# EFFECT OF GEOMETRY OF PROSTHESIS STEM ON THE STRESSES OF AN ELBOW JOINT PROSTHESIS

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## Introduction

Biomechanics studies on joint replacement have received a great deal of attention during the past three decades. With rapid development of computer hardware and software technology, numerical methods such as Finite Element Analysis have been extensively used in prosthesis design, the current study focuses on results of a closed form solution for an elbow prosthesis with a simplified analytical model. The variation of stresses developed in the prosthesis stem as well as the bone due to static loading depends on the size and shape of the component. The effects of variation of geometry of the ulna stem of elbow prosthesis, on the bending stresses in the prosthesis stem and the bone have been investigated.

## Materials and Methods

It has been established by Huiskes et al. (1983) and Rupasinghe et al. (2009) that the bending stress distribution of the bone-prosthesis system can be well represented by using the beams on elastic foundations model. Mathematical models incorporating simple beam theory and beams on elastic foundations theory were used to obtain bending stress variation of the prosthesis stem as well as the bone. Figure 1 illustrates the basic geometry of the model used in the analysis. The elbow joint, the proximal end and the distal end of the prosthesis stem are denoted by J, EP and ED respectively.

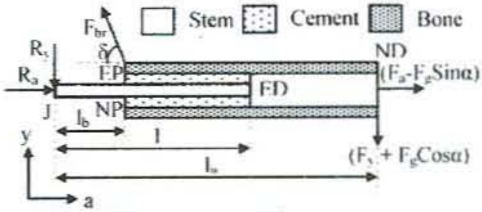



**Figure 1. Free body diagram of the ulna after inserting the prosthesis.**

The proximal and distal ends of the ulna are denoted by NP and ND respectively. $R_y$ and $R_a$ are the components of the reaction at the elbow joint and $F_{br}$ is the contraction force of the brachialis muscle. $F_a$, $F_g$ and $F_y$ are components of the external force applied at the proximal end of the ulna. The mathematical models were used to analyze the bending stresses that developed in the prosthesis stem and the bone due to static loads applied at the distal end of the ulna. The Young's modulii of acrylic cement, bone and prosthesis were taken as 2, 20 and 200 GPa respectively while the Poisson's ratios were taken as 0.3 for the three materials.

The mathematical models were used to analyze the bending stresses developed in the prosthesis stem as well as the ulna bone. The locations where the maximum bending stresses occurred were identified. Special attention was given towards identifying locations of stress concentrations in both the bone and prosthesis stem as well as the effects of stress shielding (reduction of the bending stress in the bone due to the insertion of the prosthesis). The variation of stress patterns with changes in the geometry of the prosthesis stem was investigated. Figure 2 illustrates the different types of cross sections and prosthesis stem geometries used in the analyses.

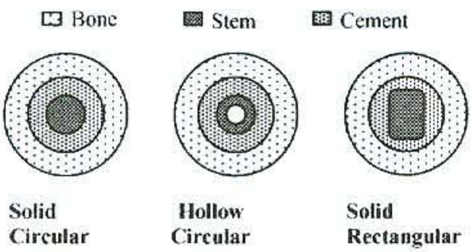
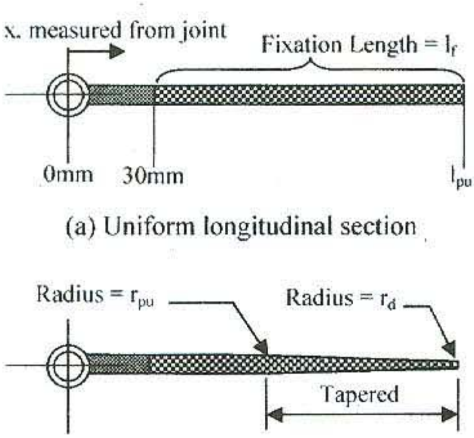



**Figure 2. Different types of cross sections of prosthesis stems used in the study.**

The longitudinal geometric parameters of the stem that were used in the analysis are given in figure 3.




(a) Uniform longitudinal section

(b) Tapered longitudinal section

**Figure 3. Different types of longitudinal geometries of prosthesis stems used in the study.**

It was of particular interest to identify the geometric parameters such as prosthesis cross section type, length, shape (uniform or tapered at the distal end) *etc*, that would have a significant effect on reducing stress concentrations and effects of stress shielding while at the same time reducing the amount of material used for the component.

**Results**

The results of the study indicate that the variation of the length of the prosthesis has little effect on the bending stresses in the stem. However the reduction in prosthesis length was found to have a positive effect on the bending stresses in the bone since it reduces the effect of stress shielding and renders the stress distribution to be more natural.

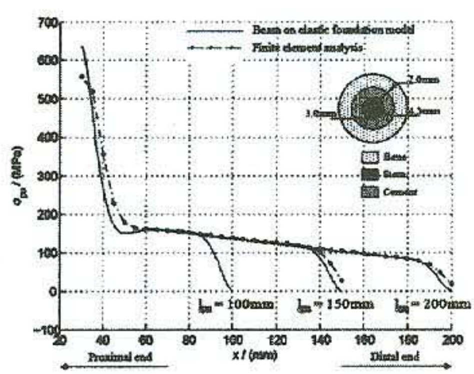



**Figure 4. Effect of stem length on the longitudinal stress in prosthesis stem top fibre.**

The results also indicated that there is an increase in the stress concentrations in top fiber of the bone cross section with the reduction of prosthesis length. Stress concentration factors of 1.22, 1.36 and 1.41 were observed for prosthesis lengths of 200 mm, 150 mm and 100 mm respectively.

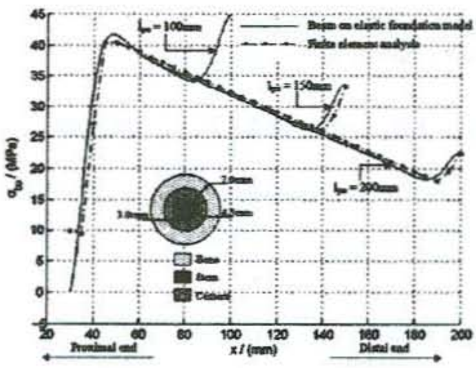



**Figure 5. Effect of stem length on the longitudinal stress in the bone top fibre.**

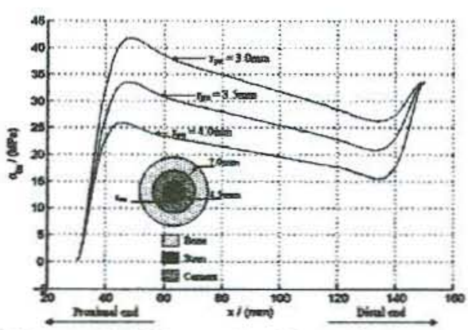



**Figure 6. Effect of radius of stem on bending stresses in the bone.**

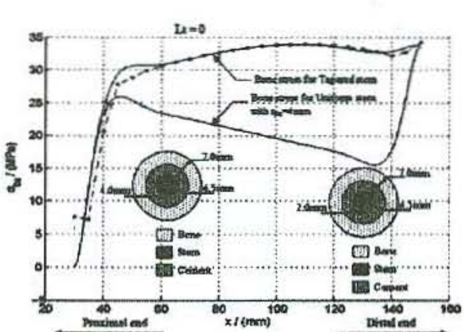



**Figure 7. Effect of tapering of stem on bending stresses in the bone.**

## Discussion

Results of the study illustrate the differences between several types of prosthesis stems having alternate cross sectional geometries based on the bending stresses developed in the ulna bone and prosthesis stem due to static loading in elbow flexion. It was found that stress shielding could be reduced by using a stem that is tapered at the distal end. Tapered rectangular sections gave the best results in terms of cost effectiveness and reduction of stress shielding.

## Conclusion

The results of the study are recommended to be used only as a guideline in the design of the ulna stem of elbow prosthesis. Further study permits the development of a generalized design methodology that could be easily used by the designer reducing the time taken to design a fully functional elbow joint implant.

## References

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Huiskes, R., Janssen, J.D. and Slooff T.J. (1983). A detailed comparison of experimental and theoretical stress-analysis of a human femur.Mech. Prop. of Bone, 45, 211-234.

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