

Statistical finite element modeling: application to orthopedic implant design

Serena Bonaretti

GCB Students' Symposium 2011

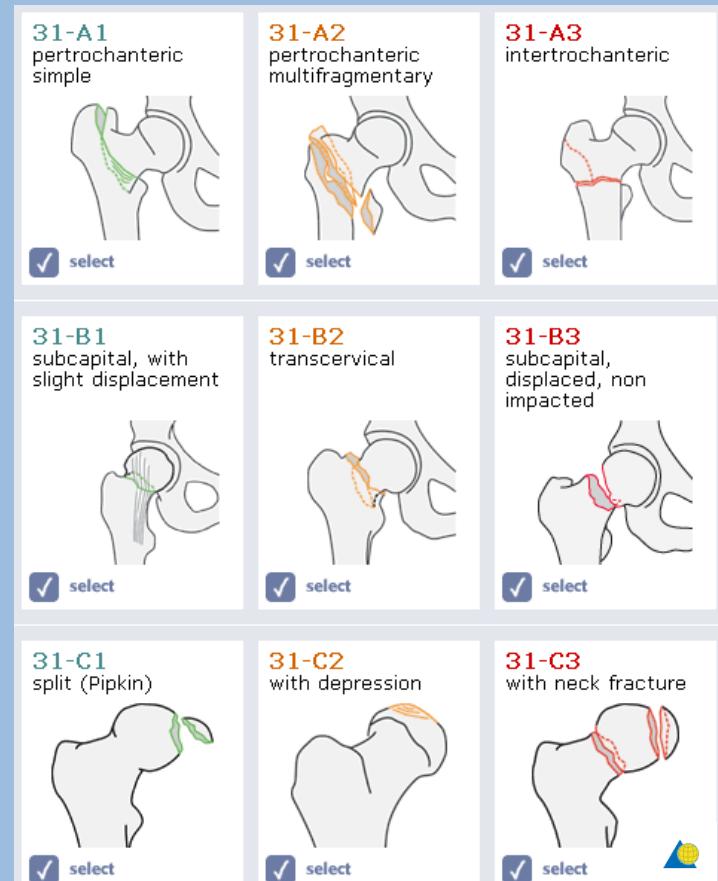
Bones

- > Rigid organs that form the skeleton
- > Functions:
 - Support
 - Movement
 - Internal organ protection
 - Mineral reservoir
 - Blood cell formation
- > Functional adaptation: “use it or lose it”



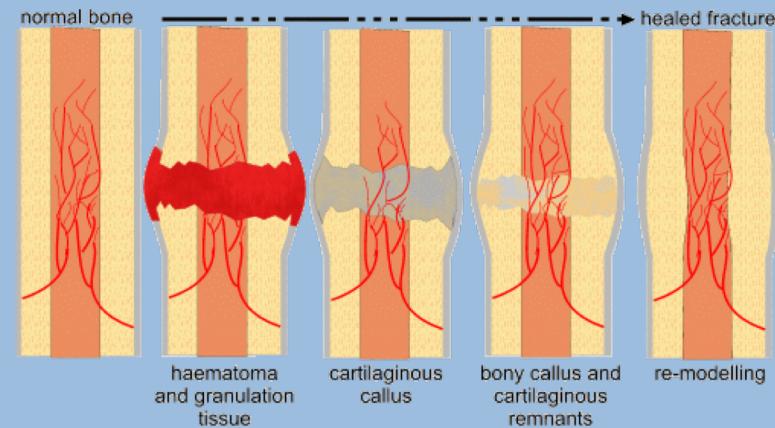
Bone fracture

- > 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



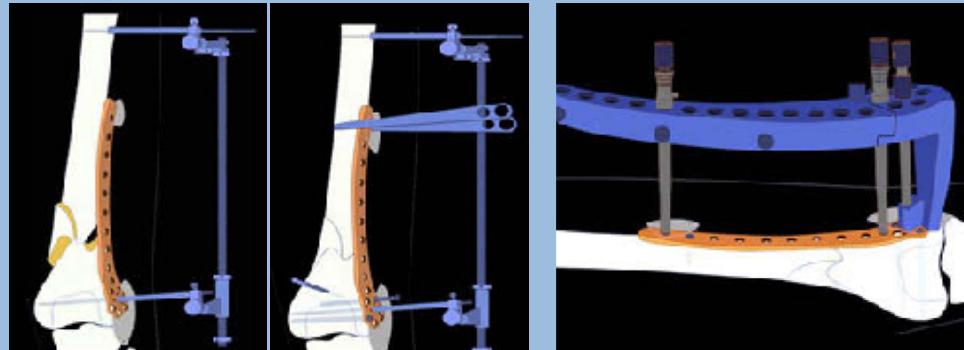
Bone fracture

- > 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

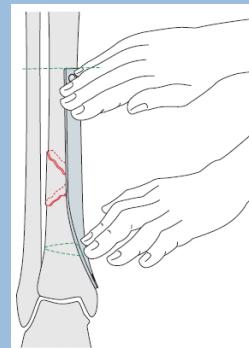
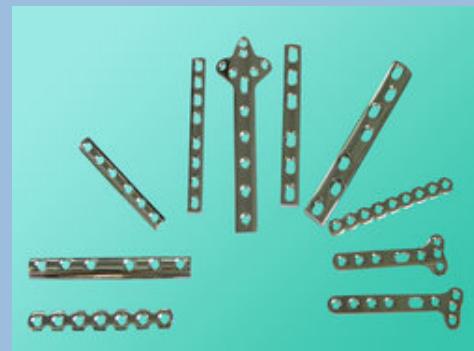
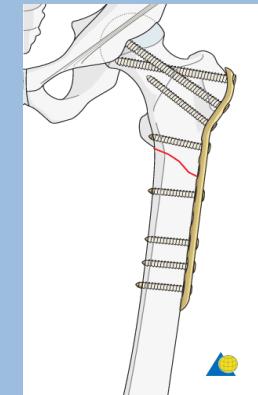
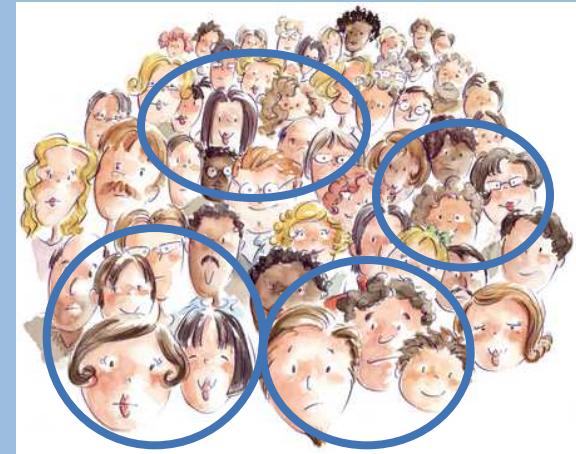
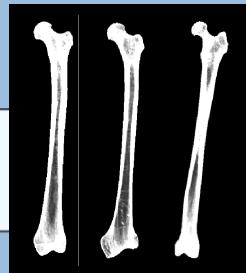


Plate evaluation

- > 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



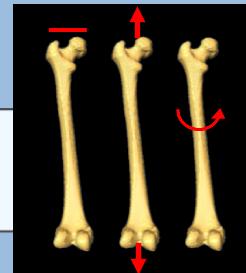
Method



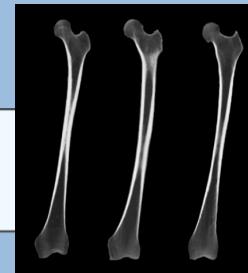
Segmented
CT images



Registration



Statistical
model

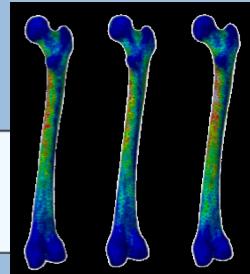


New
instances

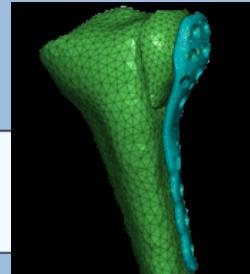
Statistical bone model

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

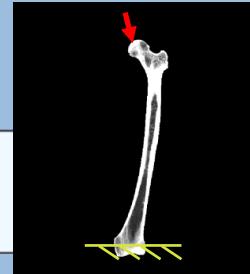
Finite element simulations



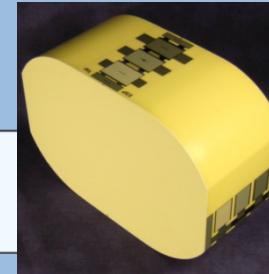
FEM
simulation



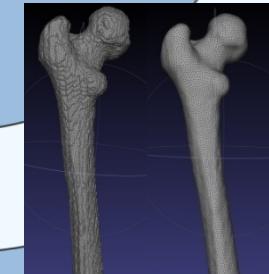
Bone-plate
fitting



BC
propagation

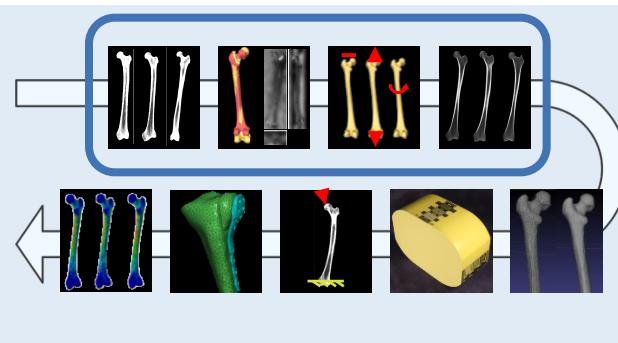


Material
properties

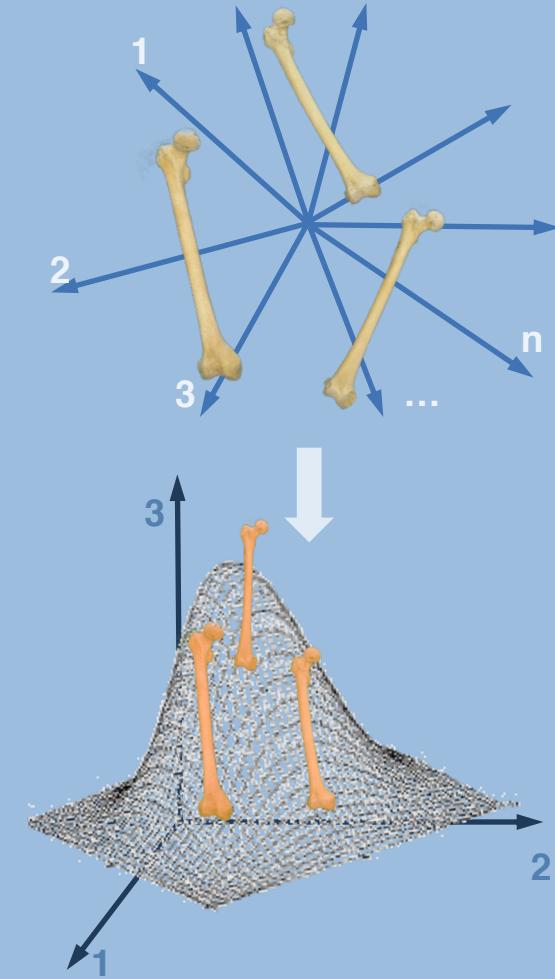


Volume
mesh

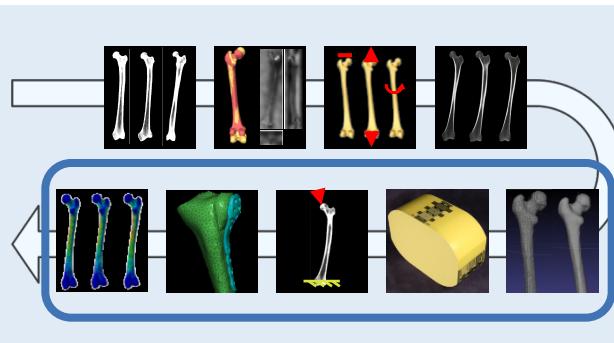
Statistical bone model



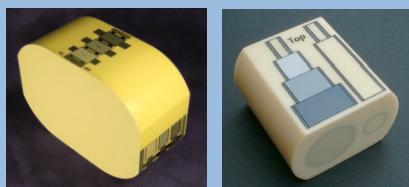
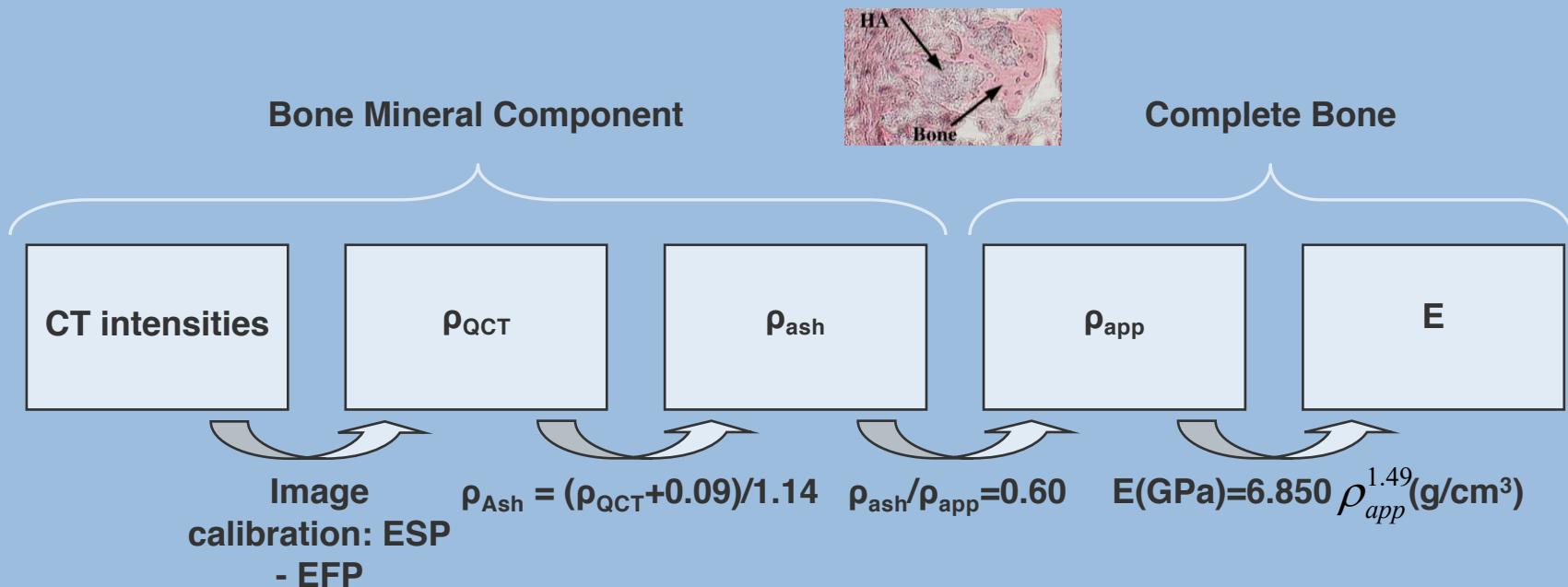
- > Bones are conceived as samples in a high dimensional space
- > Principal Component Analysis (PCA) projects bones in a lower dimensional space where bone shape and density variances are minimized
- > Virtual bones are created sampling the space using a Gaussian distribution in order to have a more dense and rationalized space



Finite element simulations



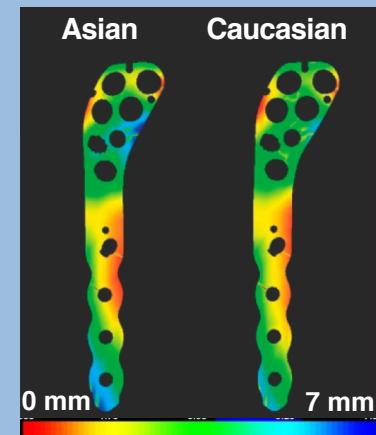
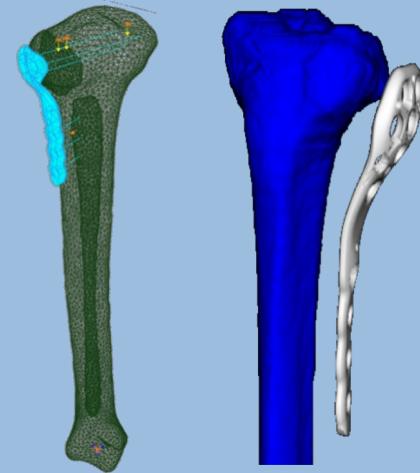
> Mechanical property assignment



Schileo E. et al. *An accurate estimation of bone density improves the accuracy of subject-specific finite element methods.* J Biomech. 41, 2483-2491. 2008.
 Helgason B. et al. *Mathematical relationship between bone density and mechanical properties: a literature review.* Clin Biomech. 23, 135-146.2008.

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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