Classification of the Human Proximal Femur Towards Improved Total Hip Arthroplasty

Solmaz Aslani

Supervisors: Prof. Dr. Philippe Zysset, MSc Alice Dudle
Institution: University of Bern, ARTORG Center for Biomedical Engineering Research
Examiners: Prof. Dr. Philippe Zysset, MSc Alice Dudle

Introduction

Total hip arthroplasty, a widely accepted treatment for individuals with femur dysfunction caused by accidents, aging, or conditions such as osteoarthritis, has witnessed a consistent increase in surgical cases globally. Currently, the design and selection of implants rely heavily on the expertise of designers and the experience of surgeons. To address long-term complications associated with total hip arthroplasty, custom-made implants have been developed to enhance compatibility with the bone structure. While significant advancements have been made in exploring bone morphology and its classification through imaging techniques, there is still limited exploration of using bone morphology to optimize implant selection. Therefore, the objective of this study was to classify the femur medullary canal and implant type using bone morphology, with the ultimate goal of enhancing the selection process for total hip arthroplasty implants.

Materials and Methods

The study utilized CT scans from 776 patients provided by Symbios Orthopedie S.A.The research consisted of two steps: a 1D analysis using 30 landmarks on the medullary canal centerline and a 2D analysis using 30 contours for each femur. These analyses involved data preparation, shape characterization using principal component analysis, and statistical analysis to associate shape model properties with age, gender, and implant type. A linear classifier based on logistic regression was then trained to classify bone and implant types.

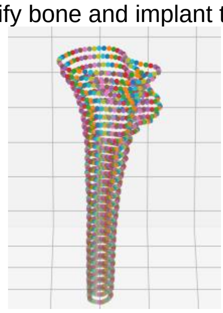

Fig. 1 Input of the SSM in 2D

Results

The analysis revealed that the first four modes of variation in the 1D analysis accounted for 90% of the total centerline variation, while in the 2D analysis, the first 13 variation modes were necessary for the same purpose. The canal flare index, which characterizes the medullary canal, was calculated as a relevant metric to bone geometry. The statistical analysis demonstrated a weak correlation between mode weights and age (p-value < 0.05, $R \leq 0.2$) in both the 1D and 2D analyses. 9 out of 13 modes showed significant correlation (p-value < 0.05, $0.08 < R < 0.45$) with canal flare index in 2D analysis. 10 out of 13 of the modes obtained from 2D analysis showed statistically significant difference between cemented and uncemented implant types (p-value < 0.05). These selected modes, along with age and gender could classify the implant type with accuracy, precision, sensitivity, and specificity ranging from 0.84 to 0.96. The next classifier, trained using age, gender and the selected modes that correlated with canal flare index reported accuracy, precision, sensitivity, and specificity ranging from 0.87 to 0.94.

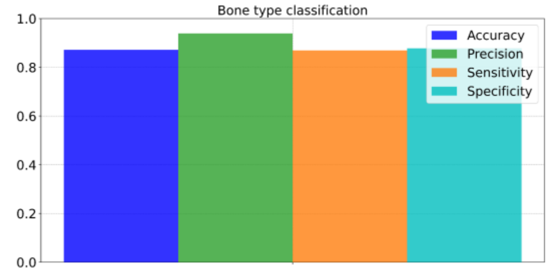

Fig. 2 Bone type classification evaluation using the age, gender and 2D mode weights as predictors

Discussion

The correlation between variation modes and age aligns with previous studies that have reported changes in the medullary canal with increasing age. The overlap of mode weights between genders supports the approach of combining genders in the analysis. The association between variation modes and the canal flare index proved useful for accurate bone type classification. Additionally, statistical shape modeling was found to be an effective approach for characterizing medullary canal morphology and classifying implant types.

References

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