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

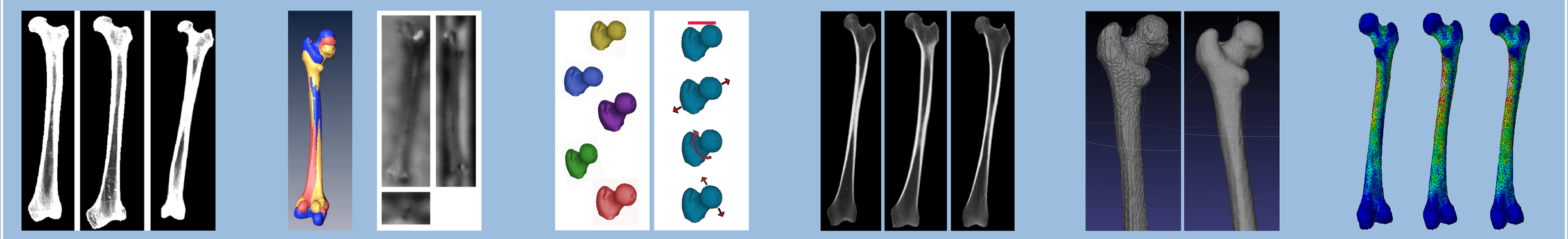
Bonaretti S., Helgason B., Seiler C., Reyes M., Büchler P.
ISTB, University of Bern, Switzerland

UNIVERSITÄT BERN
CO-ME COMPUTER AIDED AND IMAGE GUIDED MEDICAL INTERVENTIONS

Introduction

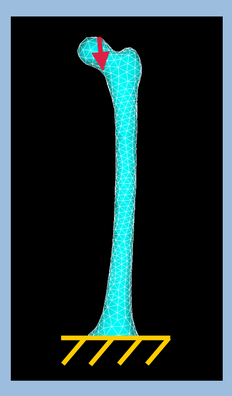
Finite element models developed from Computerized Tomography (CT) data are commonly used to evaluate the mechanical performance of the bone or the load transfer from an orthopedic implant to the bone. However, most analyses do not take into account the variation in material properties and geometry that may occur in natural tissues. We propose a method that includes bone anatomical variations for the calculation of bone performances using Statistical Shape Model. Two applications of the methods are shown: calculation of bone stiffness for different populations and biomechanical assessment of an implant design for two ethnic groups.

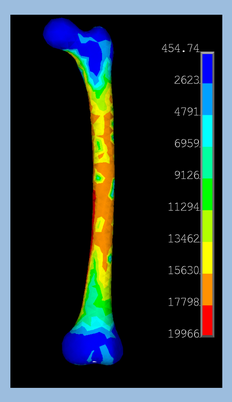
Method

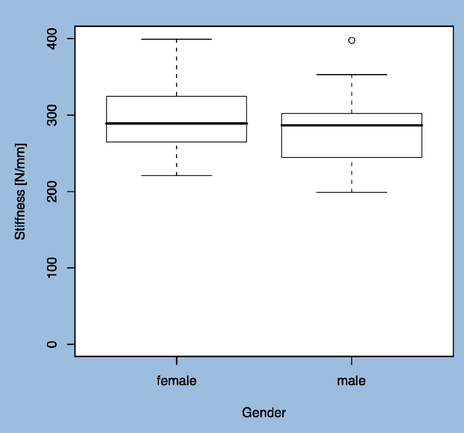


Assessment of Bone Stiffness

- Caucasian femur CT images:
  - 57 for males
  - 80 for females
- 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
- Bone: $E = 6.85\rho^{1.49}$ GPa, $\nu = 0.3$
- L = 800 N
- Femur distal part constrained
- No statistical difference between male and female
  Limitation: same length and density for all bones

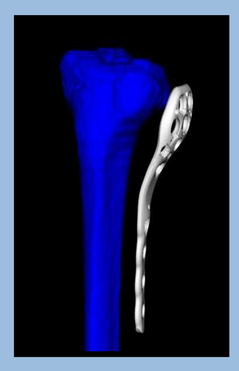


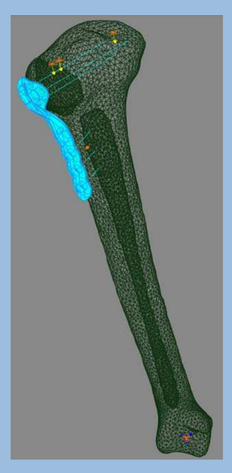


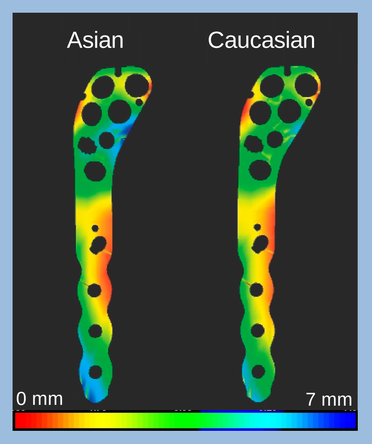


Implant Design

- Caucasian tibia CT images:
  23 males + 20 females
- Asian tibia CT images:
  28 males + 19 females
- Statistical Shape Model
  - Use of the first 2 modes (75% of variation)
  - Generation of 13 instances for each ethnic group
- 10-node tetrahedral mesh
- Bone: $E = 15.52\rho^{1.93}$ GPa, $\nu = 0.3$
- Implant: E = 110 GPa, $\nu = 0.3$
- L = 1600 N
- Tibia distal part constrained
- Bone-implant average distance higher for Asian
- Von Mises stress in the plate:
  Asian: 69±9 MPa
  Caucasian: 61±5 MPa
- Max principle stress in the screws:
  Asian: 80±17 MPa
  Caucasian: 61±12 MPa
- Stress in the plate statistically higher for Asian ($p<0.05$)







Discussion

A nearly automatic pipeline was developed to build a bone Statistical Shape Models from CT images in order to perform biomechanical simulations of bone behavior. Two applications were shown as example. Next steps will include refinements of the bone density variations and a further automation of the Finite Element model generation, simulation and data processing.

ESB2010 17th Congress of the European Society of Biomechanics

Institute for Surgical Technology and Biomechanics - ISTB
University of Bern
Stauffacherstrasse 78
CH-3014 Bern, Switzerland
+41 31 631 59 48
serena.bonaretti@istb.unibe.ch