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Dual plating for fixation of humeral shaft fractures: A mechanical comparison of various combinations of plate lengths

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Objective: The role of plate configuration was found inconclusive on the biomechanical effects of the plate size and hole number for dual plate constructions in humeral shaft fractures. The purpose of this study was to test the biomechanical stability of various dual plate constructions.

Methods: Twenty-four left humeri (4th Generation Composite Humerus, Sawbones, Malmö, Sweden) with comminuted midshaft humeral fracture were used. Four groups of plate constructs were tested: laterally fixed 8-hole locking plate and screws were combined with anteriorly locking plates containing 0, 4, 6, or 8 holes in groups I, II, III, and IV, respectively. The alterations in axial, bending, and torsional angles were recorded.

Results: There were no fixation failures during axial, bending, or torsional stiffness testing within the elastic behavior limits. Axial stiffness was highest in Group IV. Torsional stiffness, posterior-to-anterior bending stiffness, lateral-to-medial bending stiffness, and medial-to-lateral bending stiffness were lowest in Group I.

Conclusion: The similar stiffness values for the 8-to-4 hole and 8-to-6 hole plate constructions indicate that the 8-to-4 hole construction is an option in young adults, while the stiffest 8-to-8 hole combination may be an option for osteoporotic patients.

Introduction

Diaphyseal humeral fractures are seen relatively more frequently in the elderly population.[1] Even though nonoperative treatment is preferable, osteopenia as a result of lack of use leads to the need for options for internal fixation to avoid high levels of disability associated with humeral shaft nonunion.[2]

In humeral shaft fractures managed by surgery, the conventional manner for internal fixation is the use of large fragment plates. However, the variable size and shape of the humerus creates difficulties during the procedure in determining the appropriate combination of plate size and screw number.[3] The recent literature indicates that the use of dual plate yields better results in terms of mechanical properties than does the use of large fragment plate.[4] In the use of dual plate, the layout angles of the plates relative to the humeral shaft is controversial. Placement of the anterior and lateral plates at 90° was found to be best configuration for dual plating.[5]

Despite the increased usage of locking plates in osteoporotic humeral shaft fractures, the few studies on the plate configuration were inconclusive regarding the biomechanical effects of plate size and hole number in dual plate constructions. The purpose of this study was to test the biomechanical stability of various dual plate constructions.

Patients and methods

Twenty-four left humeri (4th Generation Composite Humerus, Sawbones, Malmö, Sweden) were used in the present study. The specimens were embedded in cement at both ends, which were cut into a cylindrical shape to facilitate insertion into the testing grips. The center of the bone was determined by vernier calipers, and a

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comminuted midshaft humeral fracture was modeled with a 1-cm midshaft gap created with a surgical reciprocating saw.[6–8] All specimens were prepared by the same 2 orthopedic surgeons. Standard technique for plate fixation was performed, placing all of the screws bicortically. The osteotomy provided a noncontact situation, allowing for isolated testing of the plate constructs.

Four groups of plate constructs were tested. Group I specimens were fixed laterally by an 8-hole 3.5-mm locking plate (8hLP) (all locking plates used in this study were produced by Med Tıp Medical Device Company A.S., Izmir, Turkey), Group II specimens were fixed laterally with an 8hLP and anteriorly with a 4hLP, Group III were fixed laterally with an 8hLP and anteriorly with a 6hLP, and Group IV were fixed both laterally and anteriorly with an 8hLP (Fig. 1).

All tests were performed with a mechanical test machine (AG-IS 10 kN, Shimadzu, Kyoto, Japan). The humeral bone models were fixed to the load cell of the test machine. The axial load was applied to the cylindrical embedded end (Fig. 2). In all tests, the alterations in axial, bending, and torsional angles were recorded both in loaded and unloaded states.

The bone-plate constructs were tested under axial loading with the embedded humeral head. While simultaneously recording the vertical displacement and strain, 500 N for 5000 cycles at 3 Hz were applied. Displacement was recorded.[4]

A 4-point bending model was used for the anterior-posterior, posterior-anterior (sagittal plane), medial-lateral, and lateral-medial (coronal plane) testing. In each bending test, a maximal load of 250 N was applied at 10 mm/min. Bending moment was applied to the same point by centering the device on the midpoint of the fracture gap. Load versus displacement values were recorded to calculate the bending stiffness and flexibility.

Torsion test was performed with a servo sync torque machine (SQM132, 245 Nm 100 rpm, ELSIM Elektroteknik A.S, Istanbul, Turkey). The torsion tests were conducted in the displacement control mode with a maximum moment of 4.5 Nm in both directions; the premoment was 0 Nm, and the test velocity was 0.3°/second. The testing cycle was applied from 0 to 4.5 Nm. Torque versus the degree of angle deformation values were recorded.[7–9]

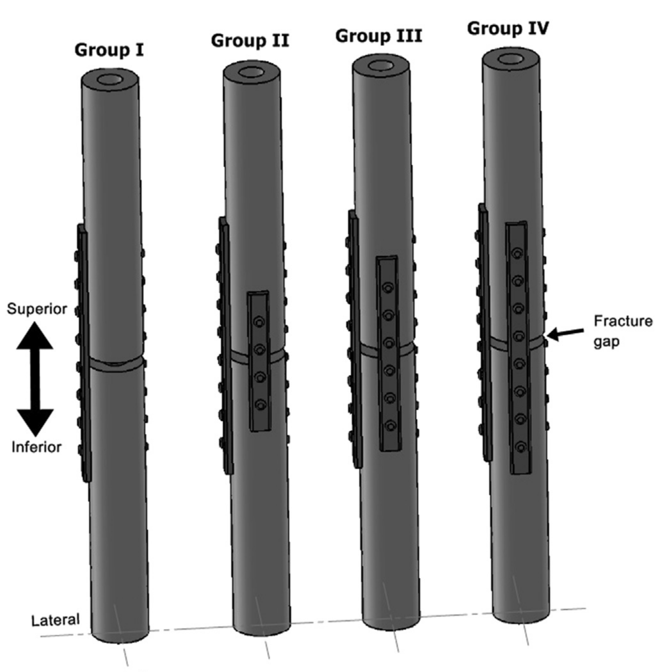

Fig. 1. Schematic illustration of the plate configurations.

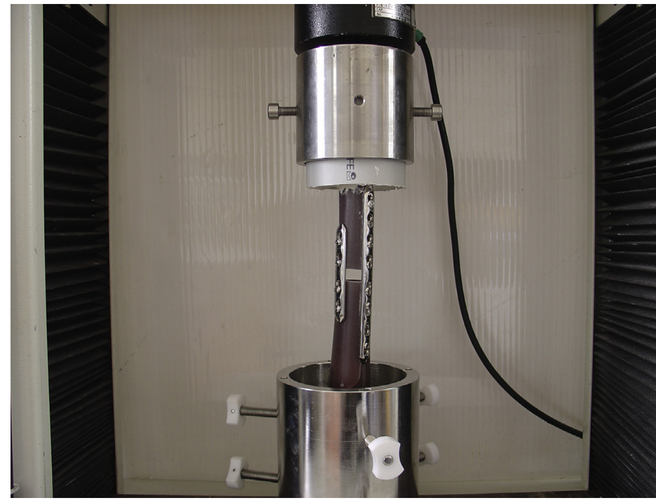

Fig. 2. Axial load was applied to the cylindrical potted end.

Each specimen was tested 3 times in bending and torsion tests to ensure reproducibility of the results. All tests were performed within the elastic behavior limits of the construct; the load–deflection data did not show any sign of plastic or permanent deformation for any of the constructs in any orientation. The testing was performed in the same order for each sample. Statistical analysis was conducted with Mann–Whitney U test by using SPSS software (version 15.0, SPSS Inc., Chicago, IL, USA). The level for significance was defined as $p < 0.05$.

Results

There were no fixation failures during axial, bending, or torsional stiffness testing within the elastic behavior limits. Mean stiffness values of all groups are presented in Table 1. Axial stiffness in Group IV was 706.2 N/mm, which was significantly higher than in Group I (475.6 N/mm, $p = 0.004$), Group II (516.6 N/mm, $p = 0.025$), and Group III (543.5 N/mm, $p = 0.006$) (Fig. 3).

For torsional stiffness measurements, stiffness in Group I was 6.31 N/degree, which was significantly lower than in Group II (12.16 N/degree, $p = 0.01$), Group III (11.51 N/degree, $p = 0.01$), and Group IV (15.10 N/degree, $p = 0.006$) (Fig. 4).

Bending stiffness was also compatible with the previously described results. By all of the measured parameters of stiffness (posterior-anterior bending, lateral-medial bending, medial-lateral bending) results for Group I were significantly lower than for all of the other groups (Fig. 5).

Discussion

Plate fixation is the gold standard for treatment of humeral nonunion. It enables compression, correction of malalignment, and stimulation of osteogenesis (grafting) in a single procedure.[10] Humeral nonunion can be severely disabling. Although several authors have recommended plate fixation for the management of nonunion at midshaft level, inappropriate plate fixation techniques are one of the main reasons that fractures fail to heal.[11–16] Foster et al reported that the most common indication for surgical management of a humeral shaft fracture is a concurrent multiple injury, and the second is nonunion of humeral shaft fracture. They reported a 96% success rate for union in their study, using both single- and dual-plate constructs either with or without lag screws.[11] Murray et al pioneered the use of double-plate constructs for