A NEW ANATOMICAL PLATE FOR EXTRA-ARTICULAR DISTAL HUMERAL FRACTURES: BIOMECHANICAL STUDY

UMA NOVA PLACA ANATÔMICA PARA FRATURAS EXTRA-ARTICULARES DISTAIS DO ÚMERO: ESTUDO BIOMECÂNICO

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ABSTRACT

Introduction: We compared the mechanical properties of two fixation techniques for the treatment of extra-articular distal third humeral fractures. Materials and Methods: Two groups were created from twenty-four humeri. Group 1 was instrumented using a new, precontoured, 8-hole (3.5-mm-diameter) locking compression plate (LCP) placed anterolaterally. Group 2 was instrumented using an 8-hole (3.5-mm-diameter) precontoured posterolateral LCP plate placed on the distal humerus. Four-point bending tests and torsion tests were performed until the specimens broke. Results: The four-point bending stiffness test showed that the stiffness of anterolaterally fixed humeri was significantly higher than that of posterolaterally fixed humeri (p<0.05). Torsion testing revealed that posterolateral fixation was associated with better yield strength (p<0.05), but the torsional stiffness did not differ significantly between the two plates (p> 0.05). Conclusions: The anterolateral plate exhibited higher bending stiffness and torsional yield strength than the posterolateral plate. Anterolateral plate fixation can thus be used to manage extra-articular distal humeral fractures. Multiaxial locking screws ensure rigid fixation, allow early elbow motion without olecranon fossa impingement, and prevent iatrogenic injury of the triceps muscle. **Level of Evidence I, Therapeutic Studies Investigating the Results of Treatment.**

Keywords: Fracture Fixation. Humeral Fractures. Fracture Fixation,Internal.

RESUMO

Introdução: Comparamos as propriedades mecânicas de duas técnicas de fixação para o tratamento de fraturas extra-articulares do terço distal do úmero. Materiais e Métodos: Dois grupos foram criados a partir de vinte e quatro úmeros. O Grupo 1 foi instrumentado com uma nova placa de compressão com travamento (LCP) pré-contornada e com oito orifícios (3,5 mm de diâmetro) posicionados anterolateralmente. O Grupo 2 foi instrumentado com uma placa LCP pré-contornada posterolateral com oito orifícios (3,5 mm de diâmetro) colocada na parte distal do úmero. Testes de flexão e testes de torção a quatro pontos foram realizados até que os corpos de prova quebrassem. Resultados: O teste de rigidez à flexão de quatro pontos mostrou que a rigidez dos úmeros fixados anterolateralmente foi significativamente maior do que os úmeros fixados posterolateralmente (p <0,05). O teste de torção revelou que a fixação posterolateral foi associada a melhor força de rendimento (p <0,05), mas a rigidez à torção não diferiu significativamente entre as duas placas (p > 0,05). Conclusões: A placa anterolateral apresentou maior rigidez à flexão e resistência à tração do que a placa posterolateral. A fixação anterolateral da placa pode, portanto, ser usada para tratar fraturas extra-articulares da parte distal do úmero. Os parafusos de travamento multiaxiais garantem uma fixação rígida, permitem o movimento precoce do cotovelo sem causar impacto à fossa do olécrano e previnem lesão iatrogênica do músculo tríceps. **Nível de evidência I, Estudos terapêuticos - Investigação dos resultados do tratamento.**

Descritores: Fixação de Fratura. Fraturas do úmero. Fixação interna de fratura.

INTRODUCTION

The goal when treating distal humeral fractures is anatomic alignment and constant fixation, to gain early motion to the elbow.[1] Distal third of the humerus has complex deforming forces due to the elbow joint and muscle anatomy.[2] Single-plate fixation is inadequate, particularly for low-lying fractures, given the limited space of distal humerus anatomy. This issue is often addressed either by placing a precontoured 3.5-mm locking compression plate

(LCP) via a posterior approach, or by placing a second plate to treat more distal fractures. The use of two plates requires extensive soft tissue dissection and exposure of the radial nerve, and may disturb the blood supply, thus causing non-union. However, when placing the plate posteriorly, fixing both columns of distal humerus is difficult via screw insertion into the small distal fragment impinging on the olecranon fossa.[3,4] To address these issues, a helical 3.5-mm LCP plate was recently introduced. The plate is modelled on a distal tibial metaphyseal plate, and extends from the lateral to the anterior surface of the humerus. The precontoured helical structure is congruent with the areal anatomy and allows insertion of up to 12 screws with minimal exposure.[5] We hypothesized that the helical plate would be more rigid than a posterolateral precontoured LCP plate.

## MATERIALS AND METHODS

Plate

Plate selection and application depends on the fracture pattern.[4] To ensure rigid (two- column) rotational fixation, finite element analysis was used to design a new anterolateral anatomical plate (Figure 1).[6] We devised a prototype with an appropriate screw configuration (Figure 2).

Study groups

We tested 24 fourth-generation composite humeri (model #3404; Pacific Research Laboratories, Inc., Vashon, WA, USA), all of which were left-sided and exhibited distal extra-articular oblique fractures located 60 mm from the lateral trochlear centre and 40 mm from
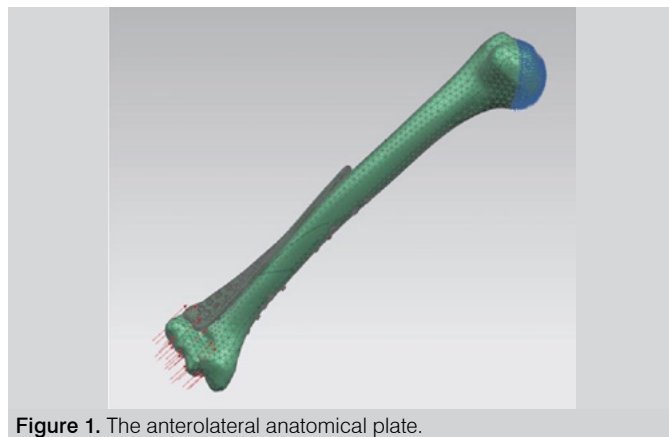

Figure 1. The anterolateral anatomical plate.
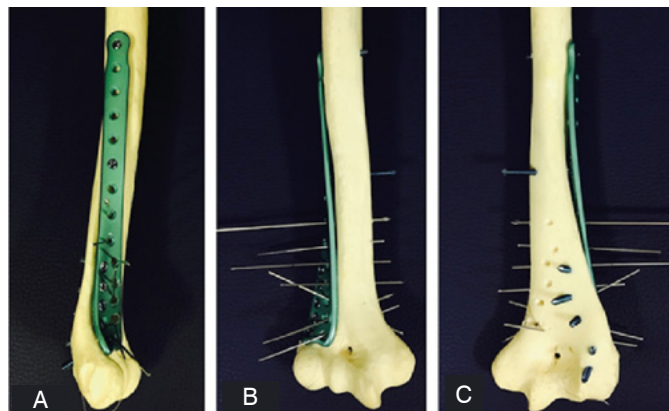
Figure 2. The locking screw configuration used to fix the double column with K-wires. A: Anterolateral plate placement, B: Anterior view, C: Posterior view.

the medial side. In Group 1, all fractures were fixed using a new anterolateral, anatomical, 8-hole (3.5-mm-diameter) LCP (Ilerimed, Istanbul, Turkey) (Figure 3). In Group 2, an 8-hole 3.5 mm precontoured posterolateral distal humeral LCP (Ilerimed) was employed (Figure 4). After plate fixation, redundant humeral bone was removed. In both groups, six specimens were used for the four-point bending tests, and six for torsion testing.

Our study did not include any human or animal test subjects; therefore, no ethics committee approval was required.

Biomechanical testing

We followed the Standard Specification and Test Method for Metallic Bone Plates (ASTM F382-14); the contact points of the loading rollers and plates were located between pairs of screw holes. Similarly, the support rollers and posterior surfaces were arranged to prohibit interaction between screws and support rollers. The distance between the supporting and loading rollers, and between the posterolateral and anterolateral plates, was 112 and 24 mm, respectively. To determine plate yield strength, four-point bending tests were conducted on six specimens of each type of plate. When placing the humeral bones, the anterior surfaces of composite models were in contact with the supporting rollers and posterior surfaces were in contact with the loading rollers. The support points were centred to ensure plate symmetry. The four-point bending test was performed using a tabletop biaxial servohydraulic test system (3369; Instron Corp., Canton, MA, USA) (Figure 5). During the tests, a constant load was applied to all specimens at a rate of 5 mm/min. All tests proceeded until fracture.[7,8] To prepare specimens for torsion testing, some humeral bone was removed from the distal ends and the specimens were potted in polyurethane resin (Unate; Unicom
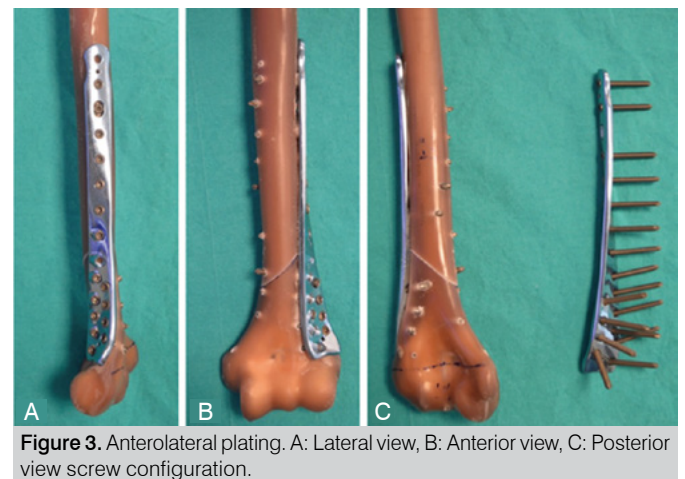
Figure 3. Anterolateral plating. A: Lateral view, B: Anterior view, C: Posterior view screw configuration.
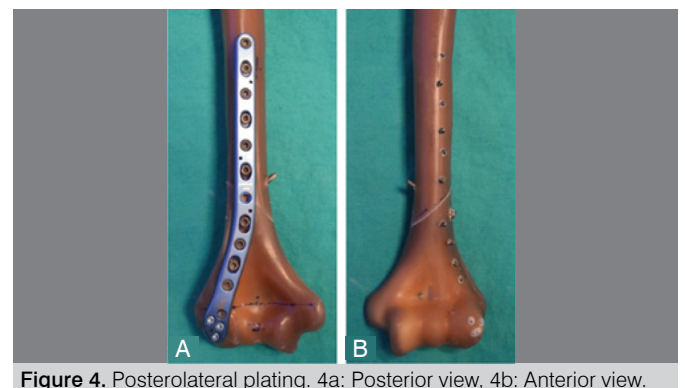
Figure 4. Posterolateral plating. 4a: Posterior view, 4b: Anterior view.

Corp., Istanbul, Turkey) (Figure 6). To ensure accuracy, the distal ends were centred to reflect the biomechanical alignment of the humerus along its longitudinal axis. We then drilled a pinhole in the resin to hold the fixed torsion shaft. We used a steel device to grasp the proximal end of each humerus; to prevent humeral dislocation, all specimens were compressed between the fixed and moving ends. We were careful to ensure that all specimens were placed along the torsional rotation axis. A 55MT device was used for torsional testing (Instron, Norwood, MA, USA). Torsional testing method includes preliminary loading with the rate of 0.5°/sec until specimen is loaded with 0.3 Nm. When this load level was obtained, tests were proceeded with the constant rate of 2°/sec rotation until fracture.[9,10]

Statistical analysis

The SPSS statistical software package for Windows (version 11.5; SPSS Inc., Chicago, IL, United States) was used for the statistical analyses. The Shapiro-Wilk test was used to determine if the distributions of continuous variables were normal. The non-parametric Mann-Whitney *U* test was used to determine which group differed from the other groups significantly according to *P* value, with the threshold for significance set at 0.05.

RESULTS

The four-point bending stiffness values were 2,815.97 $\pm$ 225.68 and 1,374.82 $\pm$ 72.51 N/mm for the anterolateral and posterolateral plates, respectively. The average loads at the yield points are listed
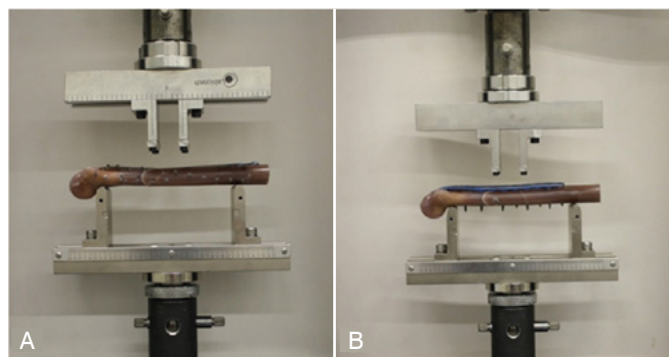
Figure 5. Experimental setup for the four-point bending test. The distance between the rollers was set to avoid contact between the screw holes and the rollers. A: Anterolateral group, B: Posterolateral group.
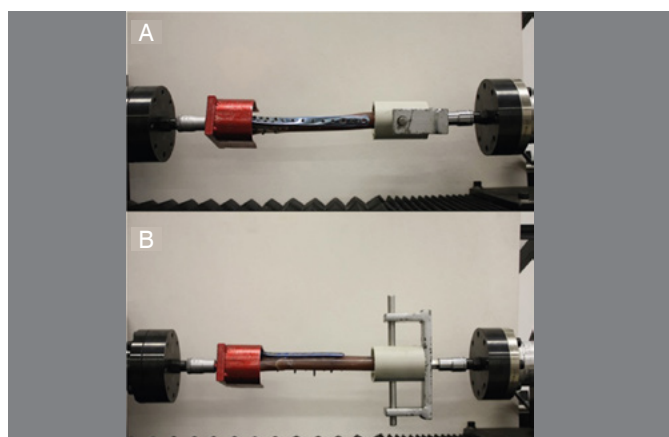
Figure 6. Experimental setup for torsion testing of humeral specimens. Potting of humeral bone models in polyurethane resin. A: Anterolateral group, B: Posterolateral group.

in Table 1. The bending stiffness of the anterolateral plate was significantly greater (p<0.05) than that of the posterolateral plate. The average peak torques are listed in Table 1. The torsional stiffness values were 1.37 $\pm$ 0.10 and 1.37 $\pm$ 0.19 Nm/° for the anterolateral and posterolateral plates, respectively; the former plate exhibited a higher torsional yield strength than the latter (p<0.05), but torsional stiffness did not differ significantly (p>0.05).

Table 1. Four-point bending and torsion test results.

Variable		Group 1 (Anterolateral)		Group 2 (Posterolateral)		P-value
		Mean	SD	Mean	SD	
Four- point bending test	Load at yield (N)	3,867	175.12	1,768	200.62	<0.0001
	Displacement at yield (mm)	1.38	0.16	1.28	0.09	<0.005
	Stiffness (N/mm)	2815.97	225.68	1374.82	72.51	<0.001
Torsional test	Torque at yield (N.m)	32.67	3.01	23.33	1.63	<0.0001
	Displacement at yield (º)	23.83	1.47	17.17	1.72	<0.005
	Stiffness (Nm/º)	1.37	0.10	1.37	0.19	>0.05

DISCUSSION

The new, precontoured, anterolateral helical plate exhibited superior biomechanical properties based on the four-point bending and torsional tests. The advantages of the helical plate include the anatomical design, bone fixation in different planes, and the need for only minimally invasive surgery.[11] Manual contouring is not recommended, because it is associated with excessive screw-hole deformation that leads to plate fatigue failure.[12] The plate was precontoured to the distal anterolateral humeral surface. Two columns may be fixed using up to 10 screws placed into the distal fragment, without any impingement of the olecranon fossa. Parmaksizoglu et al.[5] used titanium cobra head plates (originally manufactured for the distal end of the tibia) to treat humeral fractures, and observed complete healing of all 23 studied patients. This prompted us to redesign an existing helical plate to repair the distal end of the humerus. For comparison, we choose a posterolateral plate rather than a single 3.5-mm LCP, because Scolaro et al.[4] recently reported that the average bending and torsional stiffness values of a posterolateral plate were significantly higher than those of an LCP. Conservative treatment for distal humeral fractures is not always successful. The most common reason for surgery is failure to achieve or maintain acceptable reduction. Jawa et al.[13] compared the outcomes of conservative treatment and surgey; fracture alignment and the functional results were better after surgery.

Anterolateral distal screws do not approach the joint, but the posterolateral plate passes over the joint line and it is hard to put the distal four screws into the lateral epicondyle; surface of the joint is damaged if the screws are too long. Also, the arterial supply to the distal humerus is at posterior region of the lateral epicondyle; iatrogenic injury, scarring, or osteonecrosis may develop with use of a posterolateral approach.[14] Prasarn et al.[15] described dual plating for more rigid fixation of distal humerus fractures via a posterior approach. They stated the importance and difficulty of both column fixation for early elbow motion. Yin et al.[16] compared the posterior and lateral approaches for management of extra-articular distal humeral fractures. The posterior group exhibited significantly more complications, including iatrogenic radial nerve palsy, implant irritation and triceps rupture. We think that the use of two plates may disturb bone circulation, and that anterolateral helical plating allows for stable osteosynthesis after rigid fixation of both columns. A limitation of our study was that the specimens were not cadaveric bones, being rather fourth-generation composite bone models

designed for biomechanical studies and lacking soft tissue. An advantage of using composite bone models is the homogeneity of specimens in comparing the two groups, making the plates themselves and the techniques of their insertions the sole different variables between groups. Cadaver bones may differ among size, porosity, tisddue stiffness and other variables. The main strength of our study was that we presented a strong fixation technique using a new plate. Prospective randomised clinical trials are required to validate our results.

CONCLUSION

The anterolateral plate exhibited higher bending stiffness and torsional yield strength than the posterolateral plate. Anterolateral plate fixation can be used to manage extra-articular distal humeral fractures. Multiaxial locking screws allow for rigid fixation and early elbow motion without impingement of the olecranon, and pose no risk of iatrogenic triceps muscle injury.

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