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Locking Plate Augmentation of Polymethylmethacrylate-Filled Distal Femur Defects

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Background: Benign, locally aggressive tumors of the distal femur are typically treated with intralesional curettage and cementation using polymethylmethacrylate (PMMA). However, it is not known whether a locking plate should be added to biomechanically augment these PMMA-filled defects, so as to reduce the risk of postoperative fracture. The answer to this question is significant because if locking plate augmentation of PMMA-filled distal femur defects provides insignificant biomechanical benefit within physiologically relevant loads, then it may not be worth the additional cost, labor, time under anesthesia, risk of damage to local structures, risk of infection, and obstructive artifact on cross sectional imaging that interferes with assessment of local tumor recurrence.

Questions: Does the addition of a locking plate to PMMA-filled distal femur defects offer significant biomechanical protection against postoperative perilesional fracture? Under physiologic loads, where on the distal femur is cortical stress the greatest? How is overall construct stiffness and perilesional cortical strain affected by the addition of a locking plate to PMMA-filled distal femur defects?

Methods: We performed a biomechanical study using 13 composite left femurs with biomechanical properties equivalent to bone. In 9 femurs, identical contained medial distal femur defects, mimicking the post-curettage shape of a giant cell tumor of bone, were created using a robotic milling machine. Group A contained 3 intact femurs (positive control), group B contained 3 femurs with an unfilled defect (negative control), group C contained 3 femurs with a PMMA-filled defect, and group D contained 3 femurs with a PMMA-filled defect augmented by an 8-hole medial distal femur locking plate (Fig. 1). One additional intact femur was used to determine the locations of maximum stress within the distal femur. To this end, a photoelastic coating was applied to the surface of the distal femur and, while anatomically loaded to 4.5kN of compression through the femoral head, the femur was viewed through a polariscope, with areas of highest color gradient corresponding to areas of greatest cortical stress. Based on the visualized stress concentrations, three strain gauges were applied to the posterior aspect of each of the 12 distal femurs (Fig. 2). Each femur was then anatomically loaded in compression through the femoral head at 2mm per minute to 4.5kN. Testing was performed using an Instron 5500R/4204 50kN frame using a 50kN load cell. For each femur, load (N) and displacement (mm) were measured via the load frame, and these values were used to derive overall construct stiffness (N/mm). Principal strain in the posterior distal femur was measured, directly, via the strain gauges. Each femur underwent 3 runs and the mean of the data for the 3 runs was used to represent that individual femur; mean values for each of the three specimens of each group were then averaged to represent the entire group. A series of two-sample t-tests were used to compare each group, with $p < .05$ denoting statistical significance.

Results: The areas of greatest stress in the distal femur – when anatomically loaded in compression through the femoral head – were located on the posterior aspect of the distal femur, specifically in the intercondylar notch/popliteal surface. When loaded in compression to 4.5kN through the femoral head, Group A had a mean stiffness of 974 +- 44N/mm, and a mean maximum principal tensile strain of .11% in the intercondylar fossa. Group B had a mean stiffness of 1087 +- 123N/mm, and a mean maximum principal tensile strain of .15% in the intercondylar fossa. Group C had a mean stiffness of 1066 +- 34N/mm, and a mean maximum principal tensile strain of .084% in the intercondylar fossa. Group D had a mean stiffness of 1008 +- 108N/mm, and a mean maximum principal tensile strain of .082% in the intercondylar fossa. There was no statistically significant difference in stiffness or strain between experimental groups C and D ($p = 0.45$ and 0.89, respectively).

Conclusions: When anatomically loaded in compression, the location of greatest stress in the distal femur appears to be the intercondylar fossa. The addition of a locking plate to PMMA-filled distal femur defects did not significantly increase the stiffness of the overall construct or reduce the strain in the intercondylar fossa compared to defects reconstructed with PMMA alone. Therefore, in cases of PMMA-filled distal femur defects similar to the one in this study, the addition of a locking plate appears to provide insignificant biomechanical benefit, and likely does not significantly reduce the risk of postoperative intercondylar fracture.

Figure 1. Anteroposterior radiograph of a composite left distal femur, status post creation of a contained medial distal femur defect, cementation, and placement of an 8-hole medial distal femur locking plate.

Figure 2. Biomechanical testing setup with strain gauges attached to the posterior distal femur at locations of greatest stress concentration as determined by photostress analysis.