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Biomechanical comparison of orthogonal versus parallel double plating systems in intraarticular distal humerus fractures

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ABSTRACT

Objectives: In intraarticular distal humerus fractures, internal fixation with double plates is the gold standard treatment. However the optimal plate configuration is not clear in the literature. The aim of this study was to compare the biomechanical stability of the parallel and the orthogonal anatomical locking plating systems in intraarticular distal humerus fractures in artificial humerus models.
Methods: Intraarticular distal humerus fracture (AO13-C2) with 5 mm metaphyseal defect was created in sixteen artificial humeral models. Models were fixed with either orthogonal or parallel plating systems with locking screws (Acumed elbow plating systems). Both systems were tested for their stiffness with loads in axial compression, varus, valgus, anterior and posterior bending. Then plastic deformation after cyclic loading in posterior bending and load to failure in posterior bending were tested. The failure mechanisms of all the samples were observed.
Results: Stiffness values in every direction were not significantly different among the orthogonal and the parallel plating groups. There was no statistical difference between the two groups in plastic deformation values (0.31 mm–0.29 mm) and load to failure tests in posterior bending (372.4 N–379.7 N). In the orthogonal plating system most of the failures occurred due to the proximal shaft fracture, whereas in the parallel plating system failure occurred due to the shift of the most distal screw in proximal fragment.
Conclusion: Our study showed that both plating systems had similar biomechanical stabilities when anatomic plates with distal locking screws were used in intraarticular distal humerus fractures in artificial humerus models.

Introduction

Distal humerus fractures are relatively uncommon and comprise approximately 2% of all fractures.[1] Double plate osteosynthesis is accepted as the gold standard treatment of distal humerus fractures in the literature.[2–6] However, the optimal plate configuration remains controversial. Multiple biomechanical studies have compared these plating systems; however, a consensus has not been reached regarding which plating system is optimal.[7–16] Earlier biomechanical studies suggested to use orthogonal plating system in distal humerus fractures,[7] whereas more recent studies showed that the parallel plating system provided greater stability.[11–17] Comparing these studies is not possible because of many study differences, including test protocols, plate designs, screw types and count, and cadaver or sawbone usage. Most of the studies in the literature, parallel plates and orthogonal plates had different alloy.[11–18] Generally nonlocking plates were used as posterolateral plate and the fixation of the distal fragment could be inadequate with these plates if the fragment is small because of the lack of the screw holes in distal fragment. In the

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recent studies anatomic locking plates were compared however, all of the screw holes in distal fragment were not filled with screws and maximum stability could not be achieved.[12–19]

The purpose of the present study was to compare the similar anatomic locking plating system configurations maximum stabilities in distal humerus fractures biomechanically. We hypothesized that the orthogonal locking plating system provided as much stability as the parallel plating system.

Materials and methods

Specimens

The AO type 13-C2 fracture model was created in sixteen identical artificial humerus models[20] (3rd-generation sawbone, Sawbones, Malmö, Sweden). The bones were divided into two groups (8 per group), the parallel plating and the orthogonal plating group. Using a saw, a transverse osteotomy was made from the top of the olecranon fossa, leaving a 5-mm gap proximal to the osteotomy site to simulate the metaphyseal comminution.[10–19] This gap prevented bone contact at the osteotomy site during all of the biomechanical tests.

Preparation

In the parallel plating group, we first performed the medial part of the transverse osteotomy using a custom-made cutting guide. Then, we fixed the medial plate and completed the transverse osteotomy. After placement of the lateral plate, we pulled back the distal screws partially and performed the intercondylar osteotomy just in the middle of the trochlea using a 0.5-mm saw. Next, anatomic reduction was performed with a reduction clamp, and the distal screws were tightened again. In the orthogonal plating group, the lateral part of the transverse osteotomy was performed first, and the posterolateral plate was fixed. The remainder of the osteotomy and fixation procedure was performed as in the parallel plating group.

Plate configurations

Medial and lateral plates were used in the parallel group and medial-posterolateral plates were used in the orthogonal group. The Acumed elbow plating system (Acumed, Hillsboro, OR, USA) was used for all of the plates. In both groups, an 8-hole medial plate (88 mm) was used. A 10-hole lateral plate (100 mm) was used in the parallel group, and a 5-hole posterolateral plate (78 mm) was used in the orthogonal group. The medial and lateral plates were 11 mm wide and 2 mm at the thickest point. The posterolateral plate was 10.7 mm wide and 4.7 mm at the thickest point. All of the plates were titanium.

Only the medial plate was slightly bent using plate benders to adapt it to the medial cortex. Four 3.5-mm locking screws and two 3.5-mm cortical screws were used for the proximal fixation in each group. All of the proximal screws were bicortical. The distal fixation was accomplished using three 3-mm locking screws for the medial plate and four 2.7-mm locking screws for the posterolateral plate in the orthogonal group. Three 3-mm locking screws were used for the distal fixation of each plate in the parallel group. All of the distal screws were unicortical. Three screws in the orthogonal group and six screws in the parallel group passed the intercondylar osteotomy, and none of the screws passed the transverse osteotomy (Fig. 1).

Acumed's Tap-Loc system was used for the distal fixation of the medial and lateral plates. In this system, the distal locking screws may be angled up to 20° in each direction, thereby allowing surgeons to use the longer screws in distal fixation and to maximize the stability of the distal fragment. Plate positions, screw lengths and locations were determined in pilot preparations with X-rays then identical screw types and lengths were used in each sample. A targeted drill guide was used to standardize the direction of the distal screws. All of the samples were prepared by the same orthopedic surgeon.

Potting

All samples were cut 17 cm above the joint surface. The proximal 5 cm of the samples was potted into a plastic cup filled with polyester cement (DYO Chemical Inc., Izmir, Turkey) (Fig. 2). All samples were tested with an electrodynamic testing machine (MTS Acumen™ Electrodynamic Test Systems, Eden Prairie, MN, USA). The samples were fixed with a clamping device to apply force. To prevent the application of force to only one point, a custom ulnohumeral interface was made using polyester cement (Fig. 3).

Biomechanical testing

Stiffness tests were first performed in the axial, coronal (varus–valgus) and sagittal planes (anterior–posterior). Then, cyclic loading and load to failure tests were performed under posterior

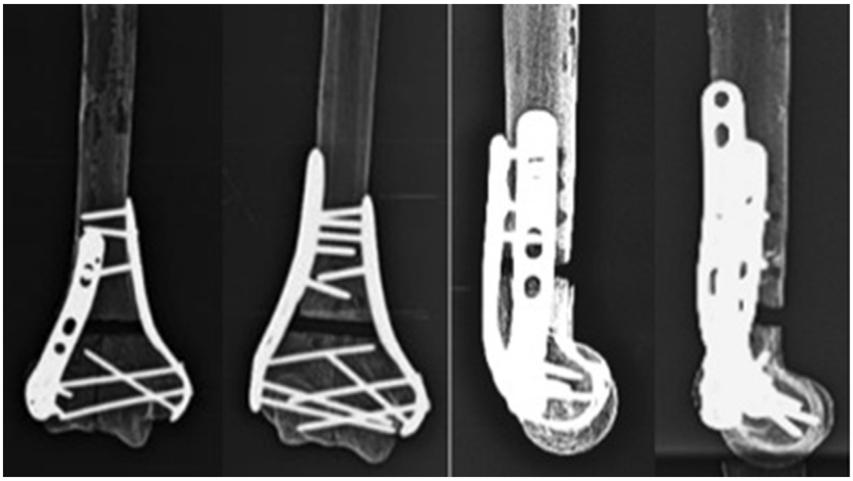

Fig. 1. Anteroposterior and lateral radiographs of the orthogonal and parallel plating samples.

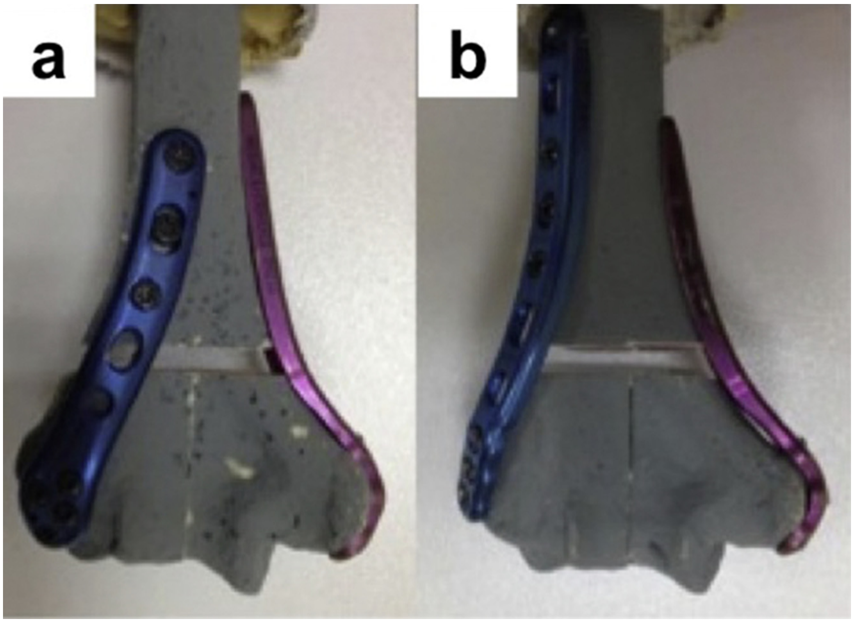

Fig. 2. Photographs of the a- Orthogonal b- Parallel plating samples in posterior view.

bending forces. Before the start of testing, destructive tests under axial and posterior bending forces were performed on two samples from each group to determine the loading forces. We calculated the loading force that would not cause plastic deformation during the stiffness tests from load–displacement curves.

For axial stiffness, 100 N was applied; 50 N was applied for the other stiffness tests. Stiffness was calculated from the slope of the linear part of the load–displacement curve. Cyclic tests in posterior bending were performed after the stiffness tests. Sinusoidal loading between 6 and 60 N was applied at 3 Hz for 4000 cycles in the cyclic loading test. 4000 cycles estimates approximately three months of elbow rehabilitation.[5–21] Screw loosening or implant failure was observed during the cyclic loading tests. The difference between the deformation in the first cycle and the maximum deformation during 4000 cycles was used to quantify plastic deformation.[11] After the cyclic loading test, the load to failure test in posterior bending forces was performed. Bone fracture, plate breakage, observable loss of reduction and screw pullout were considered as failures. During the cyclic loading and load to failure tests, a support which did not contact any plate, was placed proximal to the osteotomy gap as in the literature to increase the effect of the applied force in the fracture gap[12] (Fig. 3).

Statistical analysis

SPSS 18.0 was used for the statistical analysis. The Shapiro–Wilk test demonstrated that the groups did not follow a normal distribution. Therefore, a non-parametric test, the Mann–Whitney U test, was used to test for significant differences between the two plating groups. Significance was considered at $p < 0.05$.

Results

Stiffness values in every direction were not significantly different between the orthogonal and the parallel plating groups (Table 1). All of the samples were observed carefully during and

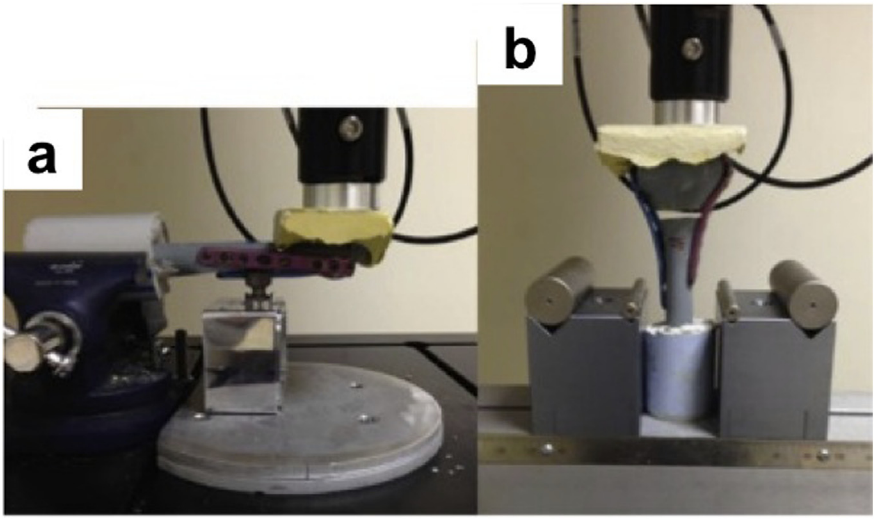

Fig. 3. a- Photograph of the cyclic loading test procedure in posterior bending b- Photograph of the cyclic loading test procedure in axial loading.

Table 1
Mean stiffness values (Newton/meter) of the groups (Standard deviations).

Group	Axial compression	Varus	Valgus	Anterior bending	Posterior bending
Parallel plating	2455.8 (1073.8)	321.6 (68.1)	393.2 (36.0)	545.5 (198.7)	473.5 (94.0)
Orthogonal plating	2203.6 (831.6)	365.0 (59.3)	385.7 (44.8)	516.5 (253.5)	627.4 (487.7)
P values	0.441	0.328	0.959	0.878	0.573

Table 2
Mean plastic deformation and load to failure values of the groups.

Results	Parallel plating	Orthogonal plating	P values
Mean plastic deformation (mm)	0.29 (0.04)	0.31 (0.04)	0.371
Mean load to failure (Newton)	379.7 (35.7)	372.4 (26.5)	0.720

after the cyclic loading test. No screw loosening or implant failure occurred during the cyclic loading test. The mean plastic deformation was 0.29 mm ± 0.04 in the parallel group and 0.31 mm ± 0.04 in the orthogonal group. No significant difference was observed between the two groups (p: 0.371) (Table 2).

The mean load to failure was 379.7 N ± 35.7 in the parallel group and 372.4 N ± 26.5 in the orthogonal group. Load to failure values were not significantly different between the two groups ($p = 0.720$) (Table 2). The failure mechanisms of all the samples were observed. In the orthogonal plating group, humerus fracture occurred at the level of the most proximal screw in five samples, and screw pullout occurred in the most distal screw in the proximal fragment due to a crack in the posterior cortex of the humerus in three samples. In the parallel plating group, 6 of the samples failed because of screw pullout in the most distal screw in the proximal fragment due to a crack in the posterior cortex. Proximal humerus fracture occurred in only two samples (Fig. 4).

Discussion

Open reduction and internal fixation with double plating is the gold standard treatment for distal humerus fractures.[2–5] Controversy between lateral column plate placement methods, direct lateral or posterolateral continues. The AO (Association for the Study of Internal Fixation) group recommended orthogonal plating in distal humerus fractures,[2,3] whereas O'Driscoll et al. recommended osteosynthesis with parallel plates.[4–22] The latter noted that orthogonal plating could not resist varus loads and sustain compression between the shaft and the metaphysis. O'Driscoll maintained that compression at the supracondylar region could be achieved with the parallel plating system. In this system, the medial and lateral columns are linked with interdigitation of the distal screws, similar to the keystone of an arch.[4] However, achieving this structure is not possible in all fractures, particularly in fractures with posterolateral bone defects. The placement of the lateral plate may be difficult because of the muscles and ligaments that adhere to the lateral column. Posterolateral plate placement is much easier. Furthermore, implant removal due to skin irritation occurs far more frequently with lateral plates.[23]

We evaluated the recent studies that compared the stability of both systems biomechanically. Although Helfett did not compare the two plating systems, he suggested that two plate construct at right angles were biomechanically optimal in distal humerus fractures.[2] In 1997 Jacobson stated that the medial plate combined with the posterolateral plate provided the greatest sagittal plane stiffness, in addition to comparable frontal plane and torsional stiffness and he recommended its use in the treatment of fractures of the distal humerus.[7]

However, most of the recent studies have shown the superiority of the parallel plating system,[8–17] and a few studies have demonstrated that both systems have similar biomechanical properties.[13–21] Notwithstanding, a comparison of these studies is not possible because of the differences among the implant types, fracture patterns, mechanical tests, screw types and numbers in these studies. In most of the studies that showed the superiority of parallel plating systems, 3.5-mm non-locking plates were used for posterolateral plating. Achieving adequate fixation of the distal fragment with these plates can be difficult, and number of screws

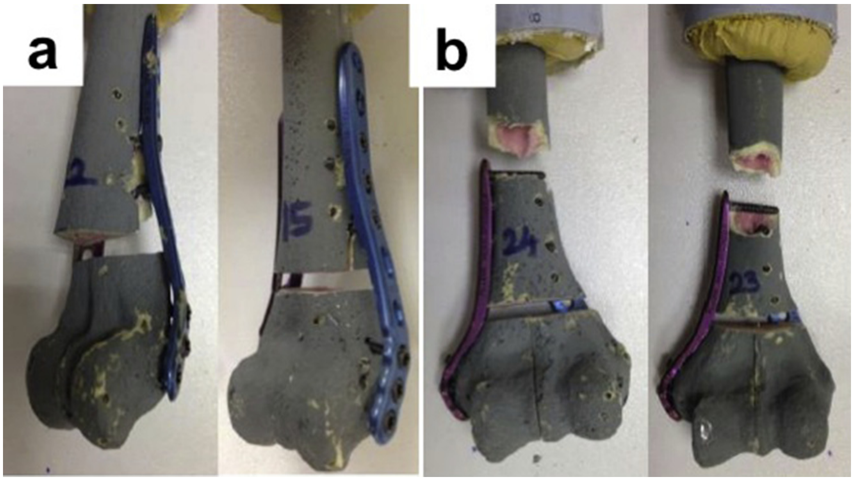

Fig. 4. a- Most common fialure modes of the parallel plating samples b- Most common failure modes of the orthogonal plating samples.

that can be applied to the distal fragment is limited. With newer precontoured locking plates, it is possible to fix the distal fragment with four 2.7-mm locking screws. The purpose of this study was to compare the biomechanical stability of precontoured locking orthogonal and parallel plating systems.

Three published studies have compared the parallel and orthogonal plating systems with anatomical locking plates. The first of these studies was that of Stoffel et al. in 2008.[11] In cadaveric bones, they found that the stiffness values in axial compression and external rotation were significantly higher in the parallel plating group, with no difference in internal rotation stiffness. In axial compression cyclic loading tests, the plastic deformation values were lower in the parallel plating group, with no difference in load to failure tests in internal rotation. The orthogonal plating group was stated to be more dependent on bone mineral density. They reported that both plating systems might be used for distal humerus fracture fixation; however, in comminuted distal humerus fractures in osteoporotic bone, the authors suggested the use of the parallel plating system. One of the negative aspects of this study was the difference in material properties. The parallel plates were made from titanium alloy and the orthogonal plates were made from stainless steel. Varus–valgus loads and flexion–extension loads were not evaluated in this study. In our study both plate systems were made of titanium and had similar wide and thickness. Differently from this study, we evaluate the stiffness values in coronal and sagittal plane and did not find any difference.

In an another study, the parallel plating group had higher values in stiffness and cyclic loading tests in axial loading but the orthogonal plating had higher stiffness values in posterior bending loading in composite humeri models. The largest displacement under 300 N in axial loading was observed in orthogonal plating. However, in posterior bending loading, the parallel plating had the largest displacement values. The study authors stated that both plating systems might be used for distal humerus fractures but that the parallel plating system had superiority in axial loading.[12] This superiority might be explained by the difference in the transcondylar screw number in each group. Parallel plating involved 4 transcondylar screws, whereas orthogonal plating involved only one screw. Torsional and varus–valgus loads were not evaluated in that study. The distal screw holes were filled with a minimal number of smaller size screws. So they did not compare the maximum stabilities of the plate systems. In stiffness tests we found higher values in parallel plating group in axial loading and in orthogonal plating group in posterior bending loads. These results were similar with this study however we did not find any statistical difference between the two groups.

Koonce et al. compared orthogonal reconstruction plates with orthogonal and parallel locking plates in their cadaver study. They observed no significant difference in stiffness tests and the load to failure test in posterior bending loading. In a cyclic loading test in posterior bending, screw loosening was observed to be significantly higher in the orthogonal reconstruction plate group. Although screw loosening was higher in the reconstruction plate group, screw loosening did not affect the load to failure values. To explain this finding, the authors proposed the larger diameter of the distal cortical screws and the longer distal screws that were used in the reconstruction plates.[21] Differently from our study varus–valgus loads were not evaluated, and both sides of the humerus were potted in this study. In locking plating groups distal screw holes were filled with smaller size screws and they did not compare the maximum stability either.

The distal fragments were fixed with a limited number of screws or smaller size screws in most of the recent studies. We filled all of the distal screw holes in the plates to produce the maximum stability of the plate systems. In this manner, we compared the maximum stability of the plate systems in our study.

There were two randomized prospective clinical study who compared orthogonal and parallel plating systems in distal humerus fractures in the literature.[16–23] Both of the studies stated that no significant differences were observed between the two plating systems.

In our study, we tested stiffness in anterior–posterior, varus–valgus and axial loadings because, with the motion of the elbow flexor and extensor muscles, axial compression loads and sagittal loads are produced in the elbow.[24] When an object is held in the hand, varus loading occurs at the elbow. O'Driscoll reported that repetitive varus loading such as this was the main cause of implant failure in distal humerus fractures.[4] We preferred posterior bending loading in cyclic loading and load to failure tests because in the rehabilitation period, active assistive flexion–extension exercise was applied and this motion causes sagittal loading in the elbow.

The usage of the anatomic locking plates which had similar properties and anatomic posterolateral plate which had four 2.7 mm screw holes for the distal fragment, comparison of stiffness values in coronal plane, filling the all of the screw holes in the distal fragment to compare the maximum stabilities of the plating systems were the main differences of our study from the literature.

Limitations

The use of 3rd-generation sawbones instead of composite bones or cadavers was one of the limitations of our study. The sawbones were anatomically identical however, 4th generation sawbones are stiffer and their variability is lower than the 3rd generation sawbones. We had tested our samples with three main functions of elbow anterior–posterior, varus–valgus and axial loadings, torsional loads were not tested. Furthermore, applying cyclic loading tests and load to failure tests in varus loading could improve the quality of the study.

Conclusion

This study showed us that the orthogonal plating with a posterolateral plate with four distal 2.7 mm screws could provide as much stability as the parallel plating system in intraarticular distal humerus fractures in sawbone model. Patient discomfort due to skin irritation of lateral plate especially in thin and elder people could be extinguished with posterolateral plating. Both systems did not have any screw loosening or failure during cyclic loading tests. This result showed us that both systems could provide the adequate stability during the early rehabilitation period until the fracture union.

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