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Biomechanical evaluation of a transcondylar screw from the dorsolateral plate support on the stabilization of orthogonal plate configuration in distal humeral fracture

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ABSTRACT

Introduction: Intra-articular distal humeral fractures involving both columns require double-plate fixation. In orthogonal plate fixation, screws from the medial plate reach the radial column, while screws from the dorsolateral plate run posterior–anterior, not creating interdigitation. The Synthes LCP-DHP system has an orthogonal plate configuration that enables dorsolateral plating with support, as the radial and ulnar columns are linked via interdigitation of the distal screws. We hypothesized that the transcondylar screw from the posterolateral plate, which interdigitates with screws from the medial plate, enables more rigid stabilization of orthogonal plating in distal humeral AO type C fractures.
Methods: A previous study reported the biomechanical properties of orthogonal plate fixation using an AO type 13-C2.3 intra-articular fracture model with a 1-cm supracondylar gap using artificial bones (Kudo et al., Injury, 2016). We performed a biomechanical study of the dorsolateral plate with support, and inserted one 2.7-mm locking screw through the support in the lateral-to-medial direction, creating interdigitation of the distal screws. A 0–200 N axial load was applied separately to the radial and ulnar columns. We calculated the stiffness of both columns, and the anterior displacement of the condylar fragment. We compared the biomechanical properties of orthogonal plating with versus without interdigitation.
Results: There were no significant differences between the two groups in radial or ulnar axial compression. The ulnar column was stiffer than the radial column in both groups. There were no significant differences between groups in the angular displacements of the capitellum or trochlea. The capitellum moved more anteriorly than the trochlea during axial compression in both groups.
Discussion: The radial and ulnar columns were linked via interdigitation of the distal screws by adding one transcondylar screw from the dorsolateral plate, which did not affect radial column stiffness or capitellar anterior movement under axial compression. In the orthogonal configuration, axial compression induced more anterior displacement of the capitellum than the trochlea, which may induce secondary fragment or screw dislocation on the dorsolateral plate or nonunion at the supracondylar level.
Conclusions: The transcondylar screw from the dorsolateral plate did not affect axial compression of the radial column or capitellar anterior displacement.

Introduction

Intra-articular distal humeral AO type C fractures are preferably treated using the double-plate configuration. Using the parallel plates, the screws can lock together by interdigitation as they pass through the distal fragments from the medial and lateral plates, thereby creating a fixed-angle architecture that provides stability to the entire distal humerus [1]. In the orthogonal plate fixation, screws from the medial plate only extend into the radial column, while screws from the dorsolateral plate run in the posterior to

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anterior direction, which cannot enable interdigitation. The Synthes locking compression plate (LCP)-distal humerus plate (DHP) (Synthes GmbH, Solothurn, Switzerland) has an orthogonal plate configuration, which enables the clinician to fix the dorsolateral plate with support. This plate with support enables additional screw insertion through the lateral epicondyle in a lateral–medial direction to achieve interdigitation with the screws from the medial plate.

A previous study comparing orthogonal versus parallel configuration reported no significant differences in ulnar axial compression, but significant differences in radial axial compression [2]. The orthogonal configuration had no interdigitation, while the parallel configuration had six interdigitated screws [2]. This suggests that interdigitation had no effect on the ulnar axial compression, but had a significant effect on the radial axial compression.

We hypothesized that having one screw from the dorsolateral plate with support that interdigitates with screws from the medial plate achieves more rigid stabilization of orthogonal plating in distal humeral intraarticular AO type C fractures.

Materials and methods

Fracture model

We used synthetic humeri (5011 right humerus; Synbone AG, Malans, Switzerland) instead of cadaveric bone to equalize the bone material for comparisons. This bone substitute is commonly used to simulate human bone, and is widely accepted as an adequate bone substitute material [3]. We used an oscillating bone saw to create a simulated intra-articular fracture of the distal humerus (Association for the Study of Internal Fixation (AO/ASIF) type 13-C2.3). We created a transverse fracture line across the top of the olecranon fossa with an articular osteotomy at the trochlear groove [4,5]. A 1-cm transverse osteotomy gap was created to simulate metaphyseal comminution 1-cm below the first transverse osteotomy line. The fracture gap ensured that the cortices of the distal and proximal fragments did not contact each other when they were deflected during mechanical testing. The three humeri in group A had a dorsolateral plate without support, and the biomechanical properties of this group were reported previously [2]; the three humeri in group B in the present study had a dorsolateral plate with support.

Implant system and configurations

We chose an anatomically-preshaped DHP-LCP system (Synthes GmbH, Solothurn, Switzerland). For orthogonal plating, this system has a medial plate on the medial aspect of the ulnar column and a dorsolateral plate on the posterior aspect of the radial column without support (group A) or with support (group B) (Fig. 1). Each plate had five holes. Internal fixation was performed immediately after the osteotomies, and the fracture gap was located at the fifth hole of the medial plate. A single experienced surgeon performed all osteosyntheses in accordance with the manufacturer's specifications.

Orthogonal plating without support (group A)

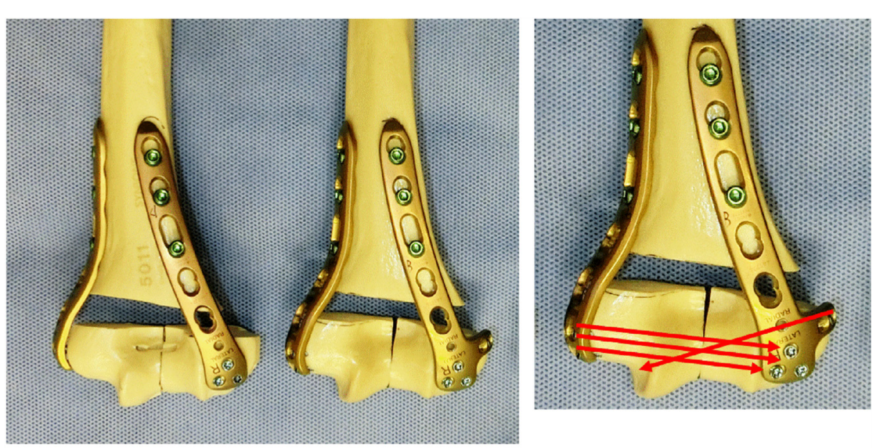
The AO/ASIF technique for perpendicular plating was used to achieve distal fixation of the articular components of the fracture, as previously reported [2]. An anatomically-preshaped dorsolateral DHP without support was applied to the radial column. Three 2.7-mm LCP locking screws were then inserted into the capitellum in a posteroanterior direction, and the anatomically-preshaped medial DHP was attached to the ulnar column. Three medial transcondylar 2.7-mm LCP locking screws were inserted in the mediolateral direction to catch the capitellum. During all of the osteosyntheses, care was taken not to penetrate the articular surface and to keep the fossa coronoidea, fossa radialis, and fossa olecrani free of implant material. None of the screws were stripped during osteosynthesis or required repositioning, and it was confirmed that all three transcondylar screws from the medial plate captured the capitellum [2].

Orthogonal plating with support (group B) (Fig. 1)

After orthogonal plating, one transcondylar screw was added from the support of the dorsolateral plate to catch the trochlea. Care was taken to ensure that this screw interdigitated, creating a fixed-angle structure. Furthermore, the distal portion of the plate was very precisely positioned to fulfil the criteria for good fixation. The screws were carefully placed to avoid both the fossa olecrani and the articular surface.

Mechanical testing

The specimens were tested on a material testing machine (Servopulser®, Shimadzu, Kyoto, Japan). The proximal ends of the



Group A Group B Group B

Fig. 1. Orthogonal plating used for distal humeral fracture.
Group A: dorsolateral plate without support; group B: dorsolateral plate with support. The red arrows indicate the inserted screws. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

humeri were placed in a holding device (not clamped) during testing, and the distal end was attached to a custom-made acrylic resin mold (Ostron II, GC, Tokyo, Japan) for the lateral and medial fragments, separately. The customized molds were used to sustain the articular fragment during compression testing [2]. Constant speed (static) compressive loading was applied in the axial loading direction at a displacement rate of 60 mm/min (maximum load 200 N) in an attempt to recreate the stress experienced at the articular level during push-ups. Testing occurred in two phases. The first phase focused on the lateral fragment side (radial column), while the second focused on the medial fragment side (ulnar column) (Fig. 2).

Three sawed bone models were used for each group. In each configuration, each bone model underwent lateral compression testing followed by medial compression testing. Compression testing was performed three times in both directions in each sawed bone model.

As the three humeri in each group underwent three tests each, there were a total of nine data sets for each study. The axial compressive stiffness was calculated using the slope of the linear region of the load versus the displacement (actuator position) plot for both 50–150 N and 100–200 N. To measure the angle of displacement of the capitellum or trochlea on the lateral view, two lines were drawn by connecting two points made on the distal fragment and shaft. These were used as coordinates (Fig. 3). Photographs of the medial and lateral aspects pre- and post-loading were analyzed using the coordinates through Photoshop® (Microsoft Corporation, Seattle, WA, USA). The equations used for the analysis were as follows:

$$a = (y2 - y1)/(x2 - x1)$$

$$\tan\theta = \pm(a2 - a1)/(1 + a2 \times a1)$$

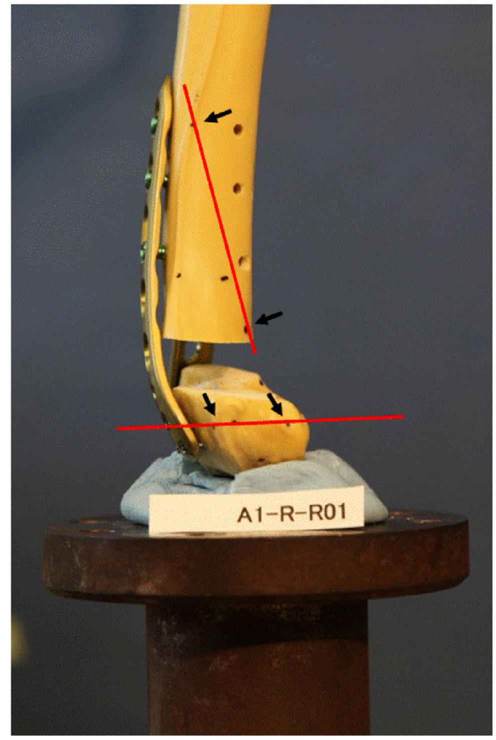


Fig. 3. Lateral view of the plated distal humeral fracture after axial loading. Distal fragment movement was estimated using Photoshop® coordinates. The angle formed by two lines was calculated, and the pre- and post-load angular displacements of the distal fragment were estimated.

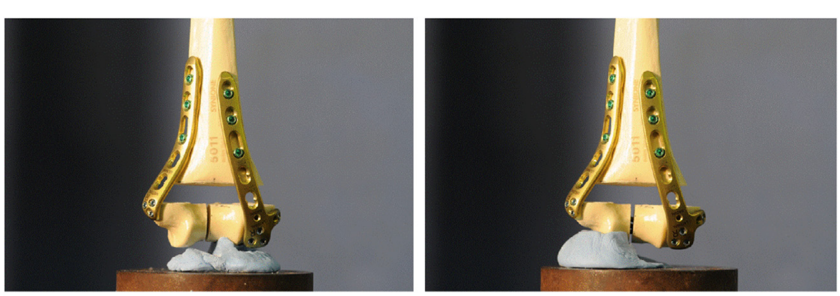
Statistical analysis

Data were analyzed using the Student's t-test. For all tests, probability values of less than 0.05 were considered to indicate significant differences.

Results

The results of group B were compared with the previously reported results of group A, the mean stiffness in the radial column was 90.4 ± 16.6 N/mm during 50–150 N and 96.2 ± 8.6 N/mm during 100–200 N axial loading on the radial column [2]. In group B, the mean stiffness in the radial column was 84.0 ± 14.0 N/mm during 50–150 N and 91.3 ± 14.0 N/mm during 100–200 N axial loading on the radial column. There were no significant differences in the radial axial compression between groups A and B at 50–150 N and 100–200 N axial loading on the radial column (p = 0.6874 and p = 0.6684, respectively; Fig. 4).

The mean stiffness in the ulnar column in group A was 107.0 ± 11.7 N/mm during 50–150 N and 126.9 ± 12.8 N/mm during 100–200 N axial loading on the ulnar column [2]. The mean stiffness in the ulnar column in group B was 103.8 ± 14.8 N/mm during 50–150 N and 114.3 ± 19.6 N/mm during 100–200 N axial loading on the ulnar column. There were no significant differences in the ulnar axial compression between groups A and B at 50–150 N and 100–200 N axial loading on the ulnar column (p = 0.8013 and p = 0.4553, respectively; Fig. 5).



(A) (B)

Fig. 2. The application of axial loading to the radial and ulnar columns.
The distal end of the humeral model was attached to a custom-made acrylic resin mold (Ostron II, GC, Tokyo, Japan) for the radial (A) and ulnar (B) fragments in Group B. An axial load from 0 to 200 N was applied on the radial column or the ulnar column, respectively (three times for each specimen).

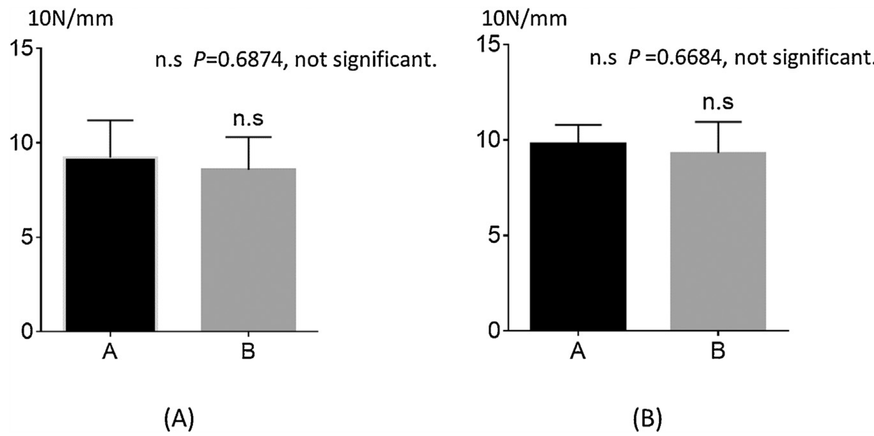


Fig. 4. Radial column-radial axial compression. Stiffness of the radial column during axial loading in group A (dorsolateral plate without support) vs. group B (dorsolateral plate with support).
During axial loading of 50–150 N (A) and 100–200 N (B), there were no significant differences in radial axial compression between the two groups.

The ulnar column tended to be stiffer than the radial column in both groups, but there were no significant differences between the ulnar and radial columns during 50–150 N axial loading in both groups (Fig. 6), and during 100–200 N axial loading in group B (Fig. 7). Only group A during 100–200 N showed a significant difference between radial column stiffness (96.2 ± 8.6 N/mm) and ulnar column stiffness (126.9 ± 12.8 N/mm; p = 0.0132; Fig. 7).

We assessed displacement of the condylar fragment anteroposteriorly as an angular displacement, as the condylar fragment was rotated anteriorly during axial compression (Figs. 8 and 9). In the lateral view, after 200 N loading, the capitellum moved anteriorly 5.4 ± 0.9° in group B, which was not significantly different from the results of group A (5.2 ± 1.2°) (p = 0.8611; Fig. 10) [2]. The angular displacement of the trochlea in group B was 2.1 ± 0.8°, which was not significantly different from the results of group A (2.8 ± 1.0°) (p = 0.4994; Fig. 10) [2]. The capitellum tended to move more anteriorly than the trochlea during axial compression in both groups; however, this change was significant in group B (p = 0.0145), but not in group A (p = 0.0872; Fig. 11).

Irrespective of the transcondylar screw from the dorsolateral plate, the capitellum in the orthogonal configuration typically moved anteriorly during axial compression on the radial column compared with the trochlear movement during axial compression on the ulnar column. This phenomenon resulted from the dorsolateral plate bending anteriorly at the fracture gap, despite the use of the transcondylar screw.

Discussion

A previous study of the biomechanical properties of orthogonal versus parallel configuration reported no significant differences in ulnar axial compression, but significant differences in radial axial compression [2]. The orthogonal configuration had no interdigitation, while the parallel configuration had six interdigitated screws. We hypothesized that the transcondylar screw from the dorsolateral plate, which interdigitates with screws from the medial plate, creates a more rigid stabilization of orthogonal plating in distal humeral intraarticular AO type C fractures. In the present study, the transcondylar screw from the support of the dorsolateral plate interdigitated with the medial screws, but had no effect on the stiffness of the radial column or ulnar column under axial compression. Moreover, it had no effect on the bending motion of the dorsolateral plate under axial compression.

The capitellum and trochlea showed 30° of anterior flexion relative to the humeral shaft; therefore, axial compression induces anterior bending of the capitellum and trochlea. Irrespective of the transcondylar screw from the dorsolateral

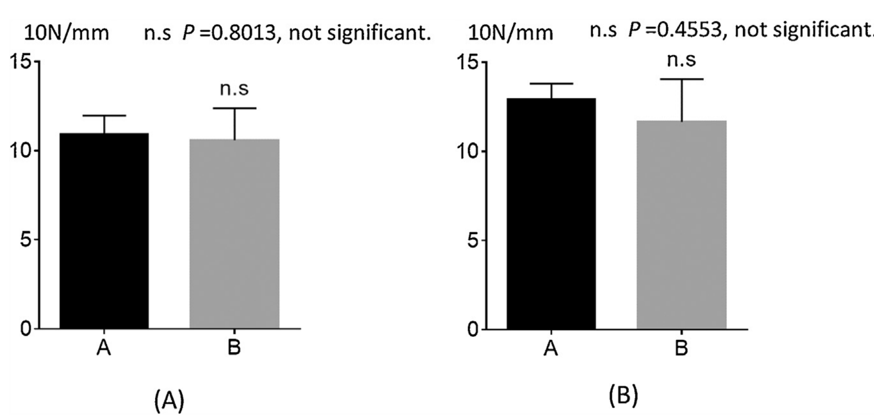


Fig. 5. Ulnar column-ulnar axial compression. Stiffness of the ulnar column during axial loading in group A (dorsolateral plate without support) vs. group B (dorsolateral plate with support).
During axial loading of 50–150 N (A) and 100–200 N (B), there were no significant differences in ulnar axial compression between the two groups.

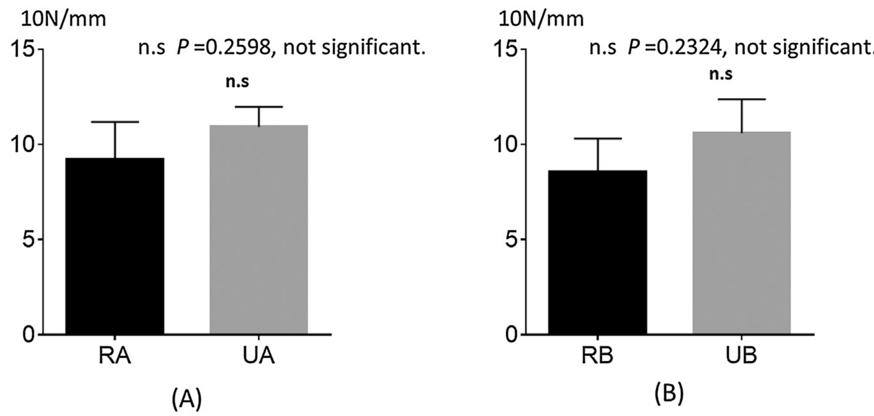


Fig. 6. Stiffness under 50–150 N axial loading of the radial and ulnar columns in group A (A) and group B (B).
There were no significant differences in stiffness between ulnar and radial column axial loading in both groups.
RA: radial stiffness under radial compression in group A.
UA: ulnar stiffness under ulnar compression in group A.
RB: radial stiffness under radial compression in group B.
UB: ulnar stiffness under ulnar compression in group B.

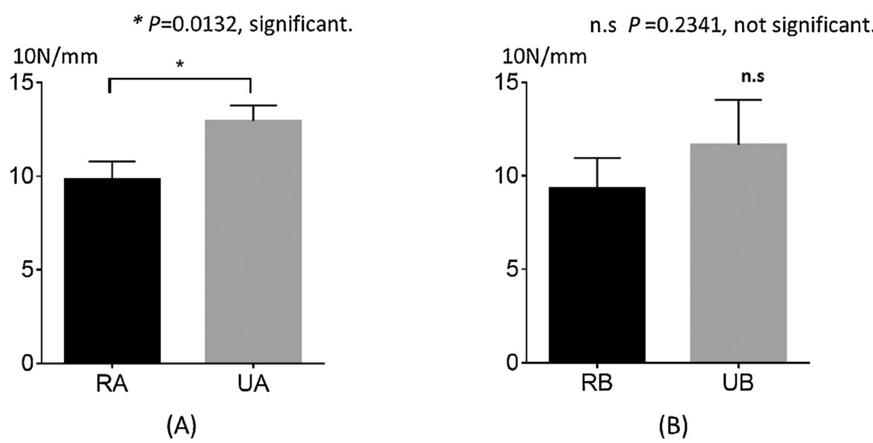


Fig. 7. Stiffness under 100–200 N axial loading of the radial and ulnar columns in group A (A) vs. group B (B).
There were no significant differences in stiffness between ulnar and radial column axial loading in group B. In group A, the radial column stiffness (96.2 ± 8.6 N/mm) was significantly lesser than the ulnar column stiffness (126.9 ± 12.8 N/mm).
RA: radial stiffness under radial compression in group A.
UA: ulnar stiffness under ulnar compression in group A.
RB: radial stiffness under radial compression in group B.
UB: ulnar stiffness under ulnar compression in group B.

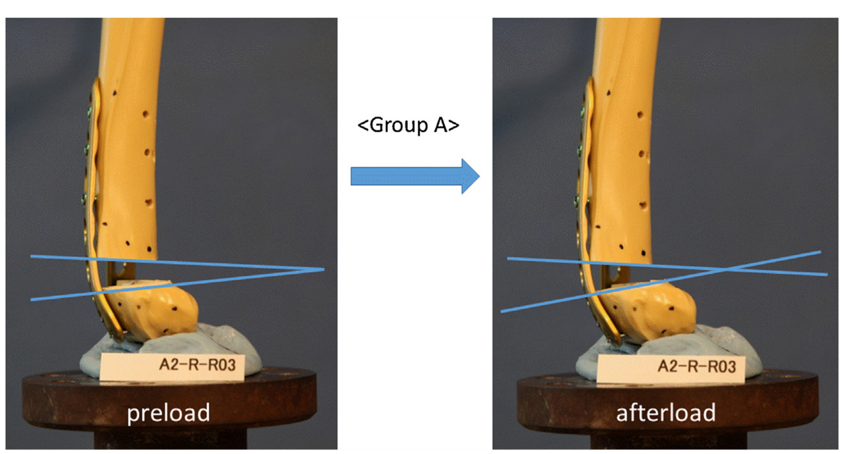


Fig. 8. Lateral view pre- and post-loading in group A (dorsolateral plate without support).
The axial compression induced a greater anterior bending force on the capitellum because of posterolateral plate bending.

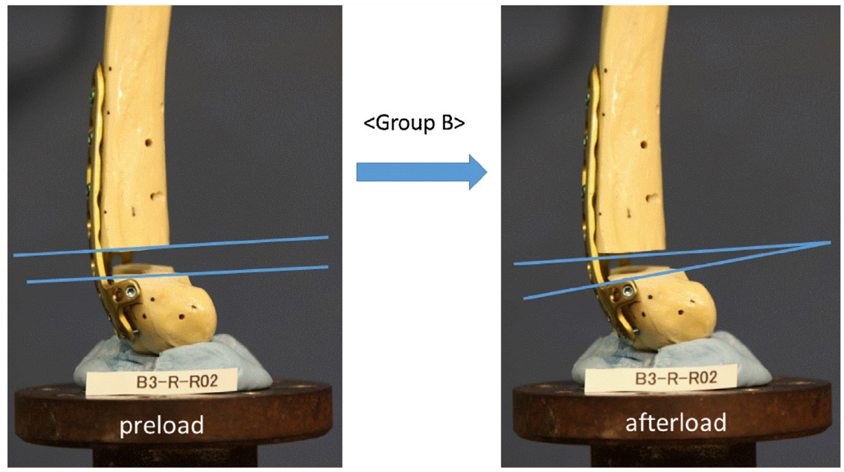


Fig. 9. Lateral view pre- and post-loading in group B (dorsolateral plate with support).
The axial compression induced an anterior bending force on the capitellum. The transcondylar screw from the support hole had no effect on this bending motion.

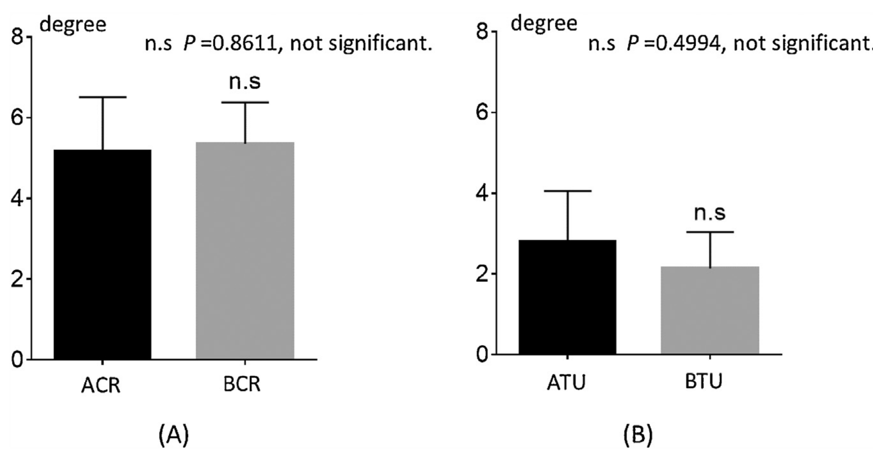


Fig. 10. Angular displacement of the distal fragment in the lateral view under axial compression.
(A) Capitellar movement during radial compression. (B) Trochlear movement during ulnar compression.
There were no significant differences between the two groups regarding the angular displacement of the condyle after application of a 200 N radial or ulnar axial load.
ACR: Capitellar movement in group A.
BCR: Capitellar movement in group B.
ATU: Trochlear movement in group A.
BTU: Trochlear movement in group B.

plate, the capitellum typically moved anteriorly during axial compression on the radial column compared with the trochlear movement during axial compression on the ulnar column. Furthermore, the dorsolateral plates tended to bend anteriorly under axial compression. Repetitive axial compression reportedly induces anterior-posterior movement of the capitellum relative to the trochlea, which may lead to distal screw pull-out at the dorsolateral plate and/or nonunion at the supracondylar level [1,4,6–8]. While proximal movement of the fragment (simple shortening of the supracondylar gap) during axial compression may not be a major problem, anterior movement of the capitellum compared with the trochlea on axial loading may be a risk factor for failure [2].

It seems that plate configuration (parallel versus orthogonal) is more important for stability of distal humeral intraarticular fracture than interdigitation of the condylar screws. Parallel plate configuration is reportedly superior to orthogonal plate configuration in distal humeral intraarticular AO type C fractures [2]. To increase the stability of the plate osteosynthesis in humeral distal intraarticular fracture, it is important to prevent the distal fragment from bending anteriorly in axial compression. To achieve this, the parallel plate configuration should be used, and the condyle should be fixed to the plate by condylar screws. Transcondylar screws would not contribute to the contralateral column stability on axial compression, but would contribute to ipsilateral column stability to fix the ipsilateral plate.

Although the dorsolateral plate with support enables the insertion of two screws on the support, we used only one screw from the support in group B. If two screws were inserted through the support in group B, eight screws would have occupied the condyle in group B compared with six screws in group A.

The limitations of this study include the use of an artificial substitute for human bone rather than cadaver bone. The artificial bone did not include ligaments, and prevented assessment of bone healing, potential damage to ligaments in different plate positions, and functional outcomes. Another limitation is that only axial load compression was tested.

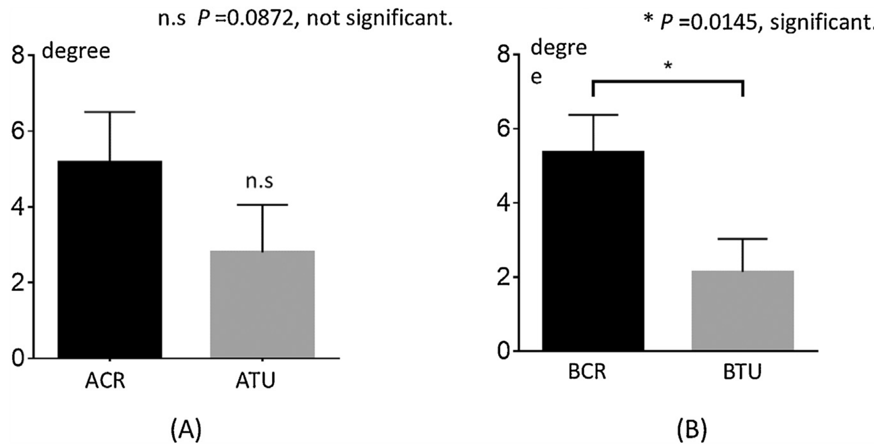


Fig. 11. Angular displacement of the distal fragment in the lateral view under axial compression. (A); group A, (B); group B.
The capitellum moved more anteriorly than the trochlea during axial compression in both groups. This difference between the anterior movement of the capitellum vs. the trochlea was significant in group B ($p = 0.0145$), but not in group A ($p = 0.0872$).
ACR: capitellum displacement under radial compression in group A.
ATU: trochlea displacement under ulnar compression in group A.
BCR: capitellum displacement under radial compression in group B.
BTU: trochlea displacement under ulnar compression in group B.

Conclusions

In the LCP-DHP system, the dorsolateral plate tended to bend under axial compression. The use of one transcondylar screw from the support of the dorsolateral plate did not contribute to the stability under radial or ulnar compression forces, or the bending motion in the lateral view.

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