# A 3D Perspective on Age-Related Morphological Changes in Cortical Bone of the Femur

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## Summary

Previous studies have hypothesized that bones possess compensatory mechanisms for aging, but these studies were limited to discrete 2D measurements. This study presents a 3D statistical shape model of the femur and its cortical bone, derived from an age- and sex-stratified dataset of 718 individuals. The model offers a comprehensive view of integrated morphological changes occurring with ageing.

## Introduction

Bone, as a living material, continues to adapt throughout life. Several studies observed age-related cortical area decrease, alongside outward cortical displacement [1, 2]. While these studies provided valuable insights from large-scale data, their interpretations were limited by 2D measurements taken at a few discrete locations.

This study addresses this knowledge gap by developing a 3D model of the femur using statistical shape modeling on a large-scale, age- and sex-stratified population. The model offers a comprehensive view of integrated morphological changes (size and shape) and cortical bone thickness.

## Methods

Right femurs were segmented from post-mortem CT scans of 718 individuals (348 women and 370 men, aged 20–89 years) collected by the Victorian Institute of Forensic Medicine (VIFM, Melbourne, Australia). To achieve intersubject nodal correspondence, a template mesh was fitted to each segmented mesh, and the fitted meshes were rigidly aligned to their anatomical axes to remove positional variations.

Diaphyseal endosteal surfaces were constructed using an adapted cortical thickness method by Treece et al. [3], with sampling lines adjusted from the normal vector to a radial direction toward the cross-sectional center of mass for improved robustness. Principal component analysis on aligned femoral cortex meshes generated a mean model for each demographic stratum.

## Results and Discussion

Comparing the mean femur models of the 20–29 and 80–89 age groups revealed regional trends of cortical thinning and outward displacement associated with ageing (Figure 1). Cortical thinning was most prominent around the linea aspera and the anterior surface, which were nearly orthogonal to the regions with the greatest outward cortical displacement. These parallel changes led to more symmetrical cross-sections and a shift in the directionality of the minimum moment of inertia (Figure 1) – an index of mechanical resistance to bending – along the longitudinal axis.

Age-related cortical thinning, dominant around muscle attachment sites, and the emergence of more symmetrical femoral cross-sections – also seen in modern compared to pre-industrial populations [4] – suggest that changes in mechanical loading environment contribute to these morphological adaptations.

## Conclusions

This study provides detailed 3D data on age-related morphological changes in the femur, extending beyond traditional 2D measures. While limited by its cross-sectional design (and yet to include bone density), our model provides a valuable resource for future numerical experiments to investigate the relationship between form and function.

## Acknowledgments

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## References

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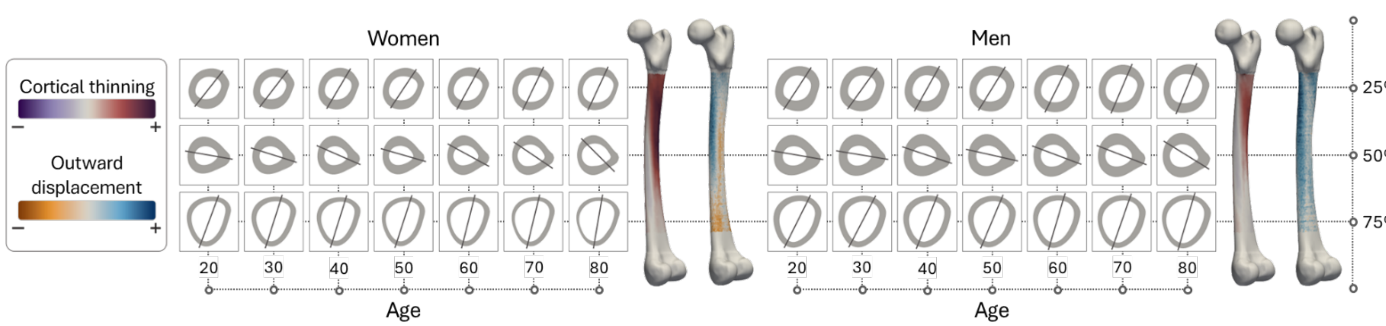


**Figure 1**: Femoral cross-sections and 3D maps of cortical thinning and outward displacement comparing young and older women and men.