Angular Stable Intramedullary Nail Versus Locking Plate Fixation of Osteoporotic Surgical Neck Proximal Humerus Fractures: A Biomechanical Comparison

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Introduction
Fractures of the proximal humerus are fairly common injuries accounting for approximately 4-5% of all fractures. There is a higher incidence of these injuries in patients with poor bone quality, especially the elderly and women (F:M ratio 4:1). Most (approx. 80%) are relatively nondisplaced and can be treated nonoperatively; however, operative intervention is recommended in approximately 20% of cases. The purpose of this study was to compare the biomechanical stiffness of a 2-part surgical neck proximal humerus fracture treated with a locking proximal humerus plate (LPHP) and an angrade angular stable intramedullary nail (locking IMN), as well as how fatigue affects the fracture fixation constructs. The null hypothesis was that there is no difference in the stiffness of these two fracture fixation constructs. Further pre-fatigue or post-fatigue, when used to instrument simulated 2-part surgical neck proximal humerus fractures in a synthetic osteoporotic bone model.

Materials and Methods
Synthetic composite osteoporotic humeral specimens were custom fabricated (Pacific Research, Vashon, WA) to mimic osteoporotic bone. The specimens were given the usual outer cortical shell of a 4th generation composite model with an elastic modulus and tensile strength of 16.0 GPa and 106 MPa respectively which is similar to the material properties of human cortical bone as reported by Bayraktar et al. However, these particular specimens were filled with solid rigid polyurethane foam with a density of 10pcf (0.16 g/cm$^3$). This is half the density of the standard cancellous inner foam material of the 4th generation composite model. This 10pcf foam has an elastic modulus of 55-77 MPa and a yield strength of 2.2 MPa which falls within the range of human cancellous bone and is the lowest grade of surrogate foam recommended by the ASTM (standard 1839) for modeling osteoporotic trabecular bone. A representative specimen was sectioned at five parallel planes through the proximal humerus in order to measure the cortical thickness which averaged 2.92 mm. This is comparable to the cortical thickness of elderly human proximal humeri as shown by Warner et al.

Identical simulated fractures were made through the surgical neck of the humerus in six specimens with the specimen mounted in a custom precision cutting jig. These specimens were then selected, at random, to be instrumented with a LPHP (n=3) or a locking IMN (n=3). The fracture fragments were then reduced manually and provisionally fixed with kirschner wires. The fracture fixation constructs were then applied, by the same surgeon, to the appropriate specimens according to the manufacturers surgical technique guide.

The biomechanical testing of all specimens, as well as the fatigue protocol, were carried out on a specially configured MTS Bionix 858 servohydraulic testing apparatus with four controlled axes. The stiffness of the fracture fixation constructs in anteroposterior bending, varus-valgus bending, axial loading, and torsion were tested first (pre-fatigue stiffness). In each case, the alignment and fixation of the specimens were identical. This was followed by a fatigue protocol which consisted of a random sequence of multi-modal loads applied to the specimen each second over a period of ten hours (36,000 cycles). Each cycle involved one of 27 different combinations of multi-modal load with each cycle having axial load (+375 N, 0 N, or -375 N), torsion, varus-valgus bending, and anteroposterior bending (each +3 N, 0 N, or -3 N). The random fatigue sequence generated for and applied to the first specimen was then repeated for the remaining specimens to ensure all specimens were subjected to identical fatigue loading simulating in vivo loads. The biomechanical stiffness of the fracture fixation constructs were then retested in the 4 loading modes described above (post-fatigue stiffness). The unaired student’s T-test was used to compare the pre-fatigue and post-fatigue stiffness of the LPHP to that of the locking IMN.

Results
The stiffness of the pre-fatigue fracture fixation constructs differed significantly with regard to three of the four modes of testing. Specimens treated with a LPHP were significantly stiffer in anterior-posterior bending and torsion (p<0.05), while the specimens treated with a locking IMN demonstrated superior stiffness with axial loading (p<0.05). There was no significant difference in stiffness between the two fracture fixation constructs with varus-valgus bending (p=0.54) (see Table 1).

As would be expected, overall the post-fatigue stiffness of both the LPHP and locking IMN were lower than the pre-fatigue stiffness for all four modes of testing. However there was no statistically significant difference between the post-fatigue stiffness of the LPHP when compared to that of the locking IMN in any mode of testing. The post-fatigue stiffness values of the LPHP demonstrated a significantly larger range than those of the locking IMN in all four modes of testing. The range of stiffness values for the LPHP were 10.10 N/mm$^2$ versus 0.32 N/mm$^2$ for the locking IMN in anteroposterior bending, 1.23 N/mm$^2$ versus 0.20 in torsion, 6.29 versus 2.14 N/mm$^2$ for varus-valgus bending, and 1607.6 N/mm$^2$ versus 187.4 N/mm for axial loading (see Figure 1).

Discussion
The pre-fatigue stiffness of the LPHP was significantly greater than that of the locking IMN with loading in the anteroposterior plane as well as in torsion. However, the locking IMN was stiffer with pre-fatigue axial loading. There was no significant difference when comparing the pre-fatigue stiffness of the fracture fixation constructs with varus-valgus bending.

Post-fatigue testing of the specimens revealed that both the LPHP and locking IMN were less stiff than pre-fatigue. While there was no statistically significant difference in the mean post-fatigue stiffness values of the two fracture fixation constructs, there was a significant difference in the range of post-fatigue stiffness values between the LPHP and the locking IMN.

In conclusion, the mixed pre-fatigue biomechanical advantages of each fracture fixation construct diminished following the fatigue protocol to the point that there is no significant difference in mean post-fatigue stiffness of the LPHP when compared to the locking IMN. In addition, the locking IMN appears to provide more consistent biomechanical stiffness following fatigue.