Characterizing the Mechanical Effects of Bone Substitute Material and Far-Cortical Locking Techniques in Proximal Humerus Fracture Reconstructions: A Cadaveric Study

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Introduction

Proximal humerus fractures are one of the most common fractures in the elderly population.[1] When surgical intervention is required, locking plate fixation is employed to provide support for the reconstructed bone as it heals. This technique is more susceptible to failure when bone quality is poor, and failure rates remain as high as 40% in some studies.[2] It has been posited that implant fixation may be improved in two ways. First, a far cortical locking (FCL) technique can be used to transfer energy away from the fragile humeral head and into the more robust shaft. In this case, the screw holes on the lateral side of the humerus are oversized, which permits controlled motion between the humeral head reconstruction and the humeral shaft (Figure 1). Second, bone substitute material (BSM) can be employed to reinforce the humeral head. Here, a bone substitute is injected through cannulated screws in an attempt to provide reinforcement to the native bone stock. It is understood that FCL "softens" the reconstruction and BSM "stiffens" it; however, it is unknown how these changes affect the fatigue life of the repair. Therefore, the purpose of this study was to make comparisons of the biomechanical properties of these techniques and to determine which fixation is most effective in reducing implant failure given the current highly excessive failure rates. We hypothesized that a combination of both techniques (ALL) will significantly improve the fatigue life of the implant.

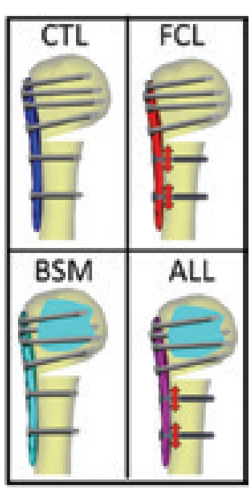

Figure 1. Computer-aided drawings illustrating the 4 groups tested in this experiment. The red arrows indicate motion provided by FCL screws and the cyan blob in the humeral head indicates BSM.

Methods

This study was performed on sixteen matched pairs of fresh frozen cadaveric upper extremities (5M, 11F, mean age: 80.2 years). Lumbar DEXA scans were performed on donors to confirm that all specimens had osteopenia or osteoporosis on at least one vertebral body (mean min T-score:-2.96). Skeletonized humeri were osteotomized at the neck with a 30° wedge to represent a simple two-part fracture. Specimens were equally divided into CTL (traditional locking plate fixation), FCL, BSM, and ALL groups (n=8). Implants (Periarticular Proximal Humeral Locking Plate, Zimmer Biomet) were fixated per manufacturer guidelines by fellowship trained orthopaedic surgeons (SM and KVO). In the case of BSM and ALL groups, two locked screws in the humeral head were replaced with cannulated screws, and up to 5cc of BSM (N-Force, Zimmer Biomet) was injected. After implantation, BSM and ALL groups were vacuum sealed and placed in a 98.5° F water bath for 24 hours to allow the calcium phosphate to cure. Non-destructive, quasi-static torsional (internal/external rotations) and axial (0°, +20°, −20° of abduction) stiffness tests were performed in a universal test frame (ElectroForce 3550, TA Instruments), similar to previous studies.[3,4] For fatigue testing, specimens were positioned at 0° of abduction and underwent a protocol that monotonically increased the magnitude of compressive loading by 0.25 N/cycle until failure. Relative displacement between the humeral head and shaft was calculated with optical 3-D motion tracking recordings (Optitrack, Natural Point, Inc.). One-way ANOVAs ($\alpha=0.05$) were performed to determine differences between the 4 groups (SigmaStat 4.0, Systat Software, Inc.).

Results

BSM exhibited significant differences between FCL and ALL in internal rotation torsional stiffness (Figure 2). Significant differences in 0° neutral and 20° adduction axial stiffness were seen between CTL and FCL, FCL and BSM, and BSM and ALL. In addition, there was a significant difference between CTL and

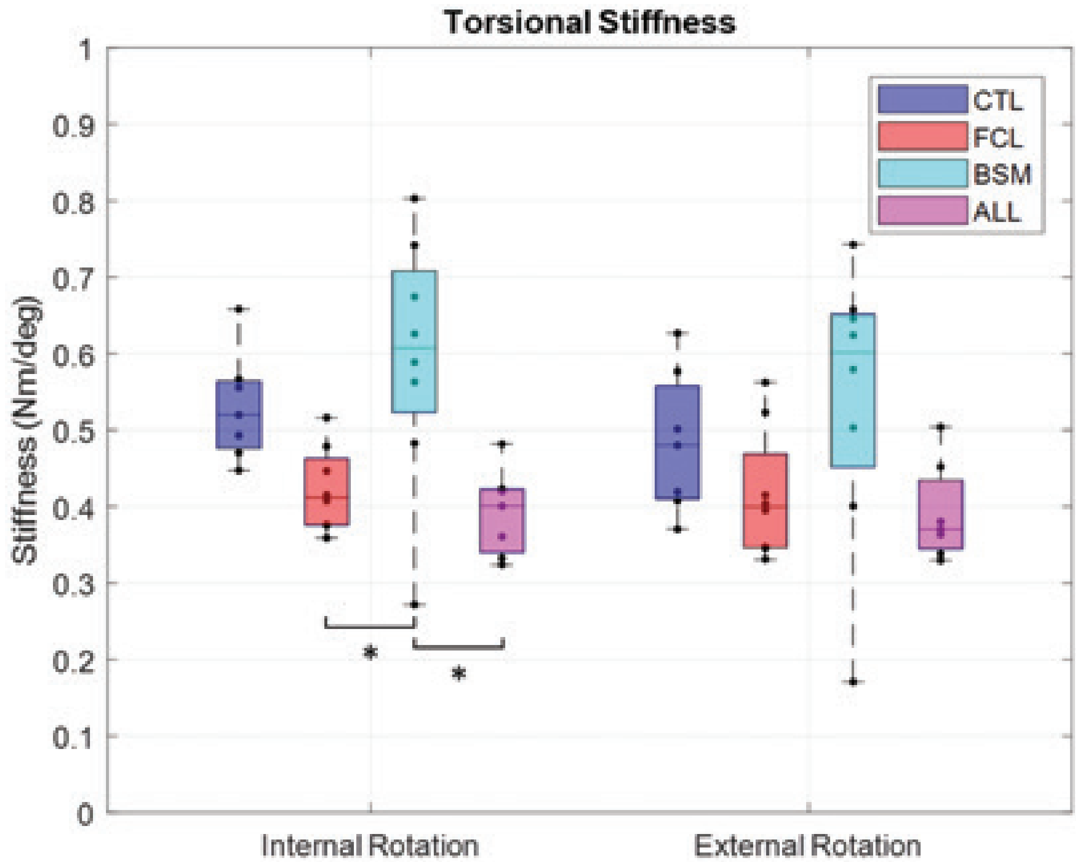

Figure 2. Plots of torsional stiffness in internal and external rotation. Significant differences between groups are marked with *.

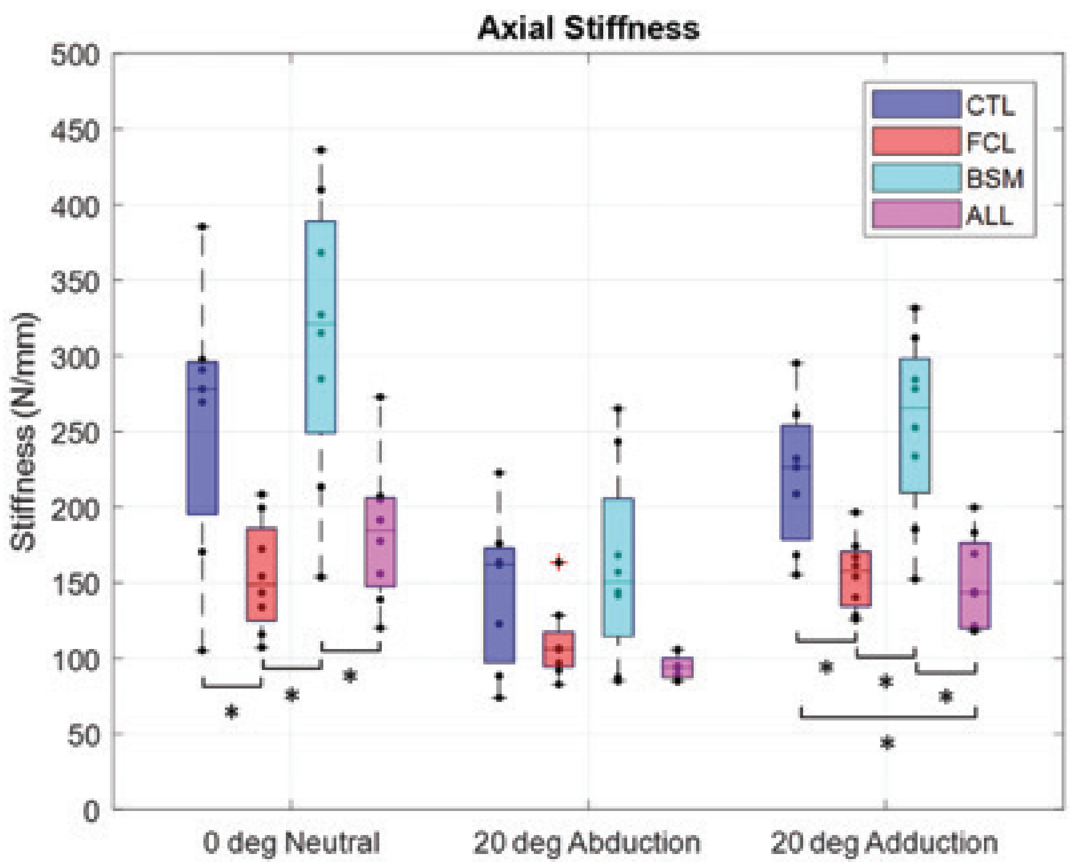

Figure 3. Plots of axial stiffness during 0 deg, −20 deg, and +20 degree tests. Significant differences between groups are marked with *.

ALL in 20° adduction axial stiffness. There were no statistically significant differences for number of cycles survived until 3 mm of permanent deformation, as measured by 3-D motion capture (CTL 2051±501; FCL 1859±626; BSM 2284±811; ALL 2049±338).

Discussion

As expected, the quasi-static torsional and axial tests suggest that BSM improves construct stiffness, while FCL and ALL provide lower stiffnesses. Results from the pooled data from this experiment suggest that the techniques used in the four groups provide similar implant fatigue life, which was contrary to our hypothesis. There are several limitations to this study that may be confounding the results. The screws used in this study were the same length for all specimens, which may have resulted in variable qualities of initial fixation. Additionally, variation in human anatomy and bone mineral density led to large data variability, which is inherent in cadaveric research. Future analyses will be performed on matched pairs of specimens to further assess the effects of these surgical techniques in a more controlled setting, and clinical trials should be pursued to further investigate this issue.

Significance

This study shows that use of FCL and BSM by surgeons may directly change the mechanics of proximal humerus fracture repairs with locking plates, but the impact these changes have on fatigue life remains unclear.

Acknowledgements

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