Statistical Finite Element Analysis for Bone Modeling

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Introduction

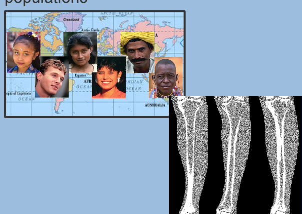
Current implant design techniques in orthopedics are based on manual fitting and fixation procedures applied on cadaver bones; in this way it is difficult to assess whether implants will fit most of the population.

Here a framework is proposed to evaluate biomechanical performances of an implant across a given population: after the creation of a statistical model that describes bone shape and mechanical properties in a given population, the 41-B1 tibia fracture (A.O. classification) was propagated from the mean bone to each new instance. Subsequently the implant was fitted to the bone in a semi-automatic way and finally biomechanical simulations were performed to evaluate the implant design.

Methods

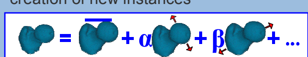
Statistical Shape Model

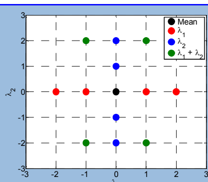
Dataset: CT images from different populations



Registration: deformation fields

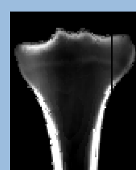
Principal Component Analysis: creation of new instances



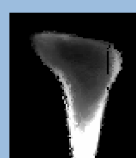


Fracture Creation

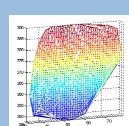
Fracture creation:
vertical cut
in the mean bone

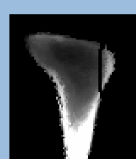


Registration:
fracture propagation
to the instances



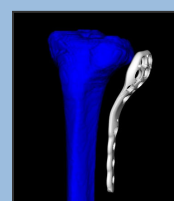
Surface creation:



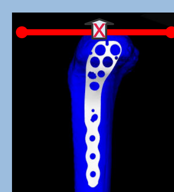


Implant Fitting

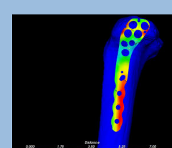
Manual initialization:



Implantation constraints:



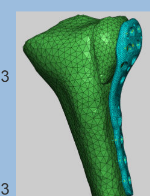
Iterative Closest Point: placement optimization



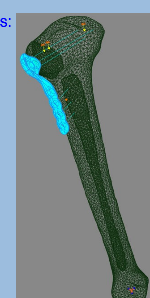
Finite Element Model

Bone:
$E=6.95\rho^{1.49}$
Poisson's ratio=0.3

Implant:
E=110 000 MPa
Poisson's ratio=0.3



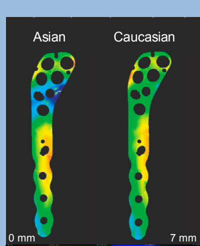
Loading conditions:
1600 N



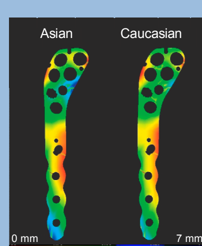
Results

Implant Fitting

Maximum distances:



Average distances:



No statistical differences between Asian and Caucasian.

Finite Element Model

	Caucasian	Asian
von Mises stress in the plate (MPa)	61	69 (+12%)
Max principle stress in the screws (MPa)	61	80 (+31%)

Both in plate and screws stresses are significantly higher ($p<0.05$) for Asian than for Caucasian.

Discussion

We presented a framework for statistical biomechanics assessment including a combined statistical model of shape and finite element analysis. Future developments will combine shape and intensity information into the statistical model; moreover different implant positions and loading conditions will be evaluated.

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