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Free Tool for the Assessment of Fracture Stiffness from Medical Images

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Development and Validation of

FEA4DICOM

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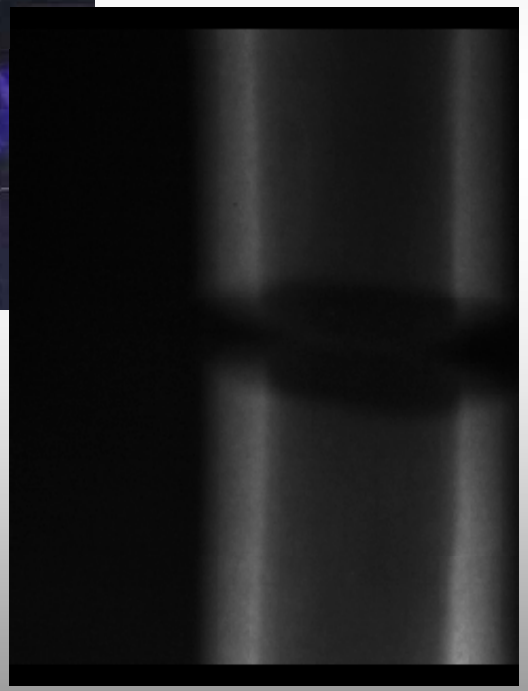
Introduction



Healing bone

Important clinical question:

When is a fracture healed?

- Standard: 2D x-rays from 2 planes
  3 of 4 cortices should be bridged
- Usage of 3D image data?
- Voxel-FE better than other projections
  [Shefelbine et al. 2002]
- Clinicians requested simple to use tools
  [OTC Boston 2009]

Aim

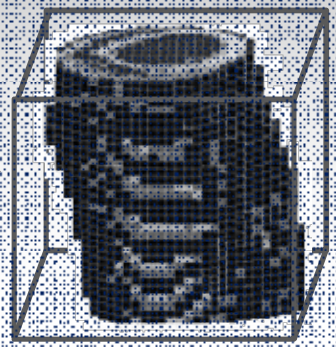
Develop a “One-Button-FEA” for stiffness calculation of CT data

Idea

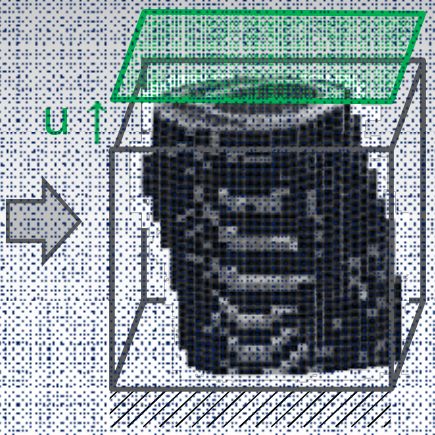
Patient

CT

Voxel-FEM



Load cases



Stiffness

$k_{xx} = \ldots$

FEA4DICOM

One button

User Input
1. Images
2. VOI
3. GV → Mat. prop.
4. Stiffness direction

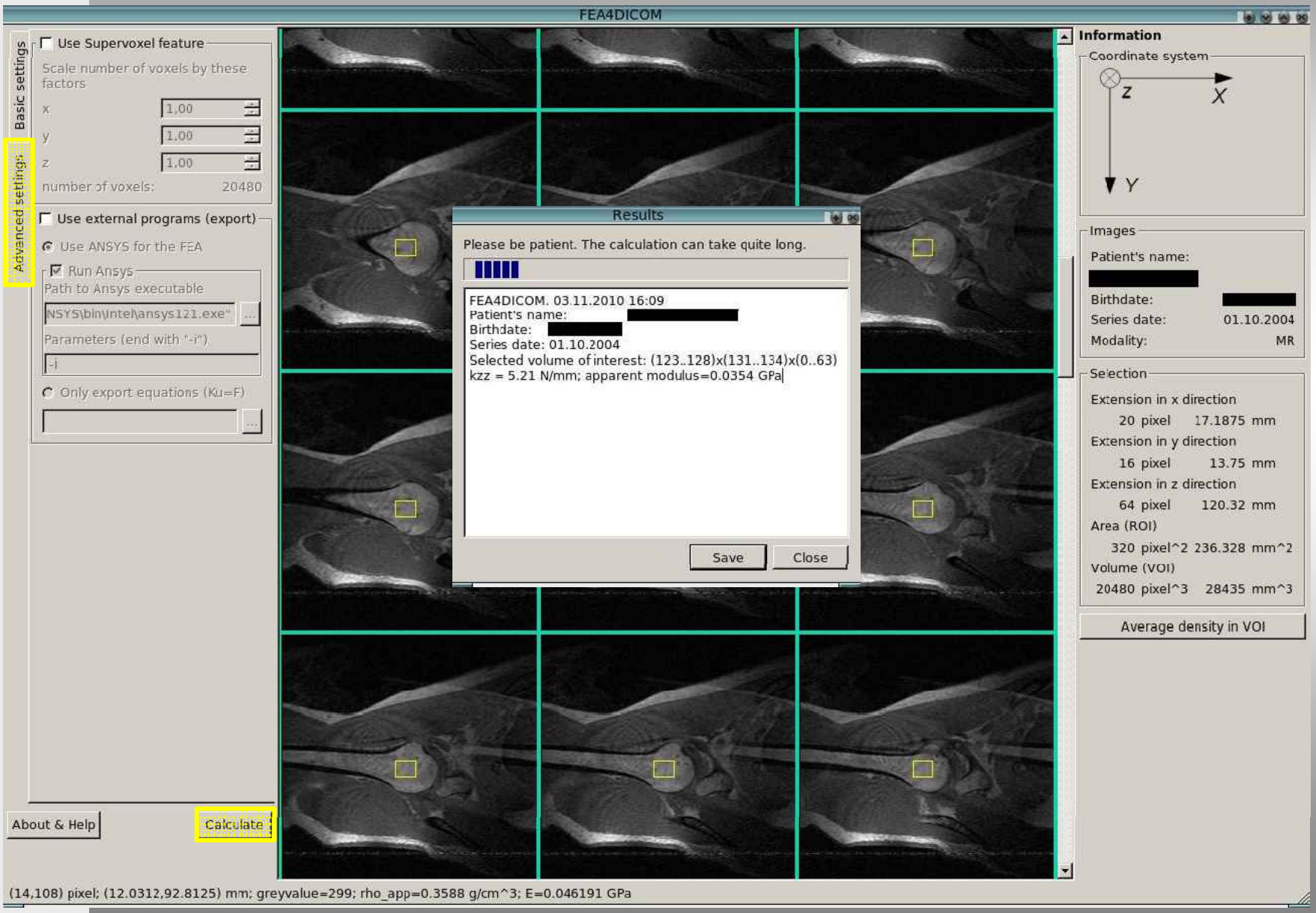
Automatic Preprocessing
- Voxel mesh
- Elem. MPs
- Load/BC

Solution
- Assemble Matrix
- Solve lin. eq.

Automatic Postprocessing

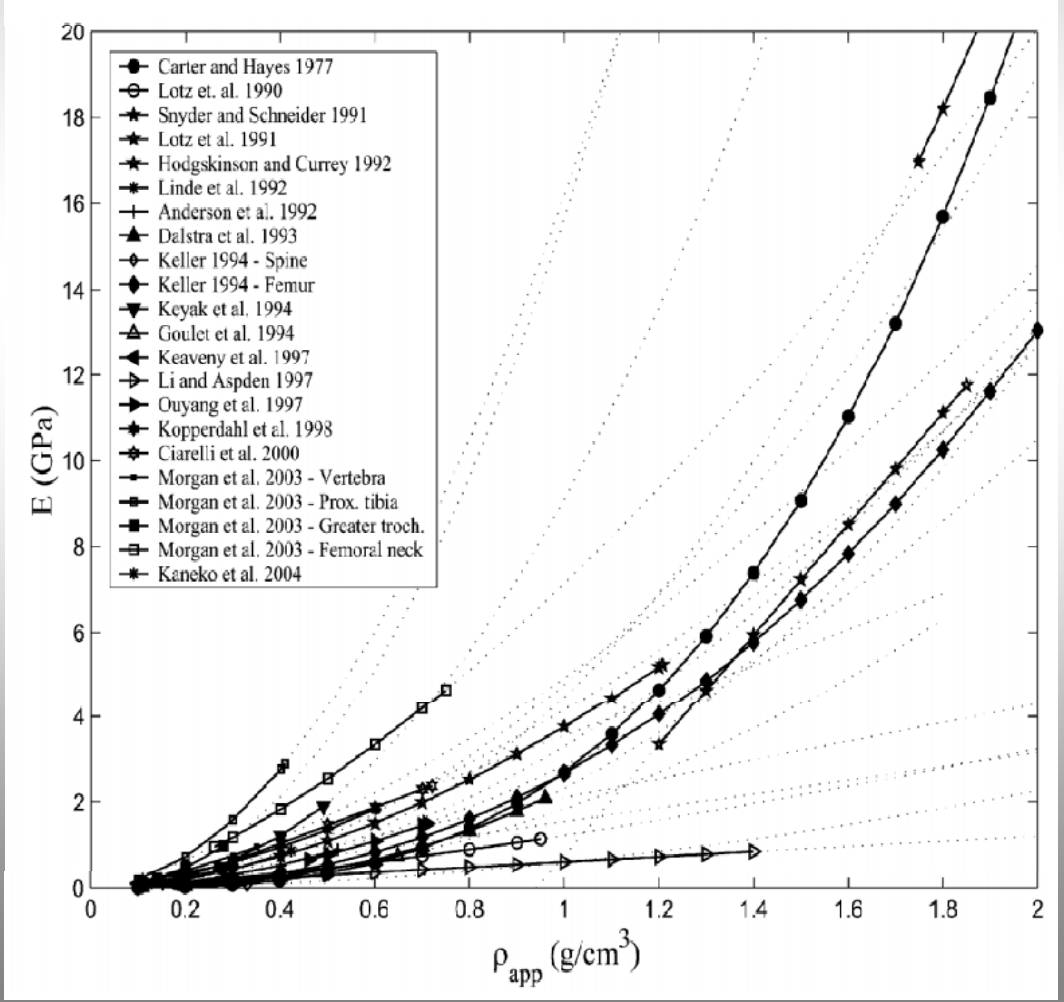
Stiffness calcul. and output

The Program FEA**4**DICOM



Gray-Value → Material Properties

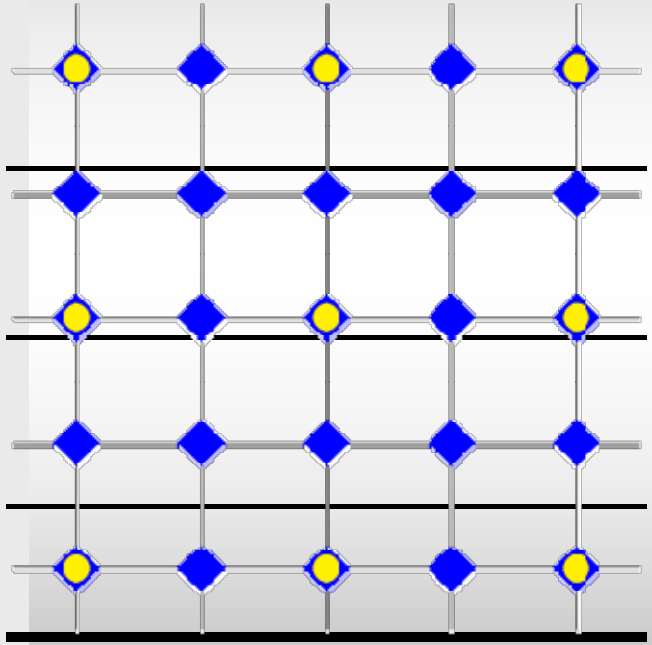
- Gray value (HU) → Density (Calibration) $\rho = c_1 \cdot \mathrm{GV} + c_2$
- Density → Young's Modulus (Literature) $E = c_3 \cdot \rho^{c_4} + c_5$



[Helgason et al. 2007]

Solver

- Direct solver: < 15.000 DOF, UMFPACK
- Multigrid solver: > 15.000 DOF, Self developed



Fine grid node

Coarse grid node

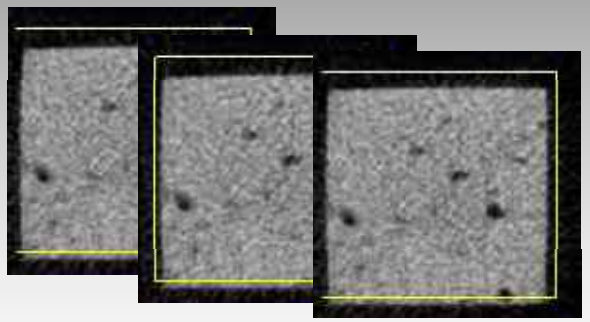
Multigrid algorithm

To get an approximation of z repeat …

- Relax (Gauss-Seidel)
- Restrict to coarse grid
- Approximate on coarse grid
- Interpolate back to fine grid
- Relax

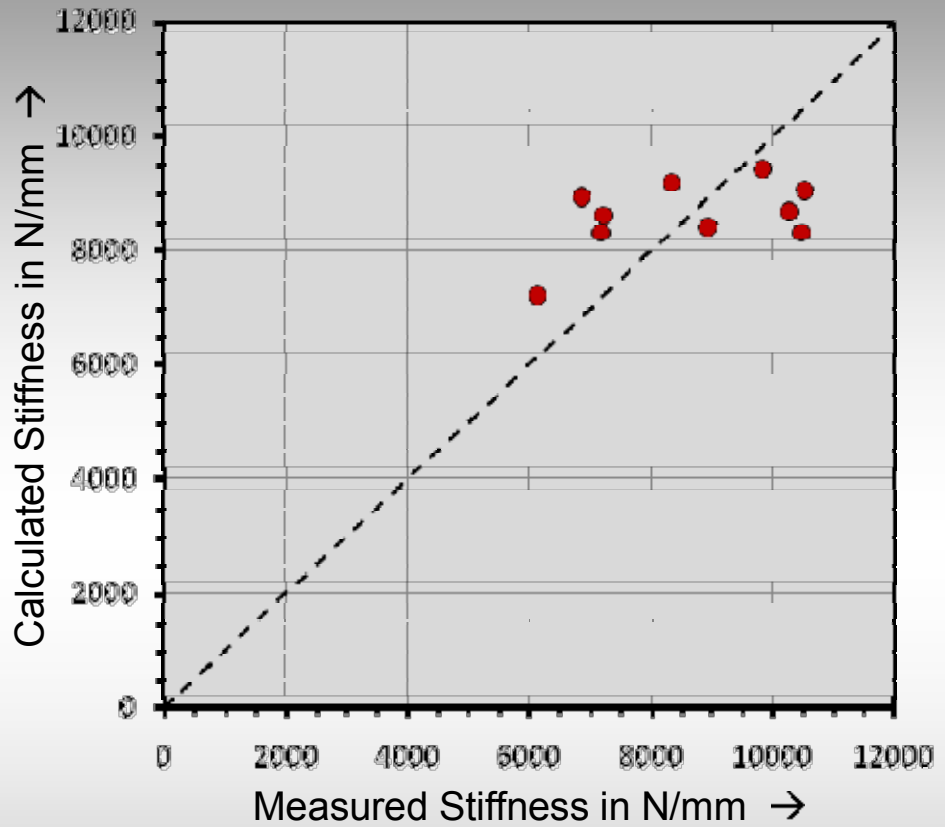
… until solution is “good enough”

Validation: Calculated vs. Measured Stiffness



Stiffness Calculations

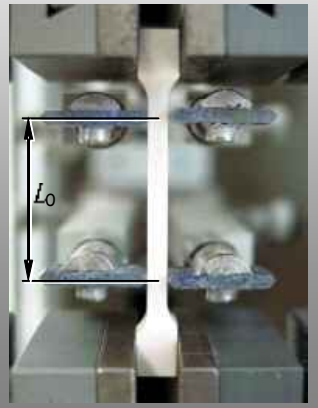
- µCT scan (10 µm), incl. phantom calibration
- Density-Modulus relation: Lotz et al. 1991
- Analysis with FEA4DICOM



Previous Validation:
[Shefelbine et al. 2002]

Stiffness Measurements

- 10 bovine bone specimen
- Tensile test
- Strain and force measuring



Discussion

Features

- Tool: Robust FEA of bony structures
- Validated
- DICOM & BMP import
- Axial & shear stiffnesses (3D)
- Supervoxel, av. Density & E-Mod.
- Solver: Direct & Multigrid
- Export to ANSYS (.cdb)
- Free! (GPL)

Limitations

- Linear
- Simplified Material Properties (Isotropic, GV → E)
- No contact

Next steps

- More load cases
- Complex VOI geometry
- Thresholding → VOI
- Integration in CT software

Download: www.uzwr.de/FEA4DICOM