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Proximal humeral fracture fixation: a biomechanical comparison of two constructs

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Background: Different options exist for stabilizing proximal humeral fractures. This study compared the mechanical stability of 2 common proximal humeral fixation plates in bending and torsion.
Methods: Tests were conducted on 40 synthetic and 10 matched pairs of cadaveric humeri (evenly fixed with DePuy S3 proximal humeral plating system [DePuy Orthopaedics, Warsaw, IN, USA] and Synthes proximal humerus locking compression plate [Synthes, Paoli, PA, USA]). Half of the humeri were tested by cantilevered bending in flexion, extension, varus, and valgus for 100 cycles of ±5 mm of displacement at 1 mm/s before loading to failure in varus. The other half were tested in torsion for 100 cycles of ±8° of rotational displacement at 1°/s before loading to failure in external rotation.
Results: Peak cyclic loads for synthetic constructs were higher for DePuy plates than Synthes plates in varus and valgus ($P < .0001$), but a difference was not detected in extension ($P > .40$) or flexion ($P = .0675$). Peak cyclic loads for cadaveric constructs showed a significant difference in extension and flexion (Synthes > DePuy, $P < .0001$) and in varus (DePuy > Synthes, $P < .05$) but not in valgus ($P > .10$). Bending stiffness during varus failure testing was higher for DePuy plates than Synthes plates ($P < .0001$) for synthetic constructs. Regarding torsion of synthetic and cadaveric constructs, DePuy plates experienced higher peak cyclic torques over all cycles in both directions ($P < .0001$). For synthetic constructs, DePuy plates showed higher torsional stiffness in external failure than Synthes plates ($P < .0001$).
Conclusions: The DePuy plate was stiffer than the Synthes plate with varus and valgus bending, as well as in torsion. The Synthes plate tended to be stiffer in flexion and extension.
Level of evidence: Basic Science Study, Biomechanical Study.

Keywords: Proximal humeral fracture; locking plates; fracture fixation; biomechanics; sawbones; cadaveric study; bending; torsion

Proximal humeral fractures are the second most common upper extremity fracture and the third most common fracture in patients aged over 65 years, after femoral neck and distal radius fractures.[4] They comprise 5.7% of all fractures, mostly occurring in the elderly population, with a higher incidence in female patients.[3] The high prevalence in this population has prompted research questioning the ideal implant stiffness for operative fixation of these fractures.[13] Proximal humeral fracture treatment usually depends on age and mobility of the patient and the fracture type. The majority of proximal humeral fractures are minimally displaced and amenable to

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nonoperative management.[5] If a surgical intervention is necessary, numerous options are available, including percutaneous pinning, intramedullary nails, blade plates, locking plates, and arthroplasty. Biomechanical testing in our previous studies as well as others consistently favors locking plates over previous methods of fixation.[6,11,16,19,24] Superior biomechanical characteristics in the locking plate versus proximal humeral nail were shown when tested cyclically in varus bending and in torsion in comminuted 2-part surgical neck fractures.[6,11,16] Increased torsional stability was reported for the locking plate when compared with blade plates.[19,24] The evolution of surgical management for proximal humeral fractures has culminated in the prevalent use of locking plate fixation.

At our institution, the Synthes proximal humeral locking compression plate (LCP) (Synthes, Paoli, PA, USA) or the DePuy S3 proximal humeral locking system (DePuy Orthopaedics, Warsaw, IN, USA) is used when open reduction–internal fixation is required. The S3 plate provides the option of using smooth or threaded screws for humeral head fixation. The 2 constructs markedly differ in their position on the greater tuberosity and the angle of fixation, as well as their fundamental profile. To our knowledge, there has been no comparative evaluation of the biomechanical properties of proximal humeral locking plate systems. The purpose of this study was to compare, in both a synthetic bone model and cadaveric model, the mechanical stability of 2 commonly implemented proximal humeral fixation constructs in terms of cyclic loading and load to failure. Our null hypothesis was that there would be no biomechanical difference between the fixation constructs. The secondary objective was to qualitatively validate the synthetic bone findings in a cadaveric model.

Materials and methods

Forty anatomically accurate polyurethane foam/cortical shell left humeri (model 1028; Pacific Research Laboratories, Vashon, WA, USA) were used for mechanical testing, providing for a uniform material and geometry. The humeri were divided into groups of 20 specimens each fixed with either the Synthes 3.5-mm proximal humerus LCP or the S3 Proximal Humerus Plating System (DePuy Orthopaedics). Both plates were manufactured from 316L stainless steel; only the S3 system was right/left specific. These groups were further divided into 10 humeri for each plating system for experiments in bending or torsion. Validation tests were conducted on 10 matched pairs of cadaveric humeri (mean age, 62.4 years; range, 44-75 years) with the S3 system applied to left humeri and the LCP applied to the right. All specimens, which were comparable in size to that of the synthetic humeri, were stored frozen at –6°C before preparation for testing. A dual-energy x-ray absorptiometry scan was taken of each humeral head and shaft with the Hologics QDR-4500A system (Hologics, Waltham, MA, USA) by use of vertebral body modalities to determine bone mineral density. Two regions of interest were measured in an anteroposterior orientation. The first region of interest consisted of the majority of the metaphyseal/cancellous bone of the humeral head. The second region consisted of an appropriate area of the cortical bone of the shaft below the osteotomy where the plate was to be affixed.[18,22]

Specimen preparation

All constructs were prepared by the same surgeon (L.R.H.). A transverse cut with an oscillating saw was made at the surgical neck approximately 5 cm distal from the highest point of the humeral head to simulate a reproducible fracture in each specimen. The cut was partial thickness to keep the bone fragments in proper anatomic position for application of the plate. The cut was completed from the medial side after attachment of the plate (as described later), and a 10-mm block of bone was excised from the shaft to simulate comminution.

Fixation plates were installed per the manufacturers' suggested procedures, by use of the manufacturers' installation instrumentation. The 2 plates were of different lengths because of manufacturer design, with 5 distal holes in the LCP (114 mm in length) and 4 distal holes in the S3 plate (84 mm in length) (Fig. 1). However, we placed the same number of 3.5-mm screws (4) with sufficient length to engage both cortices in the shaft distal to the fracture site, with 1 hole in the LCP left unfilled. For the LCP, the 3 distal screws (32 mm long) were locking whereas the most proximal (34 mm long) was nonlocking. The S3 plate was affixed to the distal shaft similarly with a 34-mm screw followed by three 30-mm screws. The most proximal and distal 2 screws were locking. The humeral head screws in all specimens were placed to the level of subchondral bone per the manufacturers' recommended technique. For the LCP, six 3.5-mm unicortical locking screws were placed in both holes at levels A (two 40 mm), C (two 45 mm), and E (two 50 mm). For the S3 plate, all six 3.5-mm proximal locking screws were placed in a divergent mode to more accurately represent the predetermined diverging configuration of the S3 plate. Three 45-mm threaded pegs were placed in the apical holes followed by two 47.5-mm pegs and a 55-mm peg in the most distal hole (Fig. 2). Screw lengths were adjusted appropriately as cadaveric sizes warranted.

The distal shaft was then cut 21 cm from the proximal surface of the humeral head in all specimens, secured in an 8-cm-long section of 1-inch polyvinyl chloride pipe with two 1/8-inch steel transfixing pins, and potted in polymethyl methacrylate. Before bending or torsional tests, the proximal surface of each humeral head was potted in a 2 × 3–inch polyvinyl chloride connector to approximately 2 cm from the proximal cut at the surgical neck. Clay was placed over the hardware with enough space to allow for cutout and prevent the polymethyl methacrylate from adhering to the construct. After clay removal, the specimen was placed in a custom fixture to maintain proper alignment during testing. There was no impingement of the potting material with any portion of either type of fracture-fixation construct in any case. Potted specimens were mounted on biaxial servohydraulic Instron 1321 materials testing equipment (Instron, Canton, MA, USA) retrofitted with an MTS TestStarII controller (MTS, Eden Prairie, MN, USA) for torsion and bending tests (Fig. 3).

Testing procedures

For bending tests, the humeral shaft was oriented horizontally with the head rigidly held in place. Load was applied to the distal shaft at