A mechanical comparison between conventional and modified angular plates for proximal humeral fractures

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The objective of this study is to present a modified angular blade plate for fixing 2-part and even 3-part fractures of the proximal humerus, as well as the results of the comparative mechanical test between the conventional angular blade plate and this new modified plate. The plates were tested in flexion and rotational trials in a wooden model that simulated a 2-part humeral fracture of the proximal extremity. The results (mean ± SD) of bending strength and stiffness obtained after testing showed findings of 601 ± 349 N and 0.5 ± 0.2 N/mm, respectively, for the conventional plate and 4005 ± 164 N and 3.9 ± 0.7 N/mm, respectively, for the modified plate. The torsional stiffness test showed findings of 1.26 ± 0.09 KN·mm° for the conventional plate and 1.74 ± 0.21 KN·mm° for the modified plate. The test of torsional moment showed findings of 57.0 ± 7.6 KN·mm for the conventional plate and 115.2 ± 9.3 KN·mm for the modified plate. The test of angular displacement at the torsional moment showed findings of 50.8° ± 7.2° for the conventional plate and 70.2° ± 2.6° for the modified plate. The results of the mechanical trials of flexion and rotation were superior for the modified angular blade plate compared with the conventional angular blade plate. (J Shoulder Elbow Surg 2008;17:631-636.)

Proximal humeral fractures, especially 3-part or 4-part fractures, still generate debate regarding accurate diagnosis and the most adequate treatment.[6]

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When surgical management is indicated for these fractures, the disagreement is centered on the type of fixation to be used for maintaining reduction.[9] Fixation depends on several factors, ranging from the type of fracture to the quality of the fractured bone.[2,5] Fixation of the cephalic segment is vital in this type of fracture because it usually occurs in the elderly, who already have osteopenia.[8]

Regarding the type of fixation, biomechanical studies have intimated that the best stability is obtained by use of a plate and screws, especially for 2-part fractures.[9] Among the various options, the angular blade plate is one of the most widely used for treatment of metaphyseal fractures, but it sometimes does not work well. We designed a new plate to achieve better fixation for proximal humeral fractures.

The objective of this study is to present a new concept of fixation using a modified angular blade plate and to compare the results between mechanical tests of a conventional angular blade plate and a modified blade plate.

MATERIAL AND METHODS

Fifteen austenitic stainless steel plates (ASTM F138) of the 90° angular blade type were used, ten of which were considered conventional plates. Of the latter, five were tested alone and the other five were attached to a wooden model that simulated a 2-part fracture of the proximal humerus.[10] The remaining five modified plates are characterized by two special screw holes, one in the vertical lamina and the other in the horizontal one, through which a cannulated screw with a special thread passes, connecting and compressing the two orifices of the plate. The "connecting" screw is passed through the two special holes guided by a Kirschner wire that was previously introduced with a guide (Figure 1).

The tests were realized by use of wooden models designed from a bone model of an adult cadaver that presented constant mechanical characteristics.

Ten wooden models with similar mechanical characteristics simulating the proximal portion of the humerus were used. By use of a 0.8-mm saw, an oblique 110° fracture was reproduced in all of the models, in relation to the longitudinal axis of the diaphysis, simulating a fracture of the surgical neck of the humerus.[3] The two parts were then fixed and stabilized in the initial position (reduction position) by the angular blade plate.

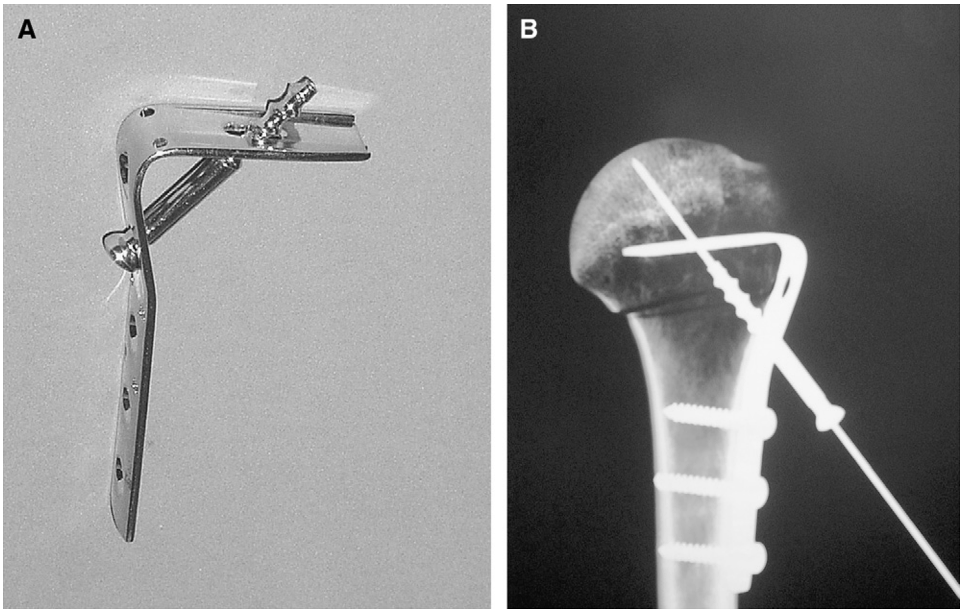

Figure 1 A, Modified 90° angular blade plate, with special connecting screw. **B**, Radiograph of the wooden model simulating the proximal humeral extremity with an oblique "fracture," fixed via the modified plate with a Kirschner wire guide and the connecting screw.

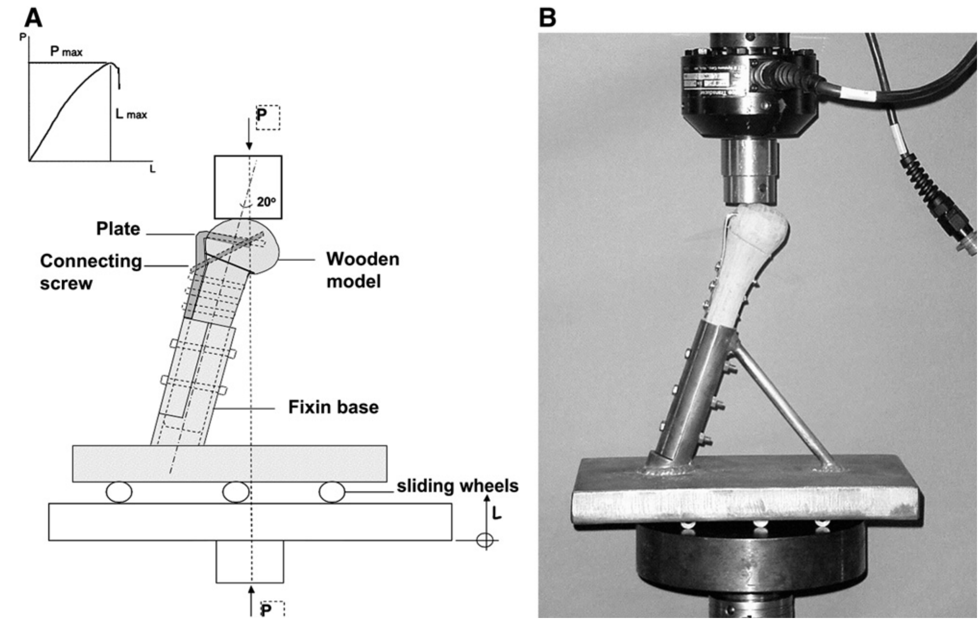

Figure 2 A, Sketch of assembly and methodology used for the mechanical tests. **B**, Complete assembly with fixation device for study. *P*, Applied load; *L*, displacement.

Five sequential experiments of static flexion and torsion were realized by use of the angular blade plate only and following ASTM F384 standards.[1] The goal was to confirm whether the curves of resistance to flexion, to torsion, and to stiffness are proportional to those curves obtained in the tests using the plate fixed to the wooden model and, therefore, capable of comparison.

Five consecutive trials were applied to each type of plate (conventional and modified) fixed to the model simulating a fracture of the surgical neck to test resistance to the

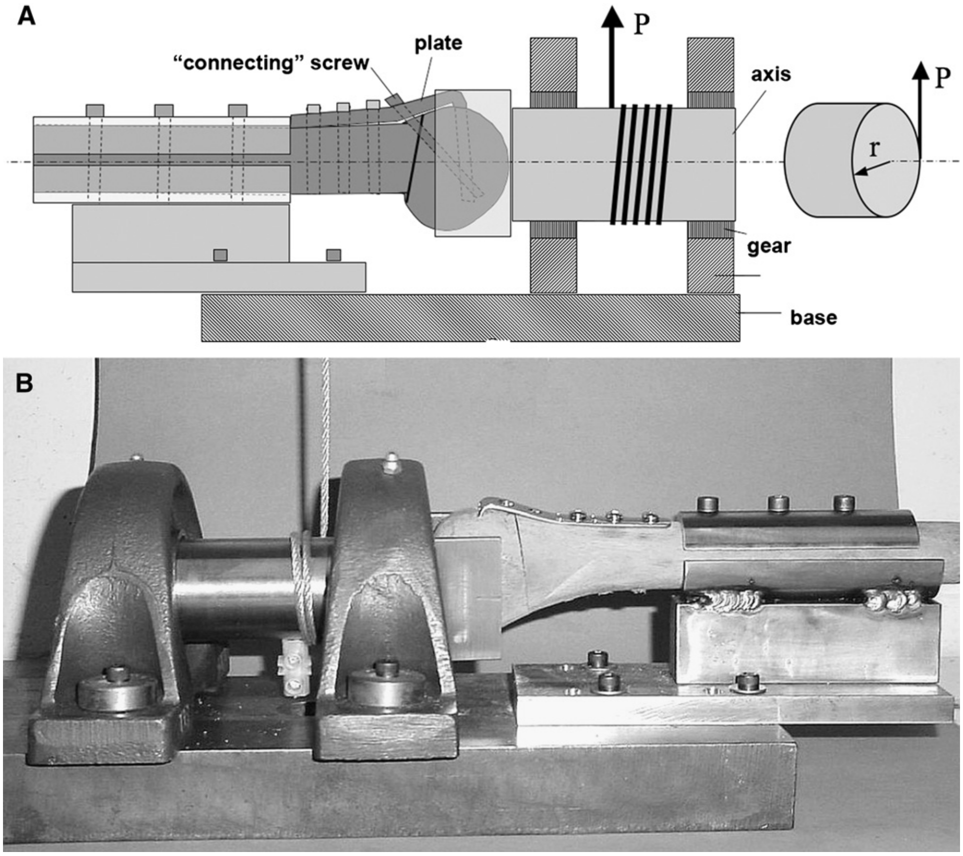

Figure 3 A, Setup of assembly and method used for rotational trials. **B**, Complete setup with fixation device for torsional tests. *P*, Applied load.

compression forces, based on the protocol of Koval et al.[9] The trials were realized by use of a servohydraulic machine (Test Star II model with a 10-ton load capacity; MTS Systems, Eden Prairie, MN), with displacement control.[2] Data were obtained for the applied load as a function of vertical displacement of the piston. The vertical displacement speed was 5 mm/min. The static flexion tests were discontinued after the maximum load tolerated by the plates was reached.

The plates fixed to the "fractures" in the wooden models simulating the proximal humerus were secured to a special fixation device specifically developed for this type of study (Figure 2).

Because we are dealing with a comparative, entirely mechanical test between 2 similar plates, except for the mechanism of fixation, the maximum loads were measured and compared. The maximum load corresponds to (1) the load immediately before a drop or marked interruption of the experimental load that, in turn, was associated with an abrupt slide of the proximal segment of the wooden model from its initial position and (2) the displacement between the two "fractured" segments of the maximum load, as previously defined.[2]

The same method used for the static flexion testing was also used for the torsion tests for each type of plate (conventional and modified). The static torsion tests were conducted with an MTS servohydraulic machine (Test Star II model) with a fixation device developed especially for this test. The speed of the load applied was 5 mm/min.

The following parameters were determined: torsional stiffness, moment of maximum torsion, and angular dislocation at the moment of maximum torsion.

A device was developed for this type of test and was attached to the plates, fixing the "fracture" to the wooden models that simulated the proximal extremity of the humerus (Figure 3).

The Kolmogorov-Smirnov test was applied to test the hypothesis that normal distribution would occur in each evaluation, that is, in each group of the study, and this hypothesis was not rejected for any of the variables ($P > .05$ for all tests applied). The Student *t* test for independent samples was used for comparing the variables analyzed in all the groups. A level of significance of .05 ($\alpha = 5\%$) was adopted for all the trials, and descriptive levels (*P* values) lower than this value were considered statistically significant.

The tests were developed at the Department of Engineering of Material, College of Mechanical Engineering, State University of Campinas, São Paulo, Brazil.

RESULTS

Trials of flexion and stiffness were conducted on conventional plates that were not applied to the

Table I Mean values for flexion and stiffness

Plate	Bending strength (N) (minimum-maximum)	Stiffness (N/mm) (minimum-maximum)
Conventional (n = 5)	601 ± 349 (274-983)	0.5 ± 0.2 (0.3-0.8)
Modified (n = 5)	4005 ± 164 (3770-4173)	3.9 ± 0.7 (3.3-5.0)

$P < .001$, Student *t* test.

wooden model to study the resulting features and the graph obtained. The mechanical characteristics of the isolated plate after testing resulted in 127.6 N of mean bending strength (range, 109-143 N), with an SD of ±12.3 N, and 30.3 N of mean stiffness (range, 27.3-34.9 N), with an SD of ±3.0 N. The curves obtained on isolated trials of the plates have the same characteristics as those obtained on the wooden models and therefore are qualified for comparison.

Flexion trials

The results obtained after the static flexion and stiffness tests in the wooden models with the conventional and modified fixed angular blade plates are shown in Table I and represented by the curve shown in Figure 4.

A statistically significant difference was noted among the groups studied with the conventional and modified fixed angular blade plates (with and without the connecting screws), regarding the mean bending strength ($P < .001$). The mean of the group fixed with the modified plate (with the connecting screw) was significantly greater than the mean of the group fixed with the conventional plate (without the connecting screw).

Rotational experiments

The results of the tests of torsional stiffness, torsional moment, and angular displacement at the maximum torsional moment in the wooden models with the conventional and modified fixed angular blade plates are shown in Tables II, III, and IV and represented by the curve shown in Figure 5.

A difference was noted between the group with the conventional fixed angular blade plate and the group with the modified blade plate (with and without the connecting screws) with regard to the mean torsional stiffness ($P = .004$). The mean stiffness of the group fixed with the modified plate (with the connecting screw) was significantly greater than the mean of the group fixed with the conventional plate (without the connecting screw).

A significant statistical difference was noted between the groups fixed with conventional and modified angular blade plates (with and without the "connecting screw") with regard to the mean torsional moment ($P < .001$). The mean moment of the group fixed with the modified plate (with the connecting screw) was significantly greater than the mean of the group fixed with the conventional plate (without the connecting screw).

A statistically significant difference was noted between the groups with conventional and modified fixed angular blade plates (with and without the connecting screws) with regard to the mean angular displacement at the maximum torsional moment ($P = .002$). The mean displacement of the group fixed with the modified plate (with the connecting screw) was significantly greater than the mean of the group fixed with the conventional plate (without the connecting screw).

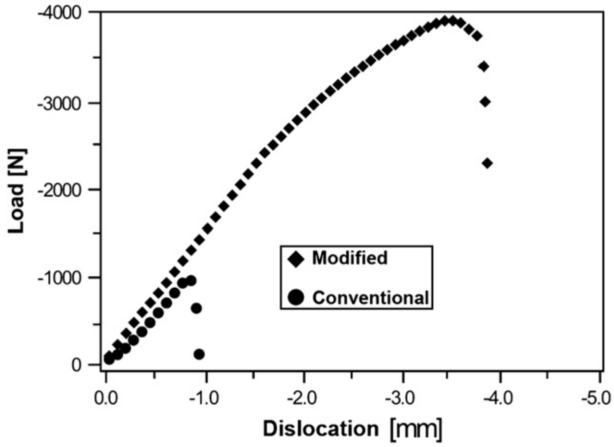

Figure 4 Representative load-displacement curve, obtained from static flexion trials applied to wooden models fixed with angular plates.

Table II Mean values for torsional stiffness

Plate	Torsional stiffness (kilonewtons per millimeter per degree) (minimum-maximum)
Conventional (n = 5)	1.26 ± 0.09 (1.12-1.34)
Modified (n = 5)	1.74 ± 0.21 (1.42-1.95)

$P = .004$, Student *t* test.

DISCUSSION

Many types of implants are available for fixing deviated metaphyseal fractures. There is evidence that, among them, the angular blade plate is a good option for fixation, principally for well-defined 2-part

Table III Mean values for torsional moment

Plate	Torsional moment (kilonewtons per millimeter) (minimum-maximum)
Conventional (n = 5)	57.0 ± 7.6 (49-69)
Modified (n = 5)	115.2 ± 9.3 (101-124)

$P < .001$, Student *t* test.

Table IV Mean values for angular displacement at maximum torsional moment

Plate	Angular displacement at maximum torsional moment (°) (minimum-maximum)
Conventional (n = 5)	50.8 ± 7.2 (43-59)
Modified (n = 5)	70.2 ± 2.6 (67-74)

$P = .002$, Student *t* test.

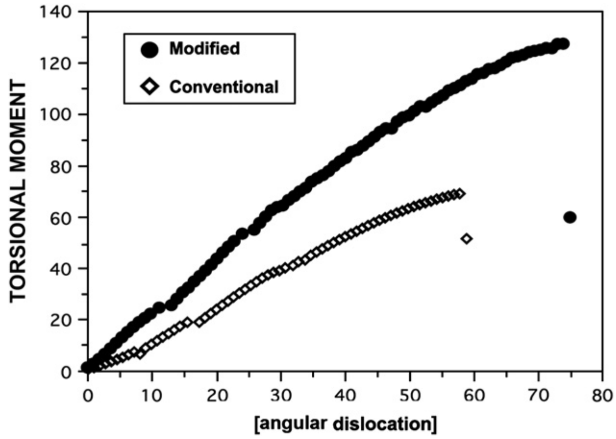

Figure 5 Representative torsional moment curve, obtained from static torsional trials applied to wooden models fixed with angular plates.

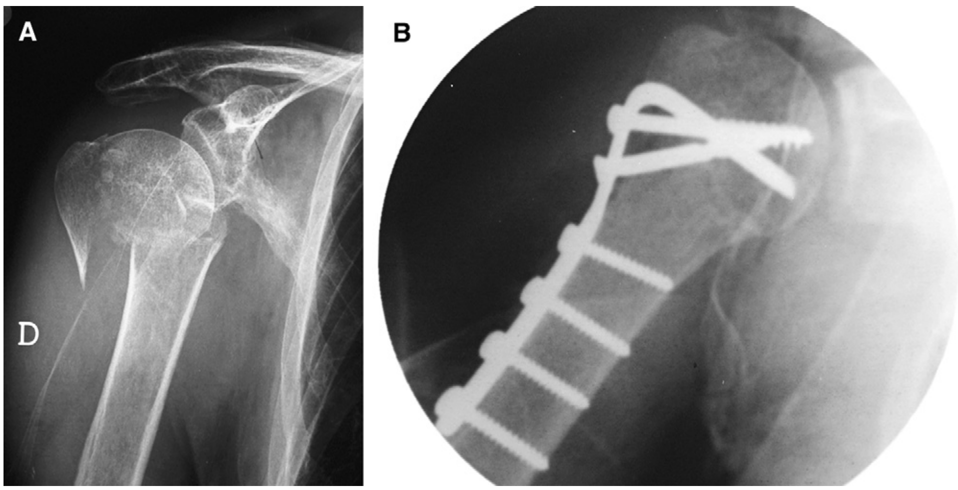

Figure 6 A, Three-part proximal humeral fracture. **B**, Clinical application of modified angular blade plate after reduced fracture.

fractures. The major difficulties are encountered in treatment of osteopenic bones. Currently, there is a tendency to use screws connected to the plate and that are not parallel to one another, ''locking'' a segment of bone and, in this way, functioning as an internal attachment.[4,7,8]

The modified plate presented in this report provides good support for the wooden models simulating the proximal humerus, through the lamina, as well as good fixation by the ''locking in'' of a model segment between the special connecting screw that is fixed between the vertical and horizontal laminae. This connecting screw between the 2 laminae promotes maximum stiffness and stability to the fixation device. In addition, there is the possibility of achieving flexion between the 2 laminae by tightening the connecting screw. Flexion between the 2 laminae increases compression on the region opposite the vertical lamina (in the case of the humerus, at the fractured medial cortical) that seems to provide major stability and resistance to the system. The connecting screw has a blocking system that allows only small amounts of flexion in the lamina (Figure 1).

The material features of the models used for fixing the plates, as well as for the mechanical tests of the conventional and modified plates, did not vary, because the wooden model showed uniform characteristics. Thus the data are accurate, and consequently, a precise comparison between the results of the 2 types of plate was achieved.

The results of the mechanical tests of the modified plate were all significantly superior to those of the conventional blade plates. In addition, we were able to verify that the descriptive level (*P* value) was less than .002 when a level of significance of .05 ($\alpha = 5\%$) was applied.

The modified plate has presented better mechanical results in wooden models simulating the proximal humeral fracture, it is necessary to verify its performance in the human humeral fracture. There are different types of fractures in the proximal humerus, and the modified plate was tested only for one type of fracture.

The modified angular blade plate has been used clinically, with good stability and fixation of the fractured parts. When some compression is necessary at the focus of the fracture, this can be achieved by tightening the special connecting screw to its limit. This limit corresponds to a maximum of 0.5 cm of flexion at the distal part of the lamina. The clinical application of this implant is currently being investigated and will be the subject of another report (Figure 6).

In conclusion, the results of the mechanical tests of flexion and rotation with the modified angular blade plate were superior to those of the conventional angular blade plate.

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