failure occurred due to screws pull-out at the distal aspect of the lateral column. They also showed that sagittal plan platting produced more stiffness than the 90°/90° plating method. They concluded that posterior platting of the distal lateral column of the humerus might result in screw pull-out due to the smaller anteroposterior diameter of the humerus in contrast to the sagittal plane which allows longer screw accommodation. Additionally, Kimball et al.[19] demonstrated that the majority of blood supply of the lateral column of distal humerus were derived from the posterior vessels. Placing the plate on the sagittal plane lowers the risk of injury to these structures and thus increases the chance of union. O'Driscoll[20] described that, to achieve a maximum stability between the distal fragment and the shaft of the humerus, every screw in the distal fragment should be as long as possible.

The reported high incidence of implant related complications such as infection and ulnar nerve neuritis, which may occur as high as 51%, discourages many surgeons to use the dual-column plating technique.[21,22] Although transposition of the ulnar nerve has been recommended by many studies, 10% of ulnar nerve neuritis has been reported despite of the nerve transposition.[22] Avoiding exposure and plating of the medial column may presumably results in decreasing implant related complications after surgery of distal humerus fractures. Many researchers have examined the efficacy of single-column plating using different plate designs. An intraoperatively contoured 4.5-mm plate was designed to fix the distal short segment and obtained good results. However, traditional 4.5-mm plates do not allow appropriate number of screw fixation in the distal short fragment and increases the risk of olecranon fossa impingement.[7,23]

The anatomically designed pre-contoured 3.5-mm LC-DCP extraarticular distal humerus plate, which is also known as the J-plate, was designed specifically to fit the posterolateral anatomy of the distal humerus and allows more screw fixation of the short distal humerus segment.[24] Scolaro et al.[25] investigated the use of variant plate designs to assess fracture design stability. They used a single-column 3.5-mm LCP (proximal straight), 3.5-mm LCP extraarticular distal humerus plate (proximal J), 3.5-mm medial and lateral distal humerus locking plates (distal dual), and a 6-hole J-plate (distal J). They concluded that the J-plate provided more stable fixation than the standard 3.5-mm plate and advised using dual column fixation, when the fracture was very distal.

The present study introduces a biplanar posterolateral plate, which fits the anatomical morphology of the distal humeral shaft on its proximal part, whereas its distal part fits the anatomical morphology of the lateral aspect of the condylar area and allows the insertion of long and sufficient number of 3.5-mm screws. This plate is pre-contoured to fit the anatomy of the posterolateral distal humerus to allow providing longer screw fixation in the sagittal plane and allows an increased number of distal segment fixation points compared to the standard straight 3.5-mm plates. Since it was difficult to create a unified AO/OTA type A3 fracture pattern in sawbones samples, a unified supracondylar extraarticular distal humerus fracture was simulated in this biomechanical study to compare the newly designed pre-contoured biplanar plate with the J-plate in conventional single-column and dual column fixation.

Biplanar plate demonstrated a statistically significant difference in the biomechanically applied three, axial, torsional, and extensional bending forces compared to the single-column fixation with J-plate. Although dual-column fixation with J-plate demonstrated superior results in the axial testing, both biplanar and dual-column fixation with J-plate demonstrated statistically non-significant results in the torsional and bending forces. The biplanar plate showed superior results than the lateral column J-plate fixation in all loading tests. Therefore, for more stability purpose, it can be a good substitute to a single-column J-plate fixation and for surgeons whom do not prefer medial column stabilization in extraarticular distal humerus fractures.

Nonetheless, this study has some limitations. Biomechanical testing was performed on sawbones and not on true cadaveric humerus models. Therefore, testing did not take into consideration the muscle attachment which may seriously affect fracture stability in different ways. Further studies should be conducted on true cadaveric humerus models to assess the newly described implant performance.

In conclusion, despite of the encountered limitations during this study, biplanar posterolateral plate is a biomechanically stable and reasonable plating system for distal supracondylar humerus fractures, particularly the unstable AO/OTA type A3. It allows applying enough numbers of long sagittal screws in the condylar area and offers more biomechanical stability than the lateral column J-plate in all loading tests and in some aspects strong as dual J-plating in the torsional and bending loading tests.

Ethics Committee Approval: No ethical committee approval since it is a biomechanical study done on saw bone.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Main concept, plate design, biomechanical trial, literature review, article writting: N.A.; Plate design, biomechanical trial: A.K.; Biomechanical trial, literature review: O.G.; Biomechanical trial, plate design, statistical analysis: R.B.H.

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