Validation Of A FE Elbow Model For Calculating Contact Pressure And Contact Area In Humeroradial Joint

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Introduction: Radial head fracture is a common elbow pathology [1] and may require radial head replacement when the radial head is comminuted and ORIF (Open Reduction and Internal Fixation) is not advisable [2]. A surgeon can choose between two basic implant designs: a monoblock prosthesis with a fixed stem and a bipolar prosthesis with a ball and socket joint to help align the implant’s foveal surface with the capitellum. In a previous study [3], a 3-D finite element (FE) model for the elbow joint to compare two different radial head options was created based from CT scans. In order to validate the FE model, maximum contact stress and contact area were measured from cadaveric elbows using Fuji pressure sensitive film. The associated hypothesis was that model predictions and contact measurements would have general agreement, i.e., that model predictions would fall within the 95% confidence intervals of the measurements.

Methods: Four fresh frozen cadaveric elbows (2 right and 2 left) were tested. All the soft tissues including skin, muscle and tendon were carefully dissected except the joint capsule, interosseous membrane and ligamentous structures of the elbow joint. Two 2 cm incisions near the humeroradial joint, one each on the anterior and the posterior joint capsule, were made for the insertion of the Fuji film packet. The ulna was excised at approximately 5 cm from the distal radioulnar joint so that the load was applied only to the radius. The proximal humerus and distal radius of the elbow were fixed in polyvinyl pipes using styrene-acrylic polymer resin, mounted in custom made fixtures and placed in an MTS Bionix 858 (Eden Prairie, MN) for application of load. Two different grades (super low and low) of Fuji film packet were prepared before the testing. Loads of 50, 100, and 200 N were applied at a rate of 10 N/sec to the radius under load control. When the load reached the specified value, that load level was held for 1 minute and the specimen was unloaded. For each load case, the measurements were repeated three times. After the measurements for the native elbow were completed, the annular ligament was transected and the native radial head was exposed, resected and replaced with one of the two radial head implants with the appropriate size selected based on the diameter of the resected radial head. The annular ligament was reconstructed with suture and the pressure measurement test performed. For the first two elbows, the monoblock implant was tested first followed by the bipolar, and for the third and fourth elbows, the testing order was reversed. After the testing, Fuji film packets were scanned at 600 dpi and saved as 8 bit grayscale TIFF images. The maximum pressure and contact area from scanned images were calculated using custom MATLAB image processing program. The scanned 8 bit grayscale images were loaded into the program and converted to pressure images using a fifth order polynomial fit. Noise was filtered out after conversion. The filter replaced each individual pixel value with the average value of the pixels in the surrounding 25 x 25 pixel area. The stain intensity of every pixel in the scanned images was converted into numbers from 0 to 255 and then into the pressure, by comparing the numbers with the calibration data computed in the laboratory.

Results: Both FE prediction and measurements from cadaveric testing showed the same patterns in both maximum contact stress and contact area (Figures 1 & 2). Most predictions fell within 95% confidence intervals of the measurements and the trends of the model and the measurements were the same except in the contact area for the native case. For the contact area in the native case, the 50 and 100 N Fuji film measurements fell beneath the predicted model values, while all other comparisons in all other cases showed higher experimental measurements than model predictions. FE predictions were up to 16% higher in the maximum contact stress and lower in contact area than cadaveric testing.

Discussion: The model and the measurements were in general agreement. The monoblock pressures were always the highest and the areas, of course, commensurately the lowest. These differences in the maximum stresses and contact areas agreed with the differences in the radii of curvature of the contacting surfaces. The radius of curvature for the monoblock was approximately twice as large as that for the bipolar. The monoblock had higher stresses, smaller contact areas and the largest difference in the radii of curvature between the radial head and capitellum. The native case had the lowest stresses, the largest contact area and the smallest difference between the radii of curvature of the contacting surfaces. While the measurements and the model predictions showed good overall agreement, the predictions did not all fall within the
95% confidence intervals of the measurements. Given that the trends were all in agreement, additional experimental measurements might produce overall agreement. The results concur with the experimental measurements by Victor et al. [4] who quantified contact areas of the native radial head and monoblock implant using dental impression material under 100 N of applied load and found a 68% reduction in contact joint area after radial head replacement.

**Significance:** The validation of the pressure measurements establishes credibility for the FE model. The differences between the native, monoblock and bipolar in the maximum contact stress and contact area resulted mainly from the differences in radii of curvature, i.e., from the differences in congruency between contact areas (capitellum and radial head for native, capitellum and implant). The native showed the smallest maximum contact stresses and largest contact areas due to the smallest differences between radii of curvature of the contact surfaces. The difference between monoblock and bipolar in maximum contact stress and contact area was as large as the difference between native and bipolar.

**Acknowledgments:**

**References:**


![Graph](image)

Figure 1. Maximum contact stress
Figure 2. Contact area

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