A statistical shape model of bone anatomical variability for finite element assessment of bone mechanics

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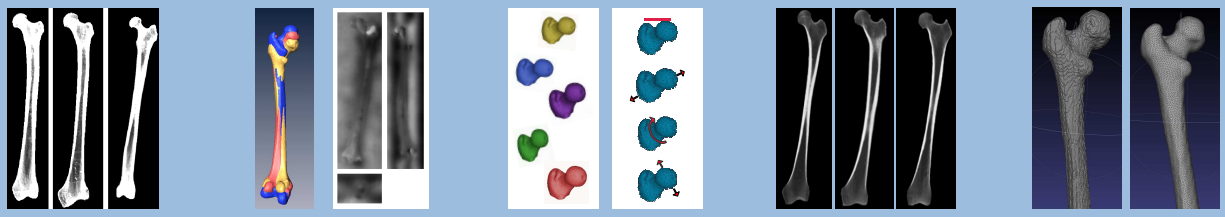
Introduction

Finite element models developed from Computerized Tomography (CT) data are commonly used to evaluate the mechanical performance of the bone or the load transfer from an orthopedic implant to the bone. However, most analyses do not take into account either the wide variation in material properties and geometry that may occur in natural tissues nor the manufacturing imperfections in synthetic materials. We propose a method to include bone anatomical variations for the calculation of bone performance using Statistical Shape Model (SSM). This statistical finite element model is illustrated through a comparison of the stiffness between male and female femoral bones.

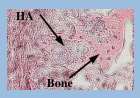
Methods

Statistical Model



Segmented femur CT → Rigid and non-rigid registration → Principal Component Analysis → Generation of new instances → 3D Mesh

Mechanical Simulation



Bone Mineral Component — Complete Bone

CT intensities → ρ_{QCT} → ρ_{ash} → ρ_{app} → E

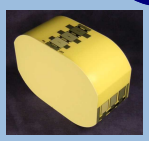


Image calibration: ESP - EFP

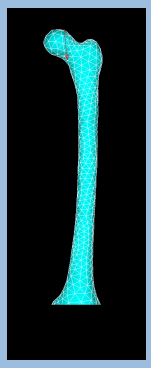
Linear relationship

$\rho_{ash}/\rho_{app}=0.60$

$E(GPa)=6.850\rho_{app}^{1.49}(g/cm^3)$

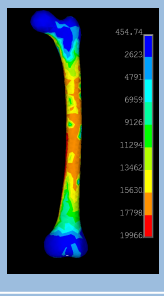
Mechanical properties

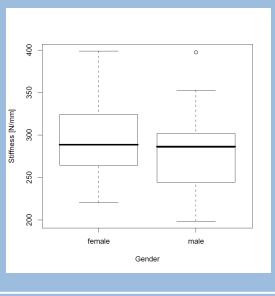
FEM analysis



Results

- CT images:
  - 80 for females (64±17 years)
  - 57 for males (65±15 years)
- Statistical Shape Model:
  - Use of the first 4 modes (77% of variation for females, 83% for males)
  - Generation of 40 instances for each gender
- 10-node tetrahedral mesh
- L=800N
- Femur distal part constrained
- Simulation for:
  30 female meshes
  20 male meshes





Discussion

A nearly automatic pipeline was developed to build Statistical Shape Models from CT images. The developed tool enables the creation of finite element models based on instances generated with the SSM.

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