Mechanical strength of the Mayo Clinic Congruent Elbow Plate System distal humerus fractures -Cadaveric and model bone model-

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Abstract

The purpose of this study was to compare the Mayo Clinic Congruent Elbow Plate System with a plate system having the same biomechanical features as a conventional non-locking system. For testing, we used a biaxial adjustable material testing machine (Mini-Bionix, MTS ® company). A compressive load of 500 N/min was applied in the axial direction, and a torque of 30 deg/min was applied in the rotational direction to simulate internal rotation of the elbow. The relationships between force (N) and displacement (mm), and between the internal rotational angle (deg) and torque (N/m), were measured. The Mayo Clinic Congruent Elbow Plate and the two types of screws used in this study may provide sufficient fixation strength. The results obtained here warrant further studies that are more dynamic (e.g., cyclic loading and repetitive torsion tests), with larger number of specimens, and that appropriate normal elbow movement in daily living to assess the
utility of distal humerus fractures after plate fixation with locking and non-locking systems.

**Key words:** Mayo Clinic Congruent Elbow Plate System, biomechanical, locking, non-locking, distal humerus fractures

**Introduction**

Several osteosynthetic implants that have improved the surgical outcomes of distal humerus fracture repair are now available. Surgical fixation of the intraarticular distal humerus using two column plates has been described, but the biomechanical properties or limitation of the technique remain unclear. Plate fixation is an excellent method that enables early rehabilitation through stable fixation, and the results obtained with a conventional non-locking system are equally or more favorable than those obtained with a locking system. To this end, herein we study sought to compare the Mayo Clinic Congruent Elbow Plate System, which is used worldwide, with a plate system having the same biomechanical features as a conventional non-locking system.

**Objective**

To investigate the mechanical strength of the Mayo Clinic Congruent Elbow Plate locking and non-locking systems
Subjects and methods

【I】Model bone

This study used a humerus bone model made of polyurethane (Sawbones®). The Mayo Clinic Congruent Elbow Plate System (Acumed®, Hillsboro, OR, USA) with 3.5-mm non-locking screws and locking screws used for implantation. For testing, we used a biaxial adjustable material-testing machine (Mini-Bionix, MTS® company). A compressive load of 500 N/min was applied in the axial direction, and a torque of 30 deg/min was applied in the rotational direction to simulate internal rotation of the elbow. The relationships between force (N) and displacement (mm) and between the internal rotational angle (deg) and torque (N/m) were measured. A bone defect was created 1 cm proximal to the distal line of the coronoid fossa in the humerus model to create an AO (Arbeitsgemeinschaft für Osteosynthesefragen) classification type A fracture (A), whereas the distal fragments were separated on the lateral side of the trochlea to create an AO classification type C fracture (C). The distal portion was fixed using a non-locking screw × 2 (N), non-locking screw + locking screw (L1), or locking screw × 1 (L2).

Thus, we examined six combinations of fracture models and screw fixing methods (AN, AL1, AL2, CN, CL1, and CL2) and created three specimens of each model type, leading to a total of 18 specimens. The humerus to which a plate was fixed was amputated 105 mm proximal to a 10-mm cross-sectional gap. Self-curing resin (OSTORON II®, GC company) was then used to embed a steel pipe of 60 mm in length. To apply compression and torsion to the specimen, a flat surface was created with self-curing resin that covered the upper, front, and back parts of the trochlea.
【Ⅱ】Cadaveric bone

In addition to the polyurethane models, we used cadaveric humeri (four bodies, eight arms) to model plate fixation with the Mayo Clinic Congruent Elbow Plate locking system and a conventional non-locking system. The mean age of the cadavers at the time of death was 85 ± 5 years. A Mayo plate (3.5-mm non-locking screws and locking screws) was used for the implant. Testing, compression (application and measurements), and the bone defects were carried out as for the model bone. However, for the cadaveric bone, the distal portion was fixed using a non-locking screw × 2 (N) and a non-locking screw + locking screw (L), producing 8 combinations of fracture models and screw-fixing methods (two each of AN, AL, CN, and CL).< Table I > The humerus was fixed, amputated, and embedded as described for the model bone, and again, compression and torsion was applied to the specimen using a flat surface created with self-curing resin that covered the upper, front, and back parts of the trochlea.< Fig 2 >

(Table 1)

(Fig 2)

Results

【Ⅰ】Model bone

Figure 3 presents the load-displacement curve for type A fractures and the mean values for the three specimens, AL1, AN, and AL2. As the curve indicates, displacement increased in proportion to the load, and there were no obvious differences in displacement between AL1, which used a
locking screw, and AN, which used a non-locking screw. The displacement in AL2, which used only one screw, was greater than that in AL1 and AN, and AL1 showed a decrease in early rigidity.

Figure 4 presents the load-displacement curve for type C fractures and the mean values for the three specimens types, CL1, CN, and CL2. Similar to type A fractures, there were no obvious differences in displacement between CL1, which used a locking screw, and CN, which used a non-locking screw. However, the displacement in type C fractures was greater than that in type A fractures. The displacement of CL2, which used only one screw, was at least 1.5 times greater than that in CL1 and CN. In addition, the early rigidity of CL2 was low, even when comparing the curve slopes.

Figure 5 presents the torque-angle curve for type A fractures and the mean values for the three specimen types, AL1, AN, and AL2. For all three specimens, torque increases were associated with angle increases. The torque of AL1, which used a locking screw, was greater than that in AN, which used a non-locking screw, and AL2, which used only one screw; however, the difference was not significant. There were considerable differences between AN and AL2, and their results showed marked variations.

Figure 6 presents the torque-angle curve for type C fractures and the mean values for the three specimen types, CL1, CN, and CL2. Compared with the results for type A fractures, the maximum torque decreased for type C fractures; however, there were no noticeable differences between CL1 and CN. Unlike type A fractures, however, the maximum torsion resistance and early rigidity was highest for CL2, followed by CL1 and CN.
We obtained four right arms and four left arms from four cadavers. The right humerus was fixed using a locking screw, and the left humerus was fixed using a non-locking screw. We then compared each right and left humerus from the same cadaver.

Figure 7 presents the load–displacement curve for a type A fracture in specimen 01. When comparing the left and right humeri, the curve for AL01, which used a locking screw, showed a greater slope than the curve for AN01, whereas early rigidity was high. However, displacement was greater for AL01 than for AN01, which used a non-locking screw, although the difference was miniscule.

Figure 8 shows the load-displacement curve for type A fractures in specimen 02. This curve indicates that AL02, which used a locking screw, and AN02, which used only a non-locking screw, had similar performance. Compared with that in AL01 and AN01, displacement was lower in this specimen.

Figure 9 shows the load-displacement curve for type C fractures in specimen 01. As the curve indicates, CL01, which used a locking screw, showed a higher early rigidity. In addition, it was possible to control the displacement, which was greater in CN01 than in CL01.

Figure 10 shows the load-displacement curve for type C fractures in specimen 02. These data indicate that it was possible to minimize the displacement in CL02, which used a locking screw, and CN02, which used a non-locking screw. Based on the slope of the curve, early rigidity was
higher in CL02.

Figure 11 shows the torque-angle curve for type A fractures in specimen 01. Similar to the results for axial compression, the slope for AL01, which used a locking screw, was greater than that for AN01 and showed a higher early rigidity. However, when approximately 8° of torque was applied to AL01, the specimen broke as the torque resistance decreased, whereas AN01 retained high torque resistance until approximately 20° of rotation was achieved.

Figure 12 shows the torque-angle curve for type A fractures in specimen 02. As indicated by the load-displacement curves, AL02 and AN02 had similar performances. The maximum torque was slightly greater in AL02 than in AN02, although there was no significant difference. Both the AL01 and AL02 specimens broke after approximately 20° of torsion.

Figure 13 shows the torque-angle curve for type C fractures in specimen 01. Compared with CL01, CN01 did not show an increase in torque. However, some problems may have occurred during the test. In addition, neither CL01 nor CN01 broke during testing.

Figure 14 shows the torque-angle curve for type C fractures in specimen 02. There was no major difference between the performance of CL02 and CN02, while maximum torque was attained for both CL01 and CN01.

(Figs 7-14)

Discussion

The Mayo clinic congruent Elbow Plates, designed by Shawn O’Driscoll, Ph.D., M.D., have revolutionized surgical treatment of distal humerus fractures. Essentially, this plate
concept was designed for “parallel” plate placement on the distal humerus, combined with increased plate strength over standard reconstruction plates, allowing for early rehabilitation and preservation of elbow function and motion.9-12)

Usually, surgeons can determine the trajectory of the locking screws in a distal humerus fracture treatment,13,14) offering the surgeon a means to maximize fixation in the distal fragments and providing the best possible outcome for the patient. However, the biomechanical properties of this plate fixation system remain unknown. Thus, this study was designed to determine the static biomechanical strength and characteristics of this new plate system for distal humerus fractures.

In the model bone study, we compared the effects of compression and torsion on models of type A and type C humerus fractures repaired using the Mayo Clinic Congruent Elbow Plate System or a conventional non-locking system. We observed no major differences between fracture types using locking screws (AL, CL) and non-locking screws (AN, CN). Focusing only on the compression results does not fully indicate the differences in fixation strength for the two screw types; however, the displacement for type C fractures was greater than that for type A fractures. This difference likely resulted from the addition of a fracture line and the assumption that complex fractures increase displacement. The displacement was greater in specimens that used only one locking screw (AL2, CL2) and had fewer screws inserted into the distal bone compared with those using two locking screws. In addition, these results were more prominent in type C fractures, which are classed as complex fractures. Based on these results, we conclude that it is important to use more than one screw for fixation of complex fractures to increase stability and safety.15-17) In
contrast, the torsion results produced few differences, if any, between specimens that used two
types of screws for fixation and those that used only one screw. Based on these cases, the plate
appears to have greater interactions with torque compared with the screws, regardless of type and
number, and performing fixation simultaneously from the lateral and medial sides could greatly
affect the resistance toward torsion. In addition, we believe that an increased resistance to torsion
might also be associated with medial plate fixation, depending on whether it covers the area up to
the medial epicondyle and whether the two plates closely match the shape of the model or bone.

In the cadaveric study, there was a difference in the displacement and torque of type A fractures
(AL01, AN01, AL02, AN02) between specimen 01 and specimen 02, and these differences likely
resulted from differences in bone density between the specimens. However, the curves show that
despite differences among their respective values, the performance of the specimens was similar
(Fig. 5-8, 5-9, 5-10, 5-11). In addition, the bone broke at a region proximal to the fracture line
during testing with all four type A fractures. This likely resulted from differences among the model
bones, the varying shapes of the cadaveric humerus, and the fact that the plates could not be placed
such that they completely matched the shape of the bone.

When type C fractures (CL01, CN01, CL02, CN02) were compared, CN01 performed
differently than the other three specimens, with rotation applied to CN01 occurring entirely at the
region of torsion, which could not twist easily. Therefore, CN01 could not be compared to CL01
(Fig. 5-12, 5-13, 5-14, 5-15). For specimen 02, there was no difference in displacement or rotation
resistance with specimens CL02 and CN02, and no difference was observed in fixation when a
locking or non-locking screw was used. In addition, none of the type C fracture models broke
during testing. This likely resulted from differences in fracture type because there is an additional
fracture line through the articular facet. In addition, only the distal bone fragment, which includes
the trochlea of the humerus, can twist easily.

In the present study, we conducted compression–torsion tests that simulated movements with
simultaneous flexion and internal rotation, to approximate normal elbow movement in daily
living.\cite{18,19} We used two different models, namely a polyurethane humerus model and humerus
bones obtained from human cadavers. In both cases, there were no differences in screw fixation
strength between locking and non-locking screw systems, and this similarity might be attributed to
the method of plate positioning and influence of plate design. The Mayo Clinic Congruent Elbow
Plate had to be positioned in parallel; therefore, fixation during this study was placed in parallel.

Generally, parallel positioning of the plate is considered more stable against torsion compared with
right-angled positioning.\cite{20,21} In addition, the plate design caused the screw holes to converge on an
area in the distal region where they were in contact with the joint, and insertion of a long screw
from both sides of the humerus was technically possible with parallel positioning of the plates.
Therefore, the same type of screw was inserted through the distal bone fragment, which improved
stability and strength. We believe that this technical feature explains why fixation strength did not
differ between the two screw types.

We also compared our test findings between the cadaver and polyurethane bones because there
was a high resistance to rotation, and differences among specimens caused the models to break.
Furthermore, it is difficult to clinically translate findings obtained with the model bone.

Nevertheless, when the elbow joint rotates internally, the maximum torque that occurs in males is generally 7.3 N/m,\textsuperscript{3} which is lower than that observed in this study. Accordingly, the Mayo Clinic Congruent Elbow Plate and the two types of screws used in this study may provide sufficient fixation strength.

This study was limited in the small number of specimens and preliminary nature. Therefore, further studies that are more dynamic (e.g., cyclic loading and repetitive torsion tests), have larger number of specimens, and appropriate elbow motion that is close to that occurring during daily activities, should be performed to assess the utility of the humerus after plate fixation with locking and non-locking screws.

**Conflict of interest**

The authors declare no conflicts of interest.
References


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<table>
<thead>
<tr>
<th>Fracture type</th>
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<th>Total</th>
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</table>

8 combinations of fracture models and screw fixing methods (two each of AN, AL, CN, and CL).

**Figures**

Model bone a: AO classification type A fracture, b: AO classification type C fracture.
Cadaveric bone a: AO classification type A fracture, b: AO classification type C fracture, c: A compressive load of 500 N/min was applied in the axial direction, and a torque of 30 deg/min was applied in the rotational direction to simulate internal rotation of the elbow.

Type A and the mean values for AL1, AN, and AL2. AL1: non-locking screw + locking screw, AN: non-locking screw × 2, AL2: locking screw × 1

Results for fracture type A (material: model bone humerus, AL1, AN, and AL2)

Results for compression load and torsion test (load-displacement curve)
Results for fracture type A (material: model bone humerus, CL1, CN, and CL2)

Results for compression load and torsion test (load-displacement curve)

Results for fracture type A (material: model bone humerus, AL1, AN, and AL2)

Results for compression load and torsion test (torque-angle curve)
Results for fracture type A (material: model bone humerus, CL1, CN, and CL2)
Results for compression load and torsion test (torque-angle curve)

![Torque-Angle Curve](image6)

Results for fracture type A (material: cadaveric humerus, A01)
Results for compression load and torsion test (load-displacement curve)

![Load-Displacement Curve](image7)
Results for fracture type A (material: cadaveric humerus, A01)
Results for compression load and torsion test (torque-angle curve)

![Torque-Angle Curve](image)

Results for fracture type A (material: cadaveric humerus, A02)
Results for compression load and torsion test (load-displacement curve)

![Load-Displacement Curve](image)
Results for fracture type A (material: cadaveric humerus, A02)
Results for compression load and torsion test (torque-angle curve)

Results for fracture type C (material: cadaveric humerus, C01)
Results for compression load and torsion test (load-displacement curve)
Results for fracture type C (material: cadaveric humerus, C01)
Results for compression load and torsion test (torque-angle curve)

Results for fracture type C (material: cadaveric humerus, C02)
Results for compression load and torsion test (load-displacement curve)
Results for fracture type C (material: cadaveric humerus, C02)

Results for compression load and torsion test (Torque-angle curve)