

Finite Element Analysis of the Effect of Varying Humeral Implant Length in Total Elbow Arthroplasty

Jomain Low¹, Pivatidevi Pareatumbbee², Andy Yew^{2,3}, Kenny Tay XK^{2,4}, Tet Sen Howe^{2,4}, Bernard F. Morrey⁵, Joyce SB Koh^{2,4}
¹Duke-NUS Medical School, Singapore, ²Singhealth Duke-NUS Musculoskeletal Sciences Academic Clinical Program, Singapore General Hospital, Singapore, ³Division of Musculoskeletal Sciences, Singapore General Hospital, Singapore, ⁴Department of Orthopaedic Surgery, Singapore General Hospital, Singapore, ⁵Mayo Clinic, Rochester, MN
jomainlow@u.duke.nus.edu

Disclosures: Jomain Low (N), Pivatidevi Pareatumbbee (N), Andy Yew (N), Kenny XK Tay (N), Tet Sen Howe (N), Bernard F. Morrey (1- SBI, Zimmer. 2- Stryker, Zimmer. 3A- Tenex. 3B- Zimmer. 4- Tenex. 6- Saunders/Mosby-Elsevier, Wolters Kluwer Health - Lippincott Williams & Wilkins. 8- Saunders/Mosby-Elsevier, Wolters Kluwer Health - Lippincott Williams & Wilkins), Joyce SB Koh (9- DePuy Synthes AO Foundation Shoulder and Elbow Taskforce)

Introduction: Total elbow arthroplasty (TEA) is increasingly used for expanding indications such as post-traumatic arthritis, distal humeral fractures and non-unions, in addition to rheumatoid arthritis which it was initially intended for. Despite its high survival rate, complications like aseptic loosening and periprosthetic fractures persist. One possible mechanism for these complications may be related to the loss of proximal bone support, which could in turn be caused by the stress shielding effect due to the implant. Therefore, our study aims to investigate the effect of varying implant length on the biomechanical behavior of the bone-implant assembly using finite element (FE) modelling. The computational analysis will allow us to quantify the stresses and the stress shielding effect in TEA across the varying implant lengths.

Methods: Synthetic humerus sawbones (Humerus, 4th Gen., Composite, 17 PCF Solid Foam Core, Large) and their corresponding three-dimensional (3D) digital models were used in this study. Total elbow implants of three different lengths (4-inch, 6-inch and 8-inch) were obtained via laser scanning of the Zimmer Biomet's Coonrad-Morrey Elbow Prosthesis. Virtual surgical implantation according to surgical guidelines was performed to create bone-implant assemblies of varying implant lengths utilizing the necessary landmarks as reference points using *Solid Edge* by *Siemens Digital Industries*. The bone and implant material properties were assumed to be linearly isotropic. For the loading condition, a load of 400 N was applied at the distal humerus at a flexion angle of 90° while applying a fixed support to the proximal humerus to represent activities of daily living. Static FE analysis was then conducted using *Ansys® Academic Student Mechanical 2023 R1*. Intact model validation was carried out to compare the experimental and computational strains. The maximum von Mises stresses of the cortical bone and the implant were extracted at every 5% humerus length and compared across all four configurations. To quantify the stress shielding effect, the percentage change in stress (%Δ stress) from the intact state was calculated.

Results: Comparison of the experimental and computational strains of the intact model showed a correlation coefficient of 0.64, validating the computational model. The maximum von Mises stress location on the cortical bone, as shown in Figure 1, was observed to be on the posterior humeral surface, slightly distal to the glenohumeral joint in all configurations, at approximately 75% humeral length. There was no significant variation seen in the magnitude of the maximum stress at this length. Peak stresses on the cortical bone were observed to stretch over a larger area in the intact state on the predicted stress contour plots compared to the implanted states, as depicted in Figure 2. Stress shielding was only observed along the bone-implant interface length with lower stresses noted in the cortical bone along the implant insertion length with the proximal humerus not experiencing stress shielding. As in Figure 1, our results reveal that the 8-inch implant experienced higher maximum stress compared to the shorter implants. The maximum stress value however, is found to be well below the yield strength of the implant material. The location of maximum stress on the implant was also found to vary with respect to the implant length, with the maximum stress noted at the tip of the implant anteriorly for the 8-inch and 6-inch implants, but posteriorly and more distally on the 4-inch implant. Maximum stress shielding occurred at the 15% humerus length location from the distal end with maximum %Δ stress occurring in the 8-inch humerus-implant. This finding is illustrated in Figure 3. The calculated %Δ stress along the humeral length demonstrated that the stress shielding effect occurs over the entire length of the implant, hence suggesting that longer humerus-implant assemblies would have a larger area affected by the stress shielding.

Discussion: Based on the results obtained, a significant level of stress shielding from the intact state was found in all prosthesis implanted assemblies. With longer implants conferring stress shielding effect over a larger portion of the humerus, the cortical bone stress hence experiences a greater deviation from the bone's natural physiological state for the longer implants. According to Wolff's law, bone adapts in response to the mechanical loading it experiences. Hence, the stress shielding effect exhibited by the longer implant could indeed result in more bone resorption leading to less bone stock over an extended humeral length. In addition, the distribution of stress shielding identified 15% humeral length from the distal end as the approximate point of maximum stress shielding effect, suggesting it as a possible point of failure at which aseptic loosening could begin secondary to bone remodeling.

Significance/Clinical Relevance: Longer prostheses could potentially induce greater area of stress shielding, leading to detrimental bone resorption. We believe that using a shorter implant length could potentially reduce the area affected by stress shielding, preserving bone stock along greater proportion of the humerus while mimicking the stress distribution of the intact bone more closely.

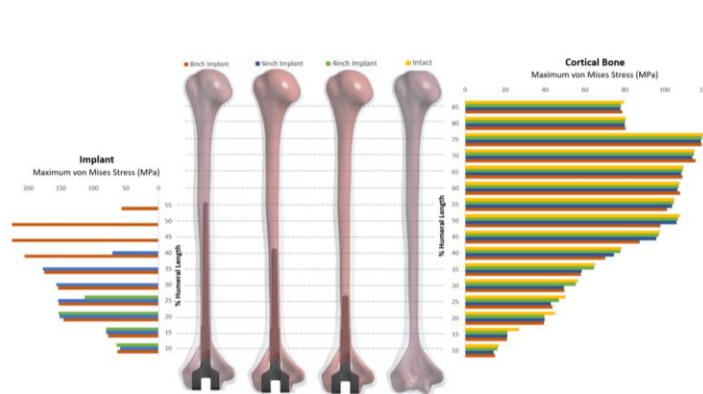


Figure 1. von Mises stress variation of implant and humerus cortical bone along the humeral length on the posterior surfaces under 90° loading.

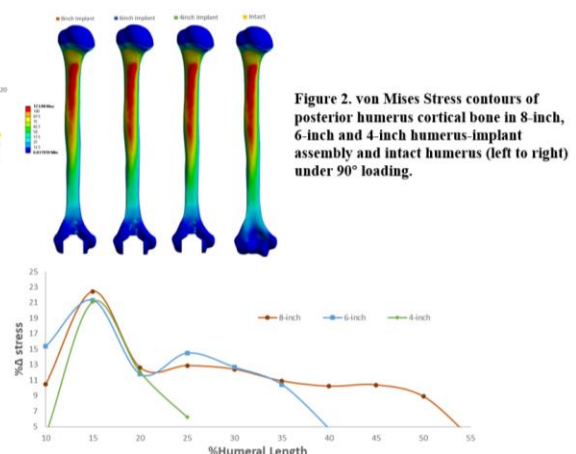


Figure 2. von Mises Stress contours of posterior humerus cortical bone in 8-inch, 6-inch and 4-inch humerus-implant assembly and intact humerus (left to right) under 90° loading.

Figure 3. Effect of Varying Humeral Implant Lengths on Stress Shielding