Statistical finite element modeling: application to orthopedic implant design

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GCB Students’ Symposium 2011
Bones

- Rigid organs that form the skeleton

- Functions:
  - Support
  - Movement
  - Internal organ protection
  - Mineral reservoir
  - Blood cell formation

- Functional adaptation: “use it or lose it”
Bone fracture

> It occurs when the bone cannot withstand the applied force
Bone fracture

> It occurs when the bone cannot withstand the applied force

> Bone is genetically programmed to heal after fracture
Bone fracture

- It occurs when the bone cannot withstand the applied force
- Bone is genetically programmed to heal after fracture
- Plates restore bone anatomy and produce stability that allows physiological exercise
Plate fixation

> Minimal skin incision
> Reduction refinement
> Plate and screw insertion

> Plate contouring

http://www.aofoundation.org/wwwelearning/modules/dlmplates/dlmplates_en.htm
Plate evaluation

> Population groups:
  - Sex, age, ethnicity,…

> Population-based implant assessment?

> Creation of a statistical bone model that takes into account bone shape and density variability in order to assess the biomechanical behavior of the bone-implant coupling
Method

Creation of a statistical bone model that takes into account bone shape and density variability in order to assess the biomechanical behavior of the bone-implant coupling.
Statistical bone model

- Bones are conceived as samples in a high dimensional space.

- Principal Component Analysis (PCA) projects bones in a lower dimensional space where bone shape and density variances are minimized.

- Virtual bones are created sampling the space using a Gaussian distribution in order to have a more dense and rationalized space.
Finite element simulations

> Mechanical property assignment

Bone Mineral Component

- CT intensities
- $\rho_{QCT}$
- $\rho_{ash}$

Complete Bone

- $\rho_{app}$
- $E$

$\rho_{Ash} = (\rho_{QCT} + 0.09)/1.14$

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

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


Preliminary results

> Tibia CT images: 43 Caucasian + 47 Asian

> Statistical shape model
  — 2 modes represent 75% of variation
  — 13 new instances for each group

> FEM simulation
  — 10-nodes 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
> Stress in plates statistically higher for Asian ($p<0.05$)
Conclusion

- Creation of a statistical bone model to assess the bone-implant coupling mechanical behavior

- Limitations
  - Dependence of the model on the training dataset
  - Linearity of PCA
  - Non-unique PCA parameter meaning

- Outlook
  - Patient-specific modeling
  - Orthopedic surgery planning
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