Current Concepts and Open Problems in Computational Clinical Biomechanics

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Introduction: Clinical Problems ...

...where computers might help:

Implants

- Function (strength, elasticity, joint kinematics, ...)
- Loading (muscle forces)
- Biocompatibility (contact, wear, elasticity, ...)
- Adaptation of adjacent tissues (stress shielding)

Osteoporosis

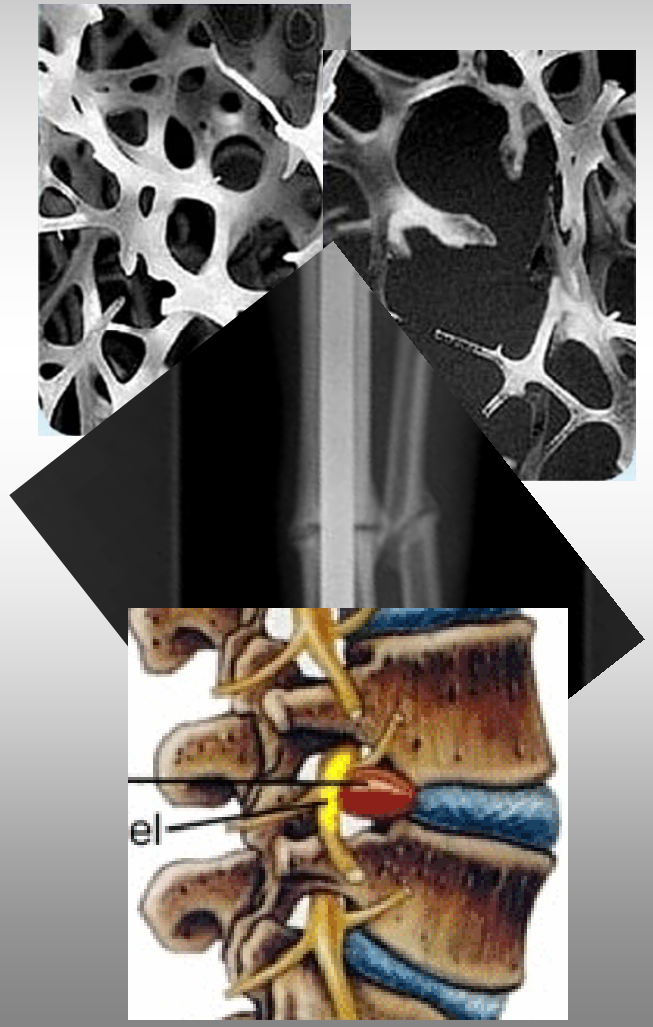
- Misalignment between formation and loss of bone
- Diagnosis: fracture risk from CT images

Fracture Healing

- Minimizing healing time
- Preventing Complications

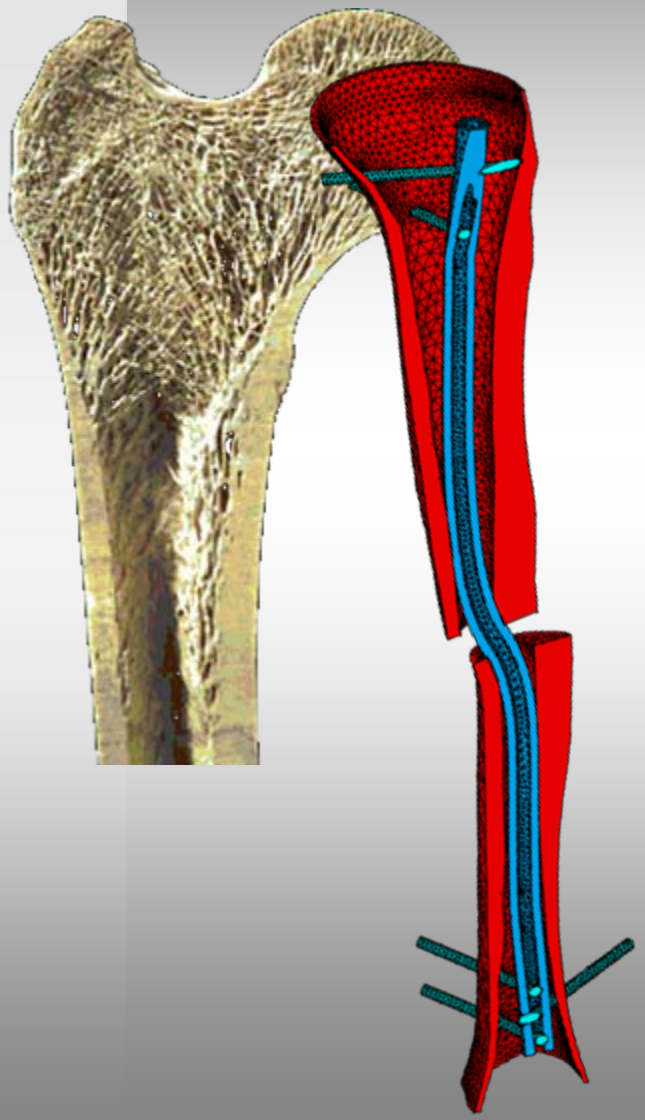
Back Pain

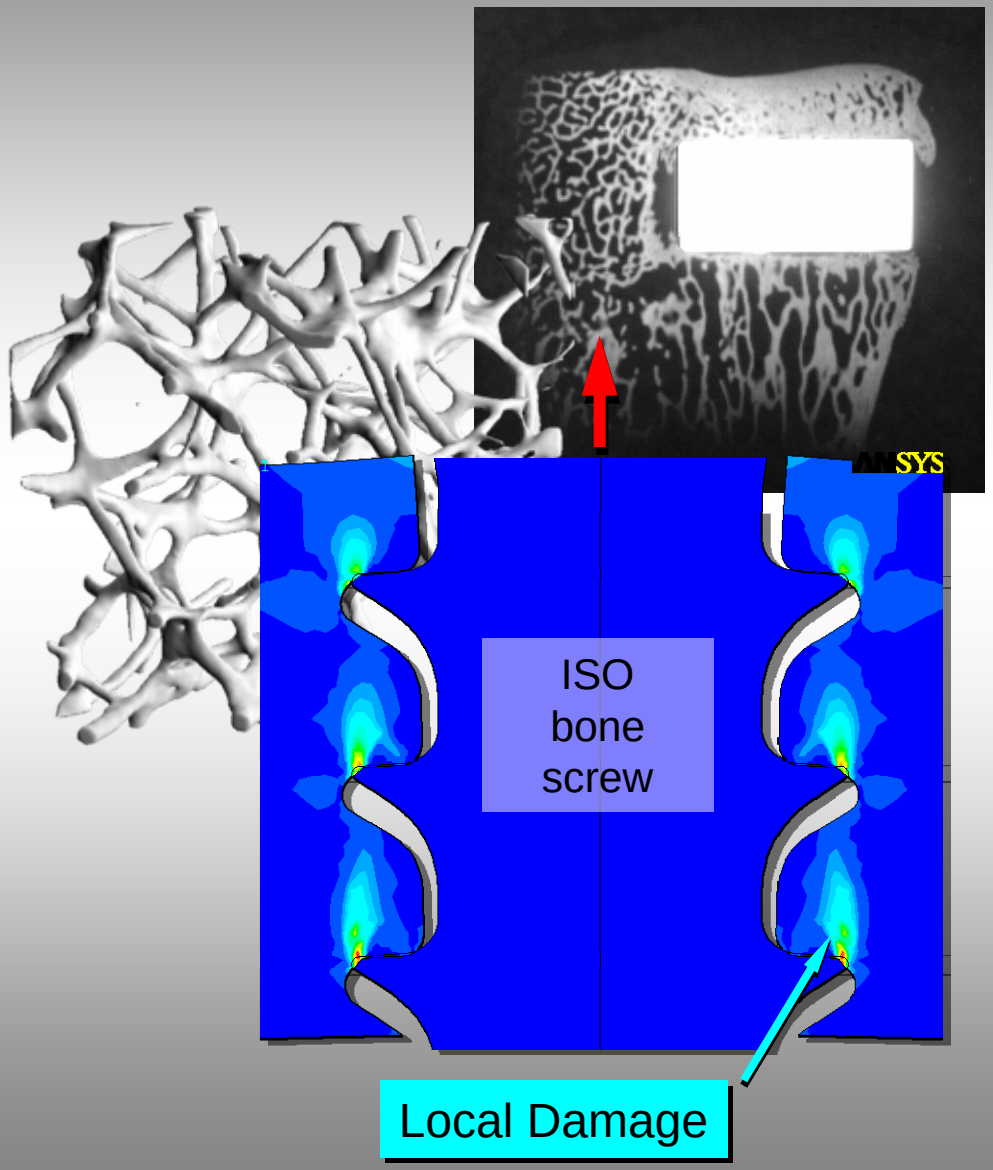
- Intervertebral disk degeneration (disk prolapse)
- Optimizing treatment and implants



Contents

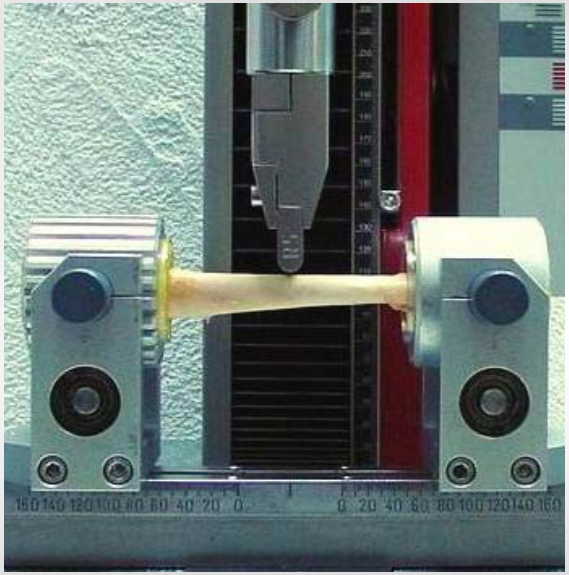
1 Structural Mechanics / Material Properties





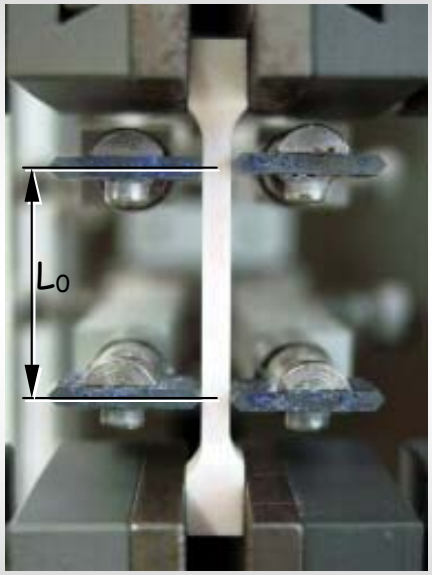
Multiscale Problem

Organ Level



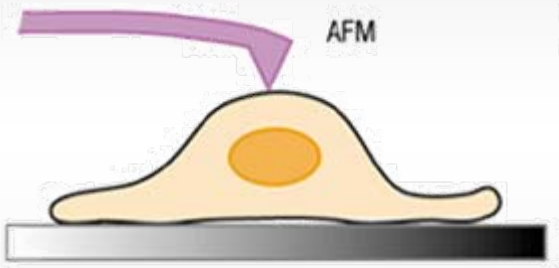
3-Point Bending
of a
bone specimen

Tissue Level



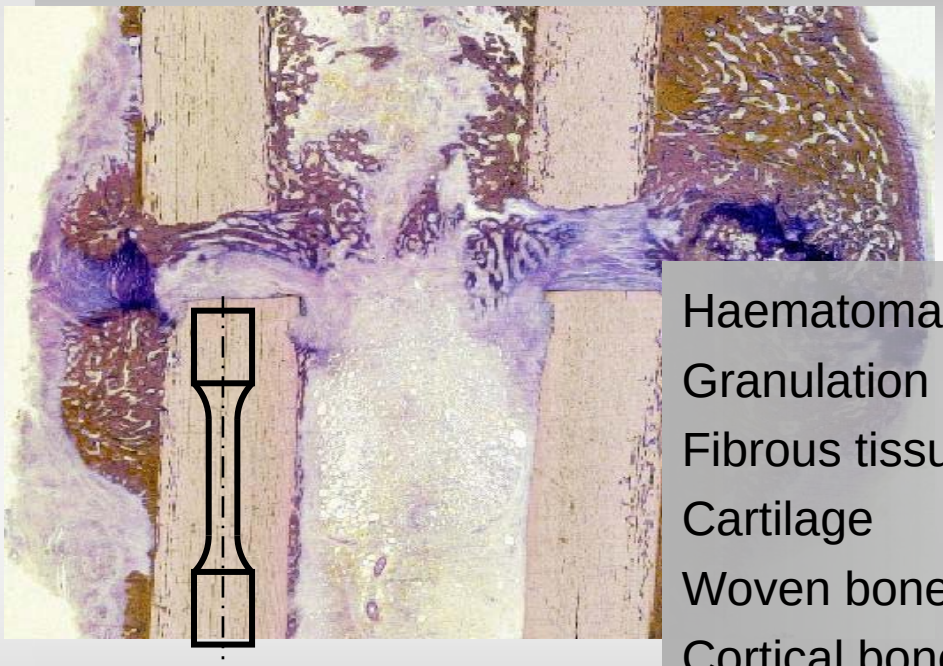
Tensile Test
of a
standardized Specimen

Cell Level



Atomic Force Microscopy
of a
living cell

Material Properties



Haematoma Granulation tissue Fibrous tissue	0,01 ... 3 MPa
Cartilage	0,4 … 500 MPa
Woven bone	400 … 6000 MPa
Cortical bone	10 ... 20 GPa

Yamada 1970; Hori & Lewis 1982; Davy & Connolly 1982; Proctor et al. 1989; Mente & Lewis 1994; Rho et al. 1995; Augat et al. 1998; Tanck et al. 1999

Material Properties

Simplest Material Law:

- Linear-elastic, isotropic (Hook's Law)

More complex Laws:

- Nonlinear
- Hyperelastic (nonlinear elastic + large deformations)
- Viscoelastic
- Non-elastic, plastic, yielding, hardening
- Anisotropic
- Fatigue, recovery
- Remodeling, healing

Biological Tissues know all of these bad things!

Structural Mechanics

current concepts

Complex Geometry

- CT2FE

Complex Material Props

- Multiscale
- Non-linear, ..., non-everything!
- ... at the same time

Contact

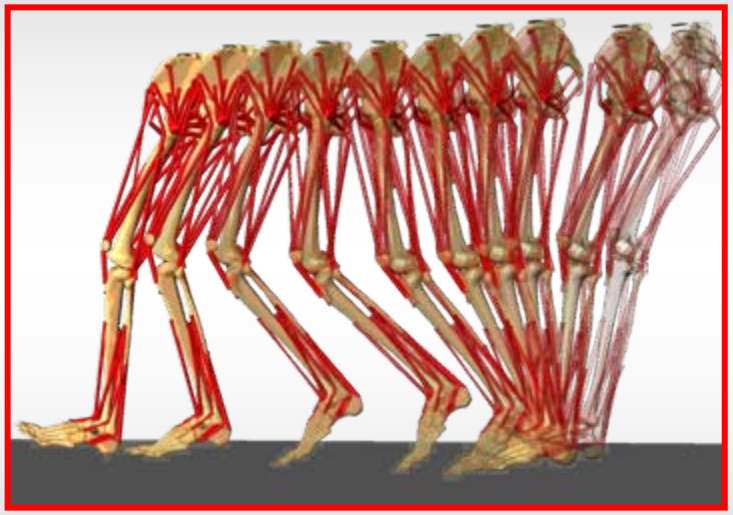
- Surface reconstruction
  - Friction: Not constant!
  - Coagulation, Ingrowth

open problems

2 Musculoskeletal Loads

Musculo-skeletal model

Measured movement →



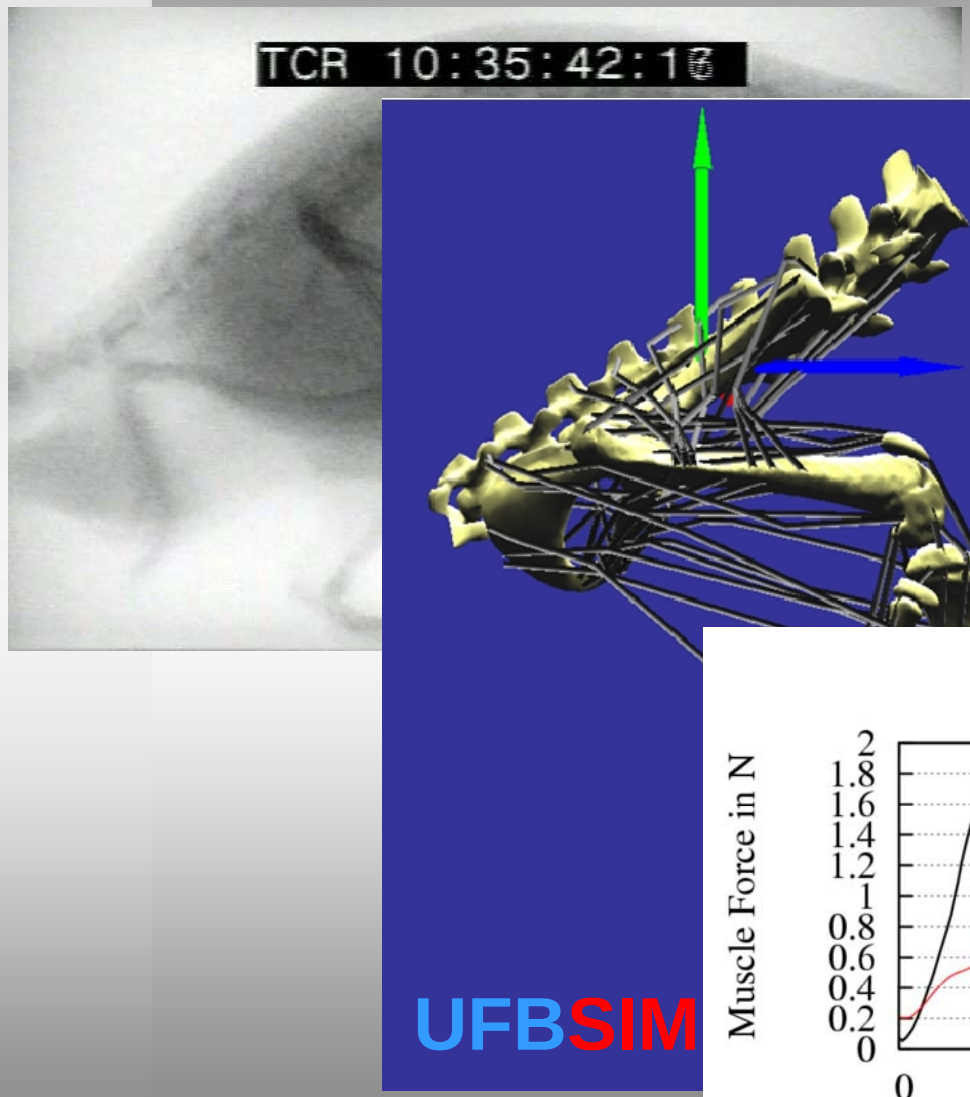
→ Muscle forces, <u>internal loads</u>

- Inverse dynamics
- Optimization

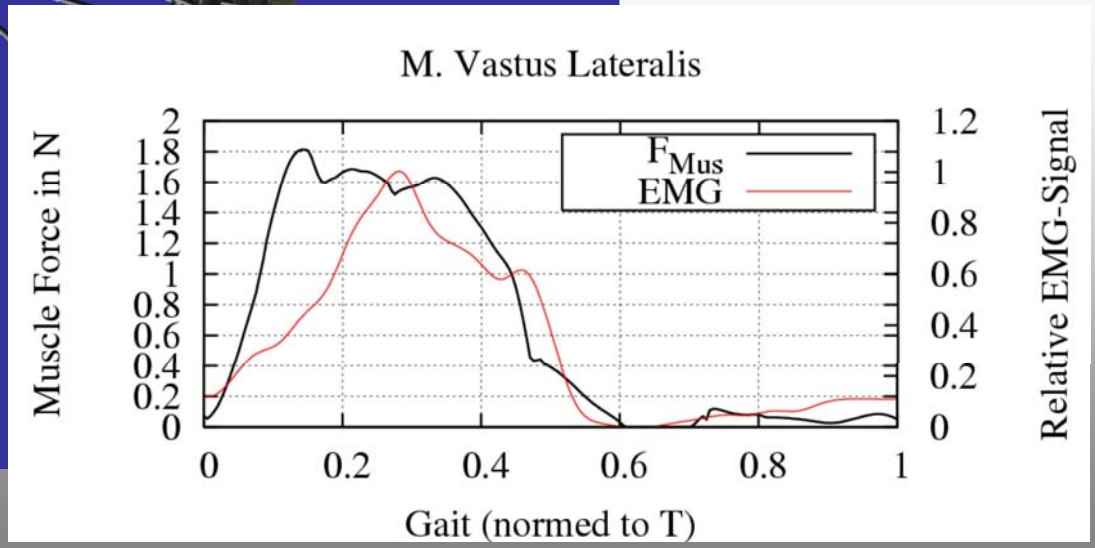
ANYBODY TECHNOLOGY

www.anybodytech.com

Example: Rat Gait



Erik Forster
Uwe Wolfram



Musculoskeletal Loading

current concepts

Modeling

- Anatomy (bones, joints, muscles)
- Anybody

Methods

- Inverse Dynamics
- Optimization (min. effort, energy)

open problems

- How to account for co-contraction?
- ... for pain?

Fracture Healing

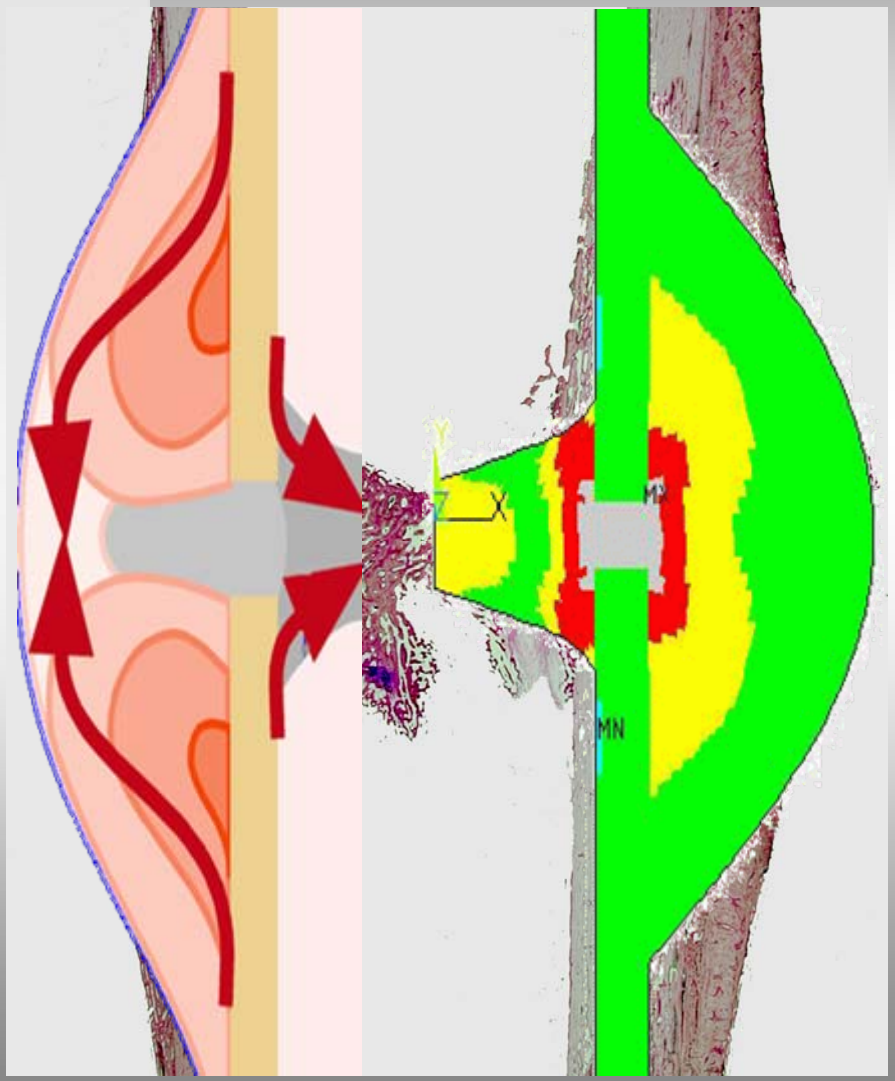
Clinical Relevance:

- 5-10% Complications

Aims:

- Minimize healing time
- Avoid Complications
- Optimize implants

Callus Healing Process



Problem:

New bone formation only with low strain state !

Biological Solution:

1. Callus: larger diameter
2. Via cartilage to bone

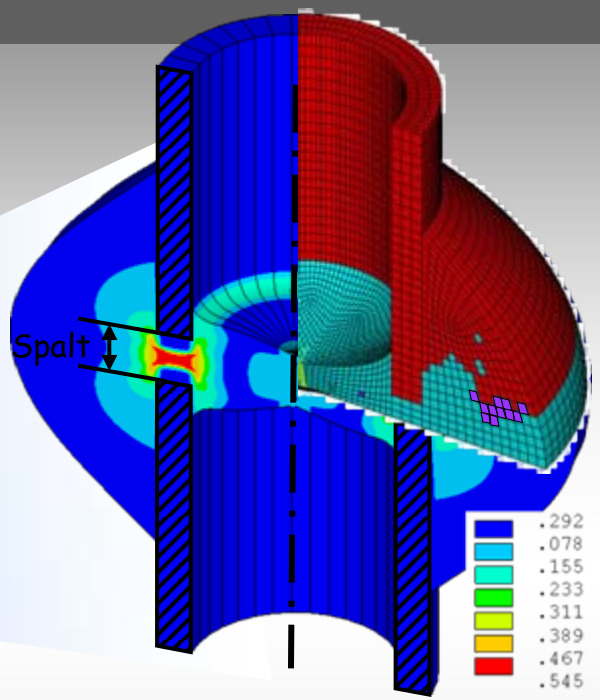
Method: Iterative Simulation

Initial state
Geometry, Mesh, Loads, BC

FEA
Strain field

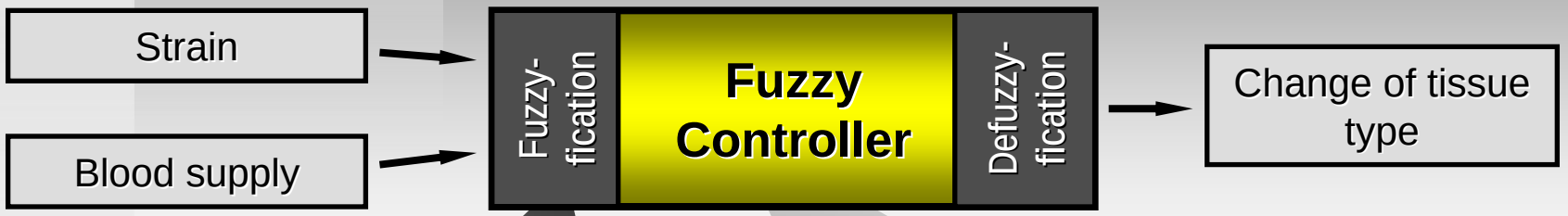
Fuzzy Logic
Biological processes

Result
Simulation over time

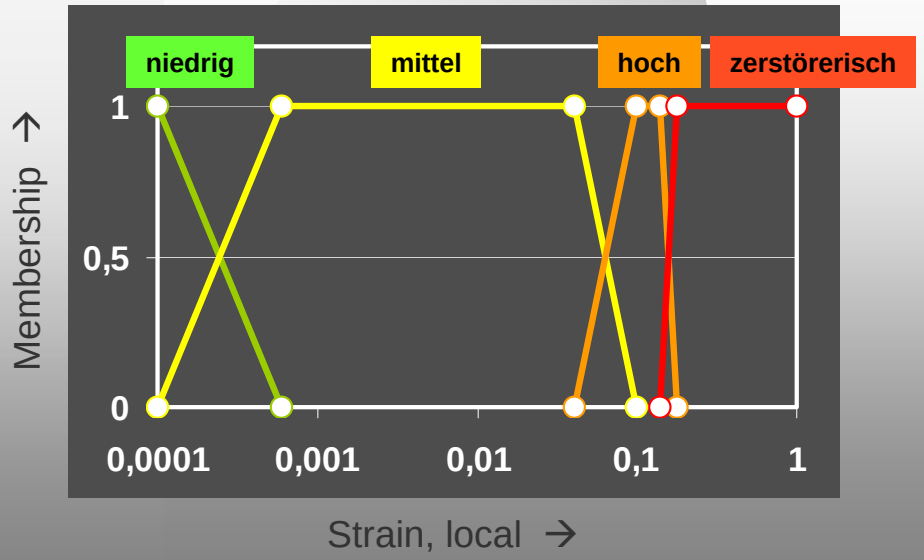


Fuzzy rules:
- Bone formation
- Cartilage formation
- Revascularization

Fuzzy Logic Controller



Fuzzyfication:



Fuzzy rules:

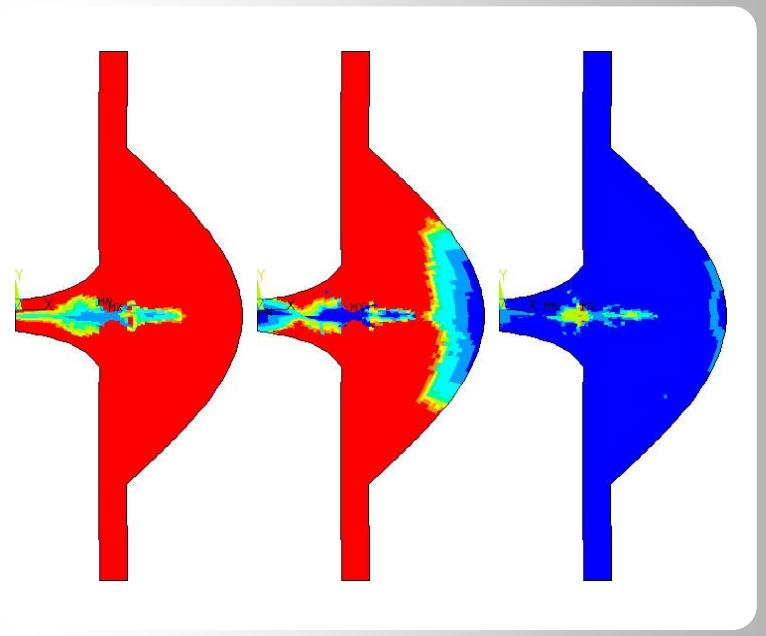
If …
strain is low
and
blood supply is good,
…
then …
bone concentration is increasing.

Results

Case A

Small initial movement 0.25 mm

Blood Bone Cartilage

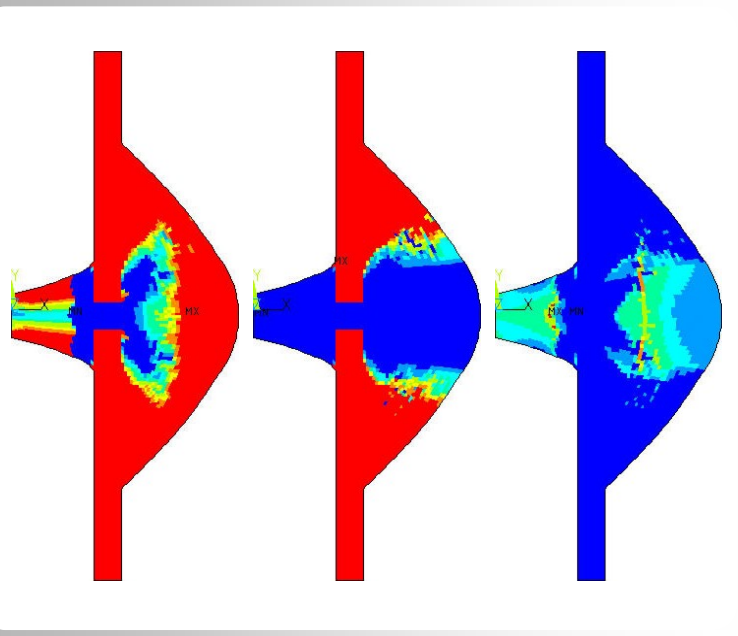


Day 35

Case B

Large initial movement 1.25 mm

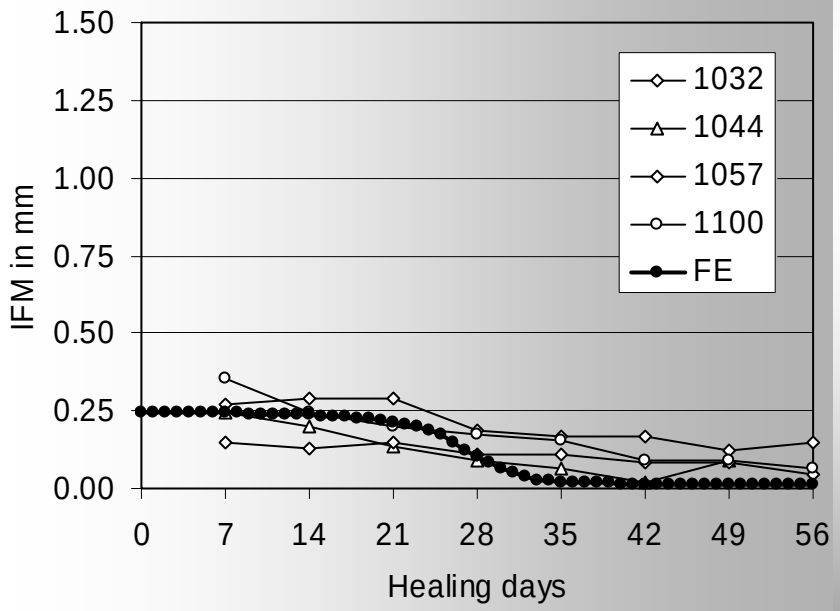
Blood Bone Cartilage



Validation with experimental results (sheep)

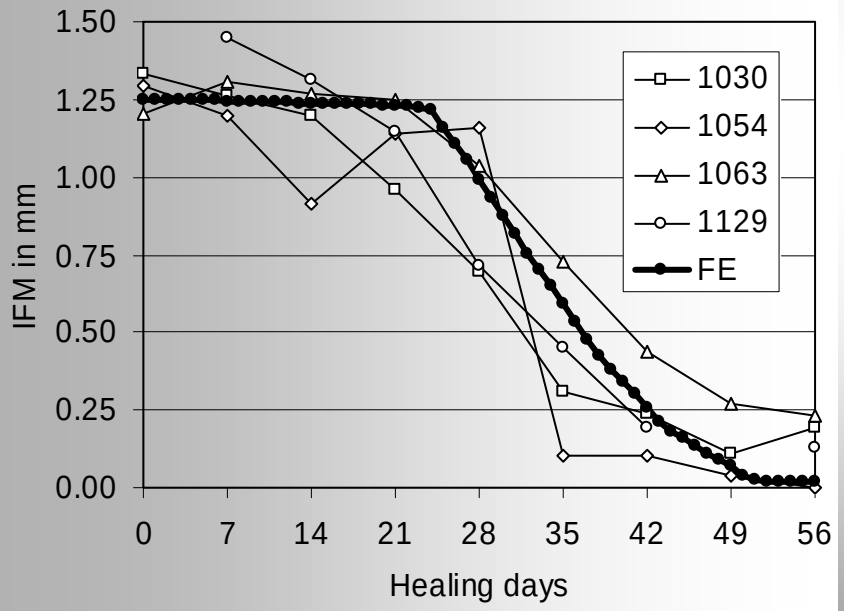
Case A

Small initial movement 0.25 mm



Case B

Large initial movement 1.25 mm



Fracture Healing / Remodeling

current concepts

Methods

- Simulation of dynamic systems
- ... adaptive systems

CPU time

- Geometry, Nonlinearities
- Automatic optimization

Including biological factors

- TGF, BMP, ...

open problems

Summary

- Methods are quit improved
- Open problems: biological factors, loads
- Validation
- Necessary: Interdisciplinary team

  clinicians, biologists, engineers, mathematicians, IT specialists

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