



# Free Tool for the Assessment of Fracture Stiffness from Medical Images

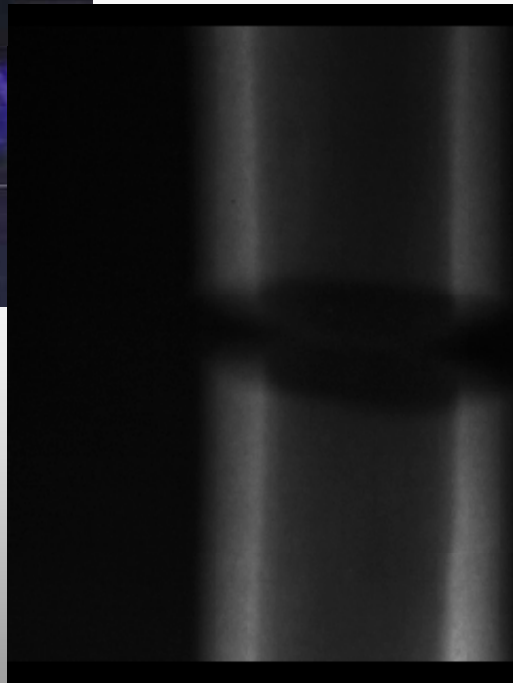
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## Development and Validation of **FEA4DICOM**

*U. Simon, M. Helmer, F. Hauser, D. Lechler,  
F. Niemeyer, T. Wehner, U. Wolfram, O. Marti*



# Introduction



Healing bone

Important clinical question:

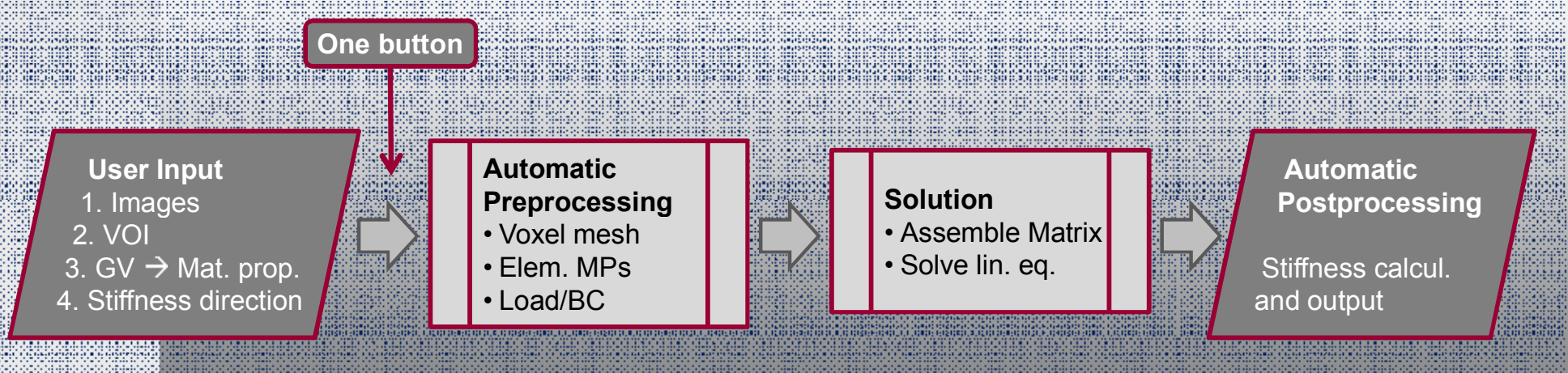
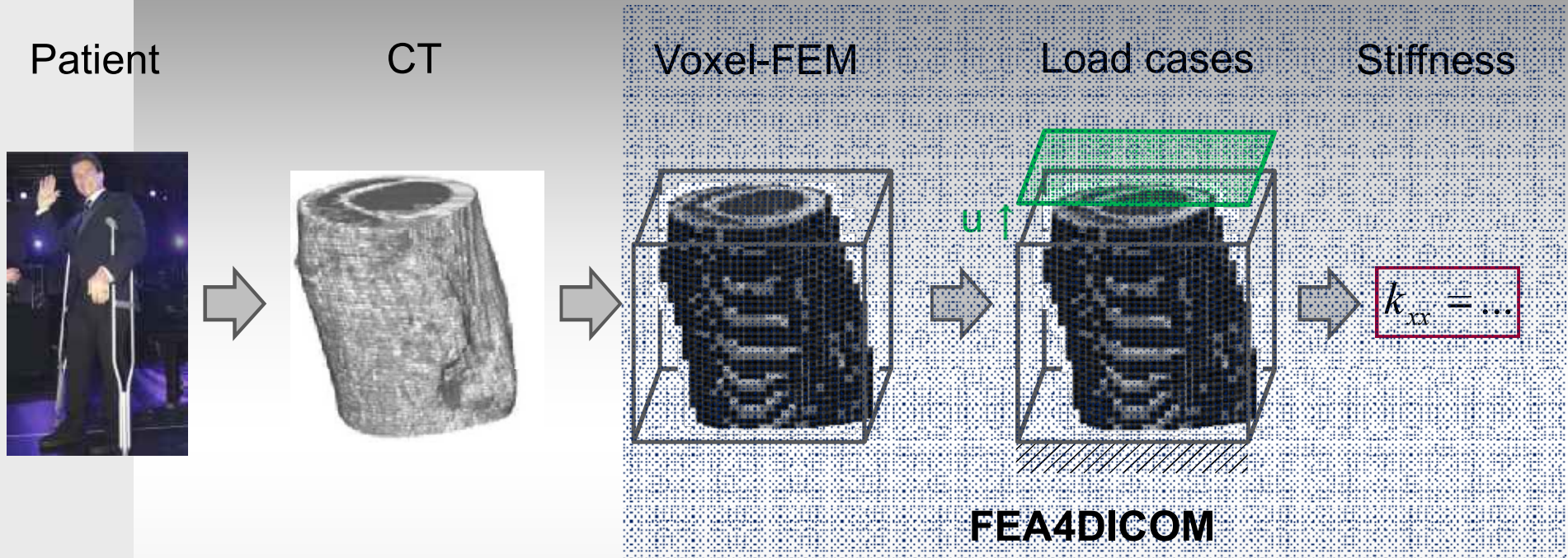
## When is a fracture healed?

- 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





# The Program FEA4DICOM

The screenshot displays the FEA4DICOM software interface. The main window is titled "FEA4DICOM" and shows a 3x3 grid of MRI slices. A central dialog box titled "Results" is open, displaying patient information and calculation results. The interface includes a left sidebar with "Basic settings" and "Advanced settings" sections, and a right sidebar with "Information" and "Section" sections. A "Calculate" button is highlighted in the bottom left corner.

**Basic settings**

- Use Supervoxel feature
- Scale number of voxels by these factors:
  - x: 1,00
  - y: 1,00
  - z: 1,00
- number of voxels: 20480

**Advanced settings**

- Use external programs (export)
- Use ANSYS for the FEA
  - Run Ansys
  - Path to Ansys executable: NSYS\bin\intel\ansys121.exe
  - Parameters (end with "-i"): -i
- Only export equations (Ku=F)

**Results**

Please be patient. The calculation can take quite long.

FEA4DICOM. 03.11.2010 16:09  
Patient's name: [REDACTED]  
Birthdate: [REDACTED]  
Series date: 01.10.2004  
Selected volume of interest: (123..128)x(131..134)x(0..63)  
kzz = 5.21 N/mm; apparent modulus=0.0354 GPa

**Information**

Coordinate system:  
Z (up), X (right), Y (down)

**Images**

Patient's name: [REDACTED]  
Birthdate: [REDACTED]  
Series date: 01.10.2004  
Modality: MR

**Section**

Extension in x direction: 20 pixel 17.1875 mm  
Extension in y direction: 16 pixel 13.75 mm  
Extension in z direction: 64 pixel 120.32 mm  
Area (ROI): 320 pixel<sup>2</sup> 236.328 mm<sup>2</sup>  
Volume (VOI): 20480 pixel<sup>3</sup> 28435 mm<sup>3</sup>

Average density in VOI

About & Help | Calculate

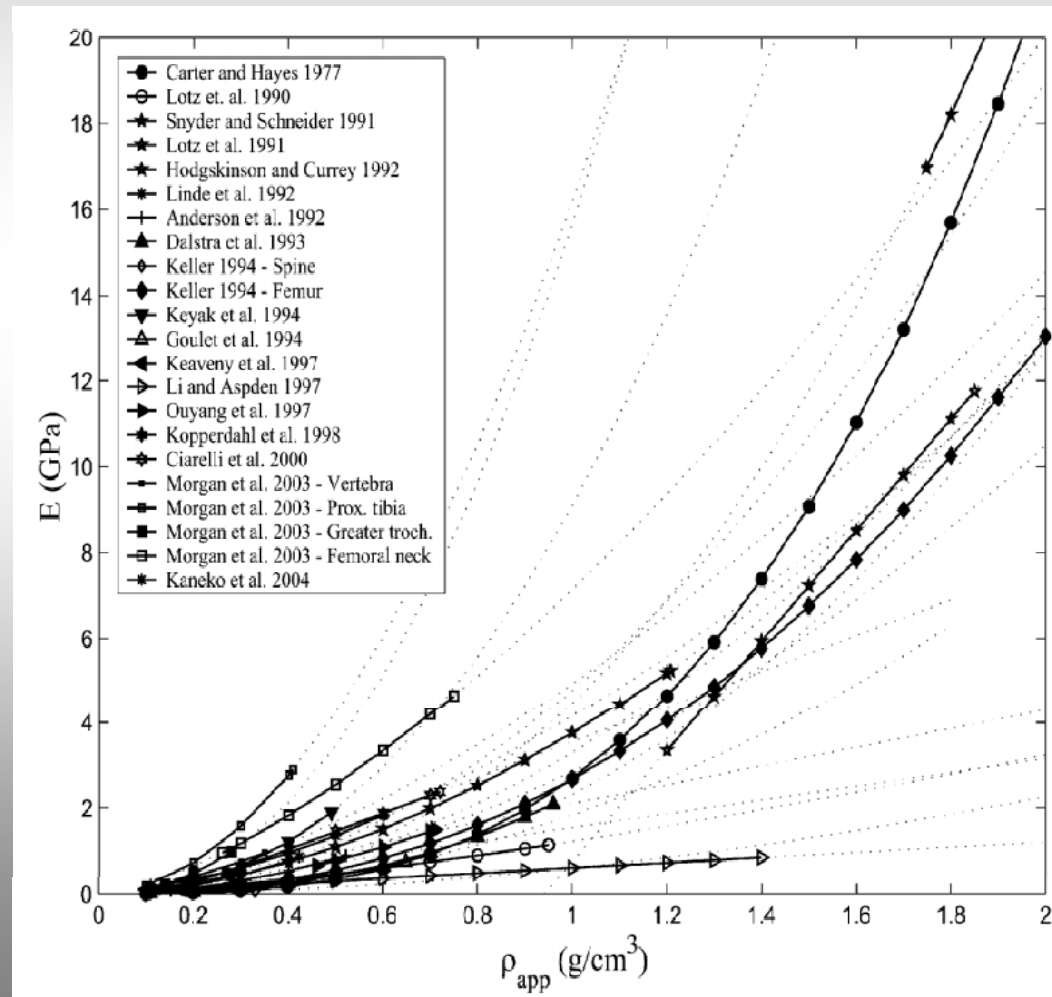
(14,108) pixel; (12.0312,92.8125) mm; greyvalue=299; rho\_app=0.3588 g/cm<sup>3</sup>; E=0.046191 GPa

# Gray-Value → Material Properties

- Gray value (HU) → Density (Calibration)
- Density → Young's Modulus (Literature)

$$\rho = c_1 \cdot \text{GV} + c_2$$

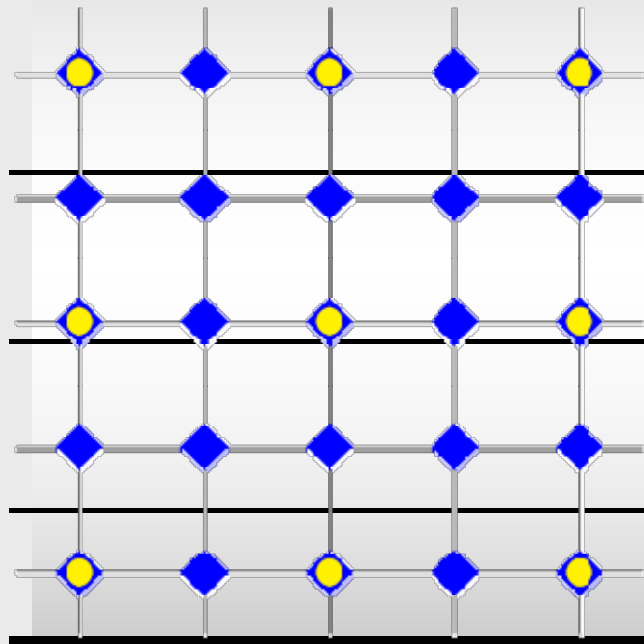
$$E = c_3 \cdot \rho^{c_4} + c_5$$



[Helgason et al. 2007]

# Solver

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



- ◆ Fine grid node
- Coarse grid node

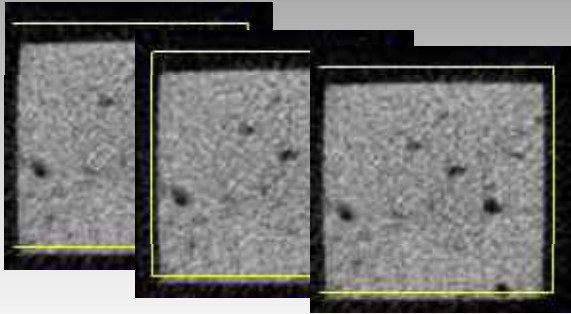
## Multigrid algorithm

To get an approximation of  $z$  repeat ...

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

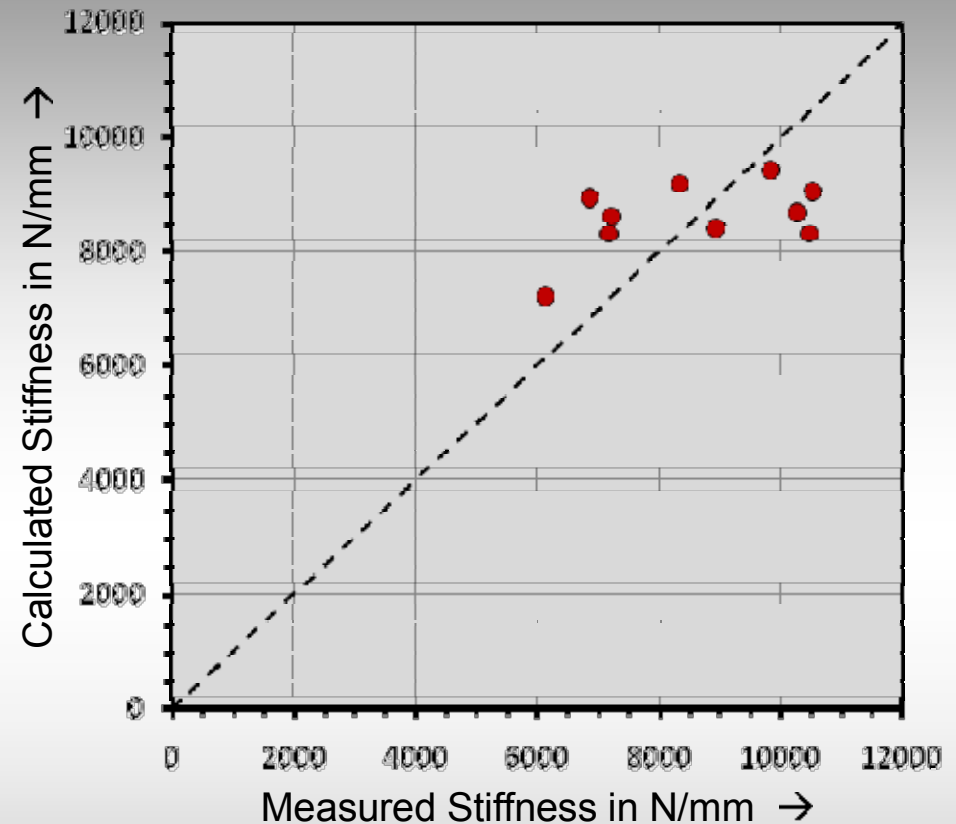
... until solution is “good enough”

# Validation: Calculated vs. Measured Stiffness



## Stiffness Calculations

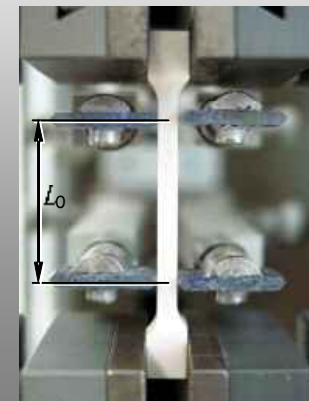
- $\mu$ CT scan (10  $\mu$ m), incl. phantom calibration
- Density-Modulus relation: Lotz et al. 1991
- Analysis with FEA4DICOM



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,  $GV \rightarrow E$ )
- No contact

## Next steps

- More load cases
- Complex VOI geometry
- Thresholding  $\rightarrow$  VOI
- Integration in CT software

Download: [www.uzwr.de/FEA4DICOM](http://www.uzwr.de/FEA4DICOM)