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MEDICAL INTERVENTIONS

# Statistical finite element modeling: application to orthopedic implant design

Serena Bonaretti

GCB Students' Symposium 2011

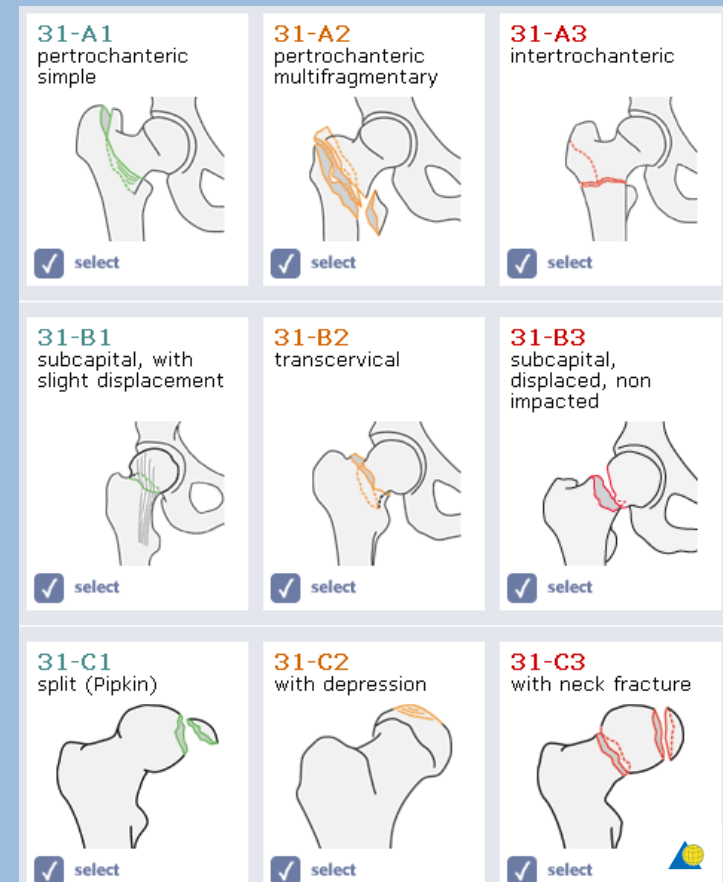
# Bones

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



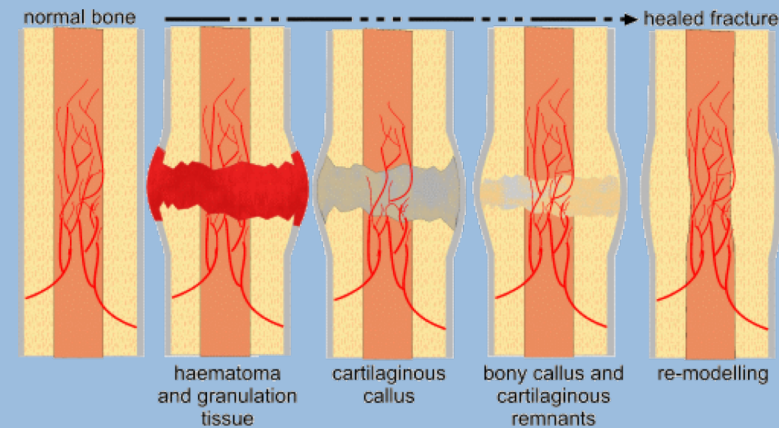
# Bone fracture

- > It occurs when the bone cannot withstand the applied force



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- > It occurs when the bone cannot withstand the applied force
- > Bone is genetically programmed to heal after fracture



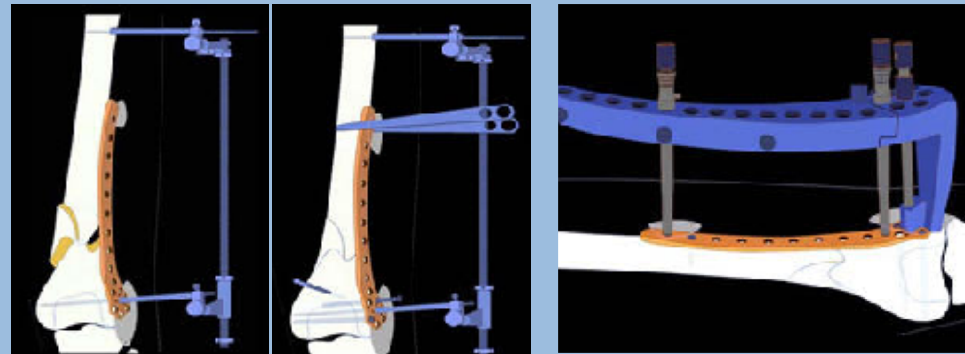
# Bone fracture

- > 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

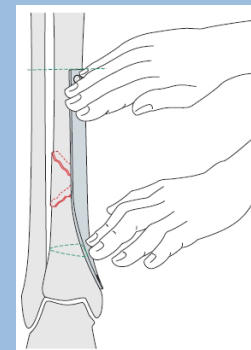


# Plate fixation

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

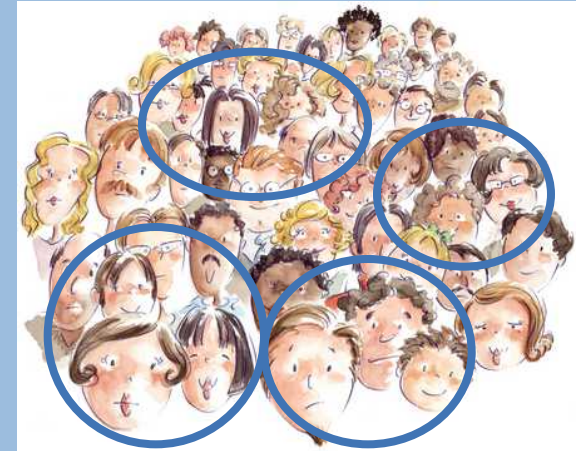


- > Plate contouring

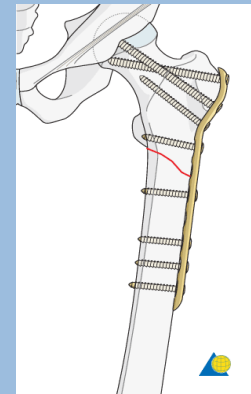


# Plate evaluation

- > Population groups:
  - Sex, age, ethnicity,...
- > Population-based implant assessment?



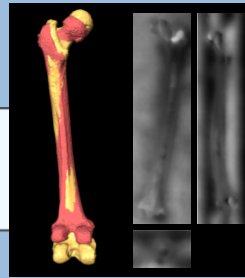
- > Creation of a statistical bone model that takes into account bone shape and density variability in order to assess the biomechanical behavior of the bone-implant coupling



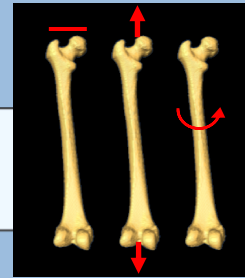
# Method



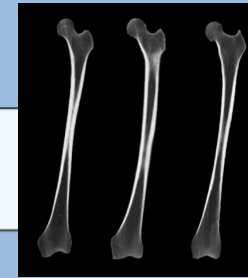
Segmented  
CT images



Registration



Statistical  
model

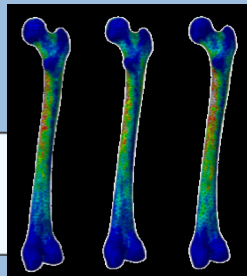


New  
instances

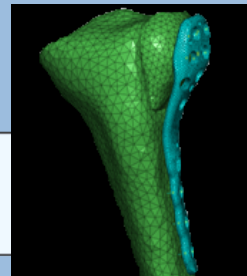
Statistical bone model

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

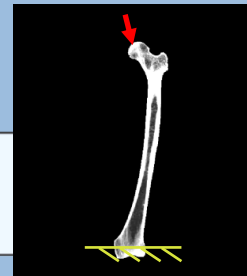
Finite element simulations



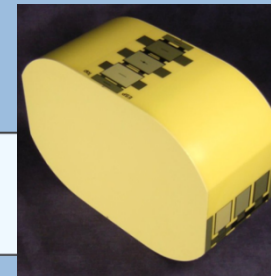
FEM  
simulation



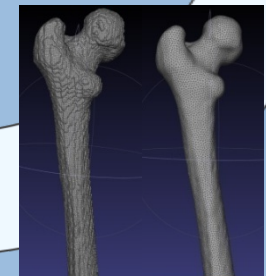
Bone-plate  
fitting



BC  
propagation



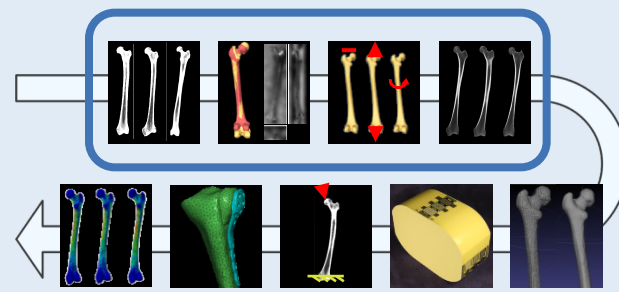
Material  
properties



Volume  
mesh



# Statistical bone model

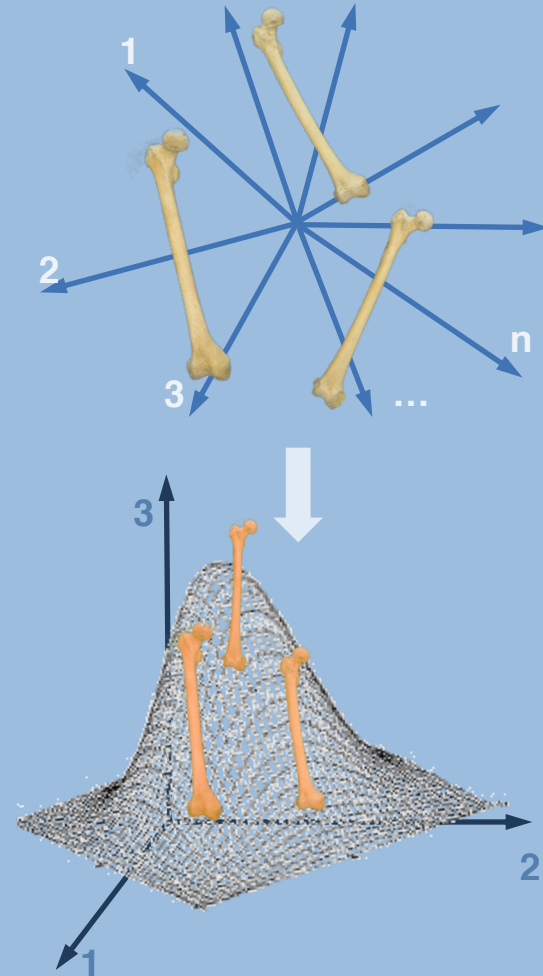


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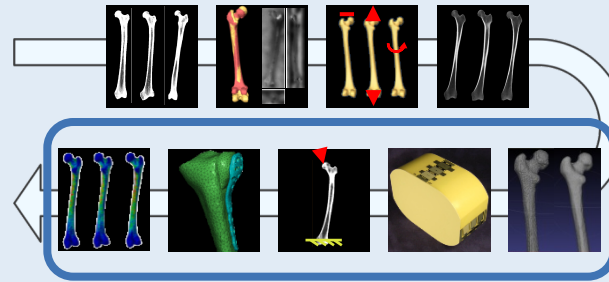
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- > Bones are conceived as samples in a high dimensional space
- > Principal Component Analysis (PCA) projects bones in a lower dimensional space where bone shape and density variances are minimized
- > Virtual bones are created sampling the space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



# Finite element simulations

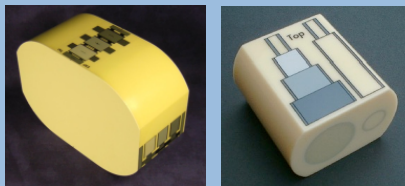
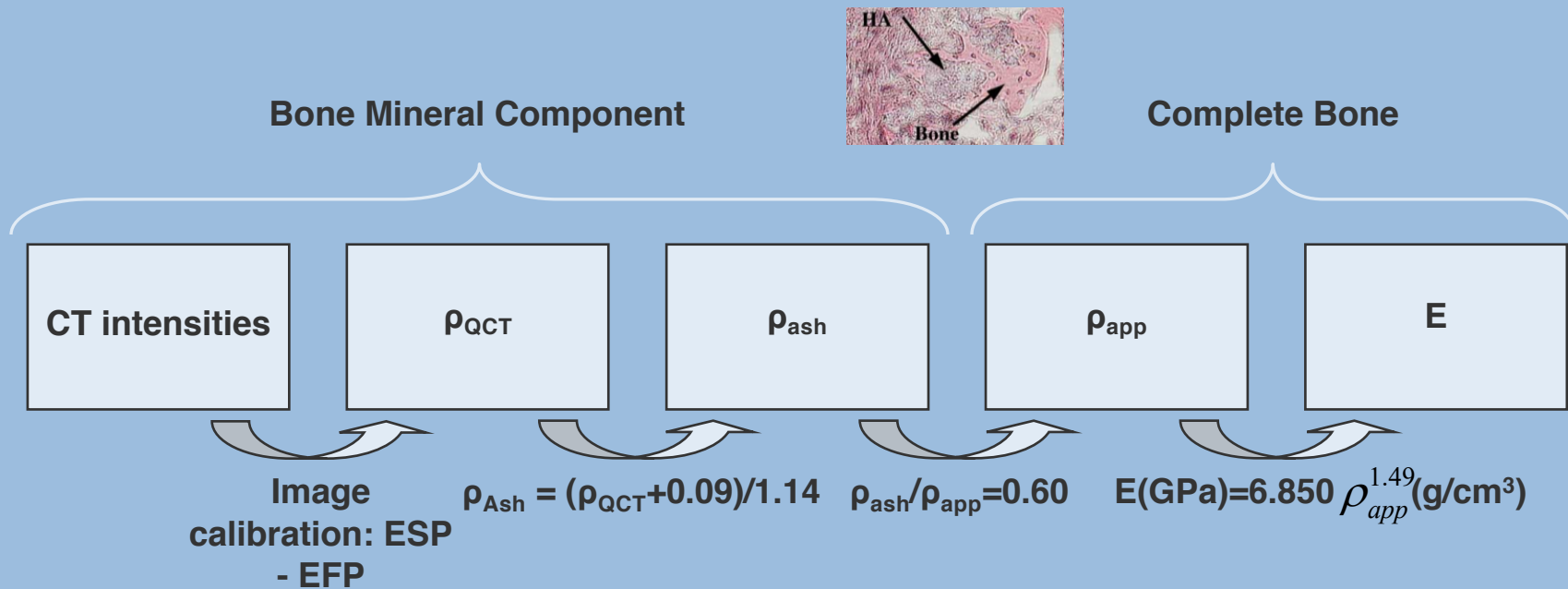


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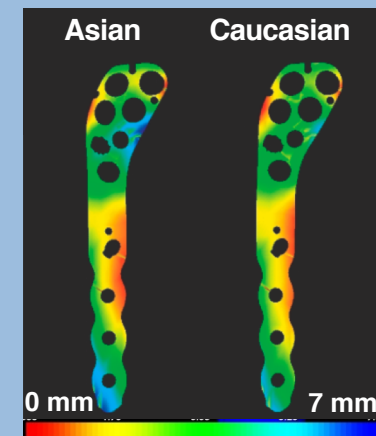
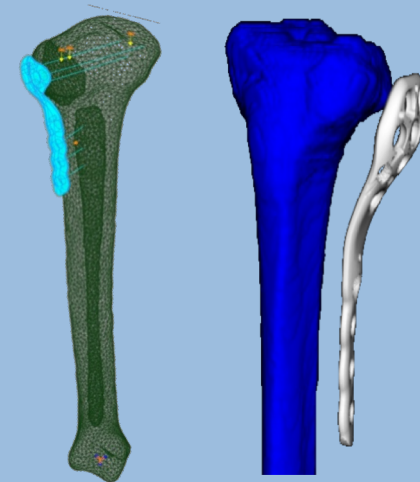
## > Mechanical property assignment



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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