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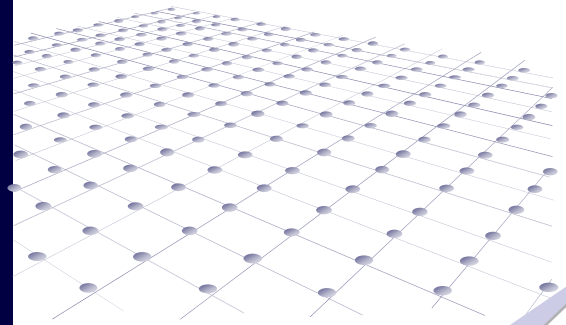

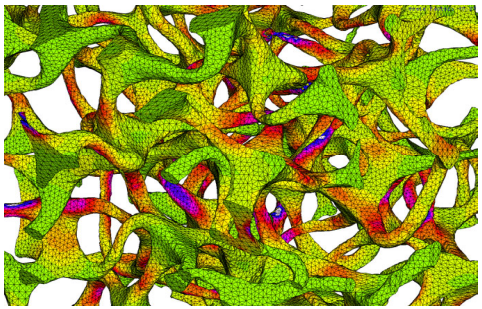

Computational Biomechanics: a challenge at the engineering /life sciences interface5th

John Middleton Georges Limbert

European LS-DYNA Conference

Birmingham UK May 25-26, 2005

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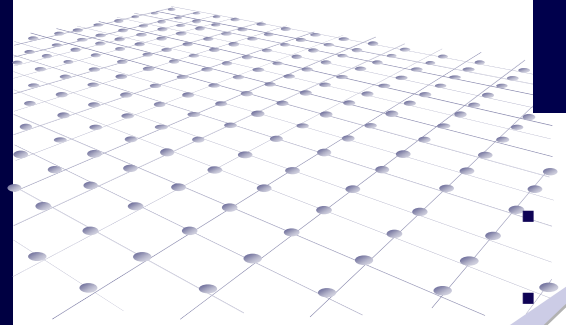
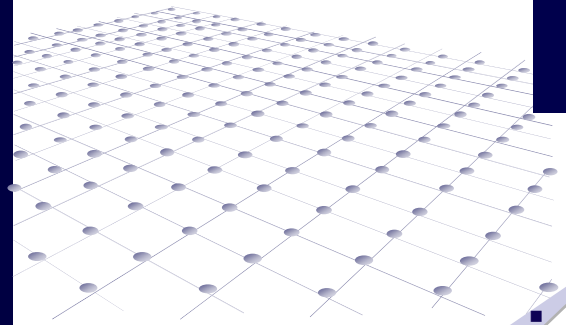


Presentation

- **Applications**
- **Numerical simulations ???**
- **Examples of applications in biomedical engineering (current R&D projects)**
- **Example: Biomedical material modelling / Ligaments**
- **Example: Medical auxetic foams**
- **Example: Biological tissue / implant interface**
- **Example: 3D facial imaging / simulation**
- **Example: Modelling dental implants**
- **The future challenge**



Expertise

- Mechanics of biological tissues and structures
- Non-linear continuum mechanics and applied mathematics
- Modelling of (bio)structures/medical device interactions
- Simulation of clinical trials within the clinical environment
- Pre-clinical assessment of implants, osseogenesis
- Development of constitutive models for soft and hard tissue
- Medical device optimisation, device/tissue interface

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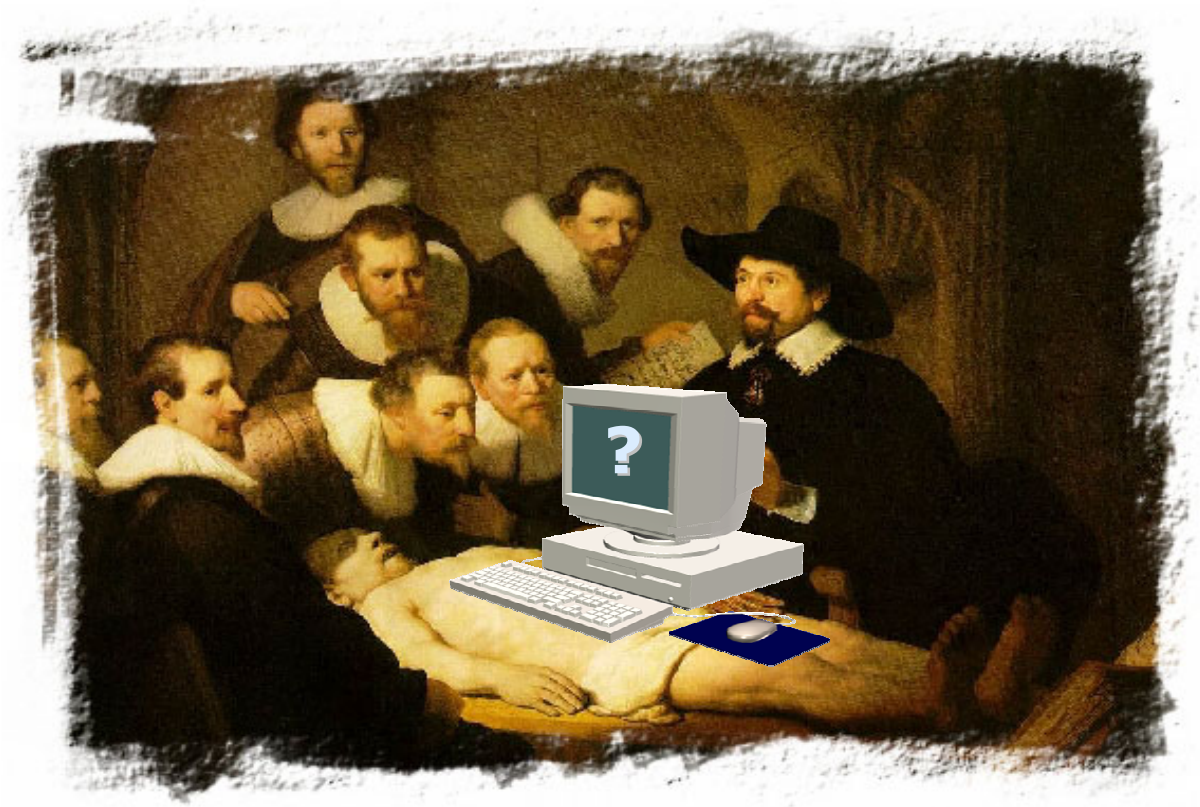
Numerical Simulations in Biomedical Engineering



The anatomy lecture of Dr. Nicolaes Tulp, Rembrandt, 1632

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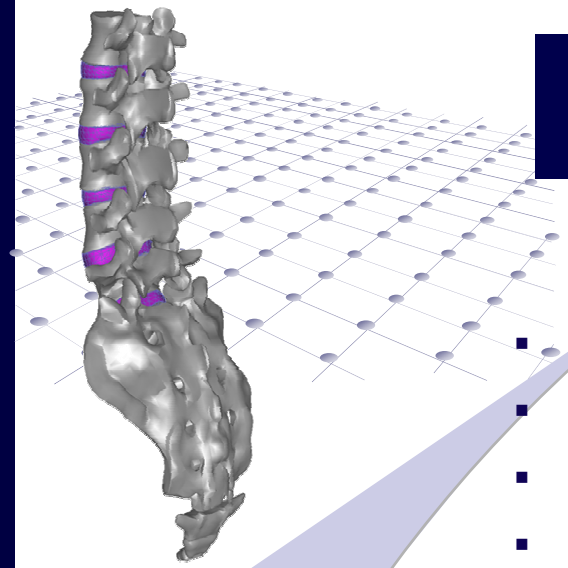
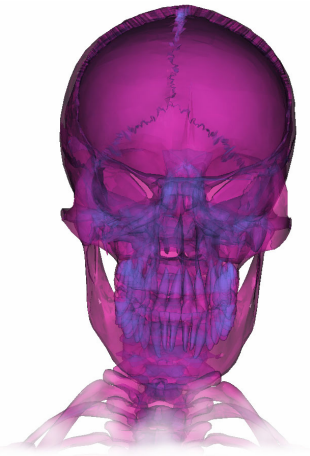
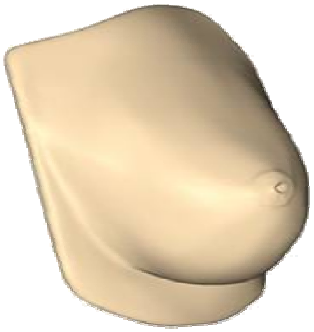
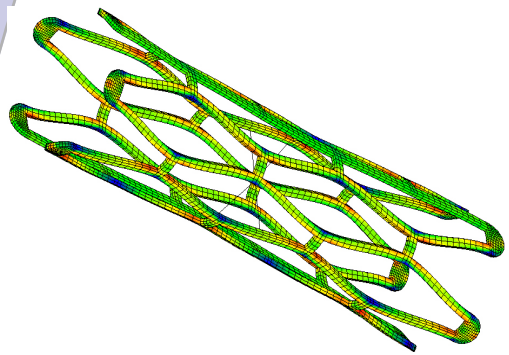


Soft tissue modelling

- Surgical procedures (suture, gravity forces, tissue remodelling)
- Pre-operative planning
- Tumour diagnosis
- Damage to breast implants (car crash)
- Ergonomics (sport equipment, etc)







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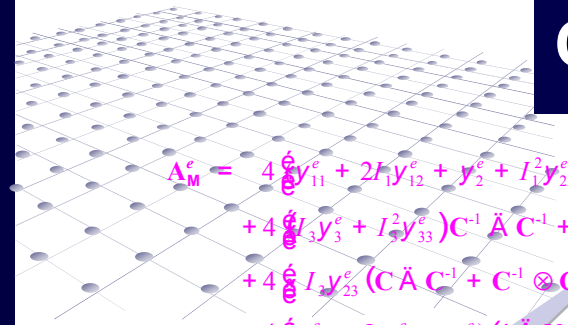
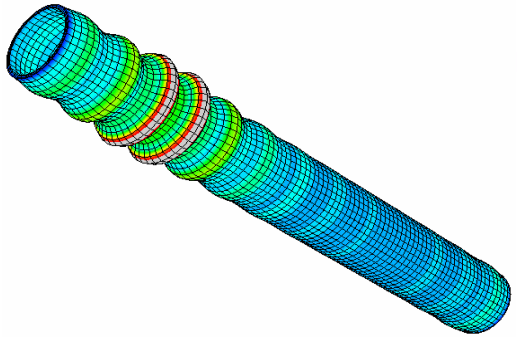
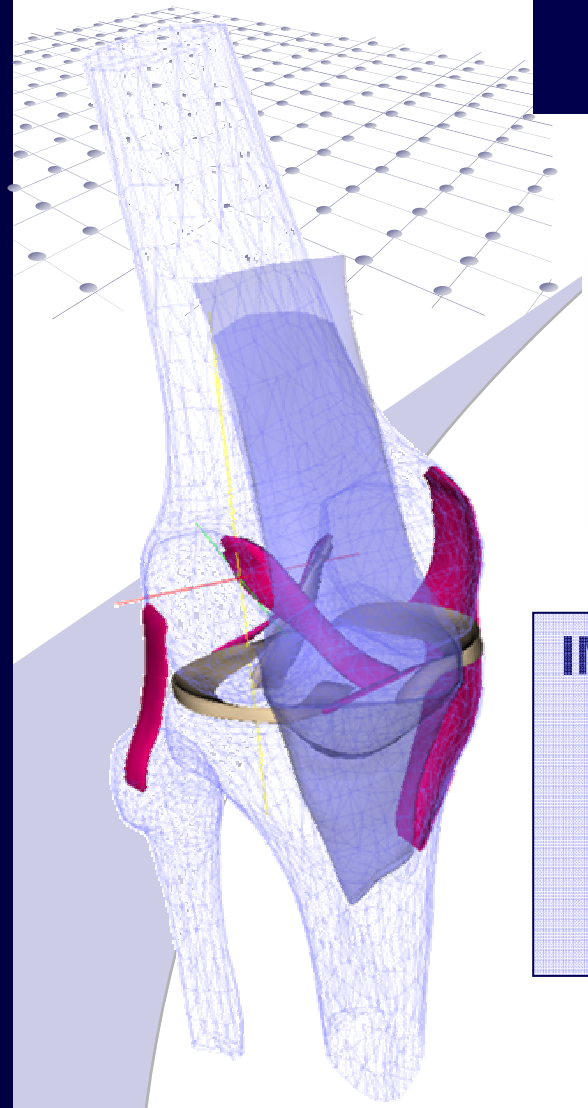
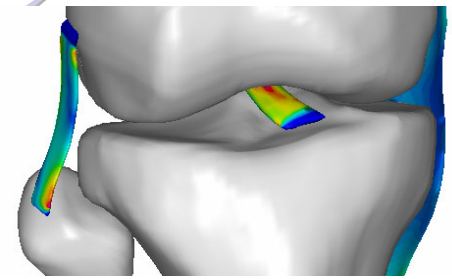
Constitutive modelling of biostructures

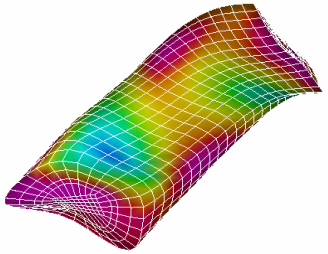




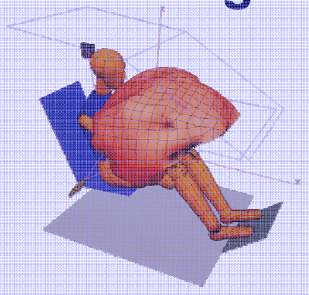
Knee joint – ligament

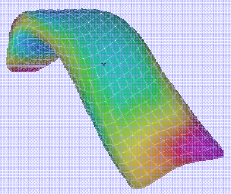


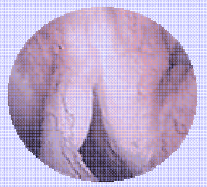




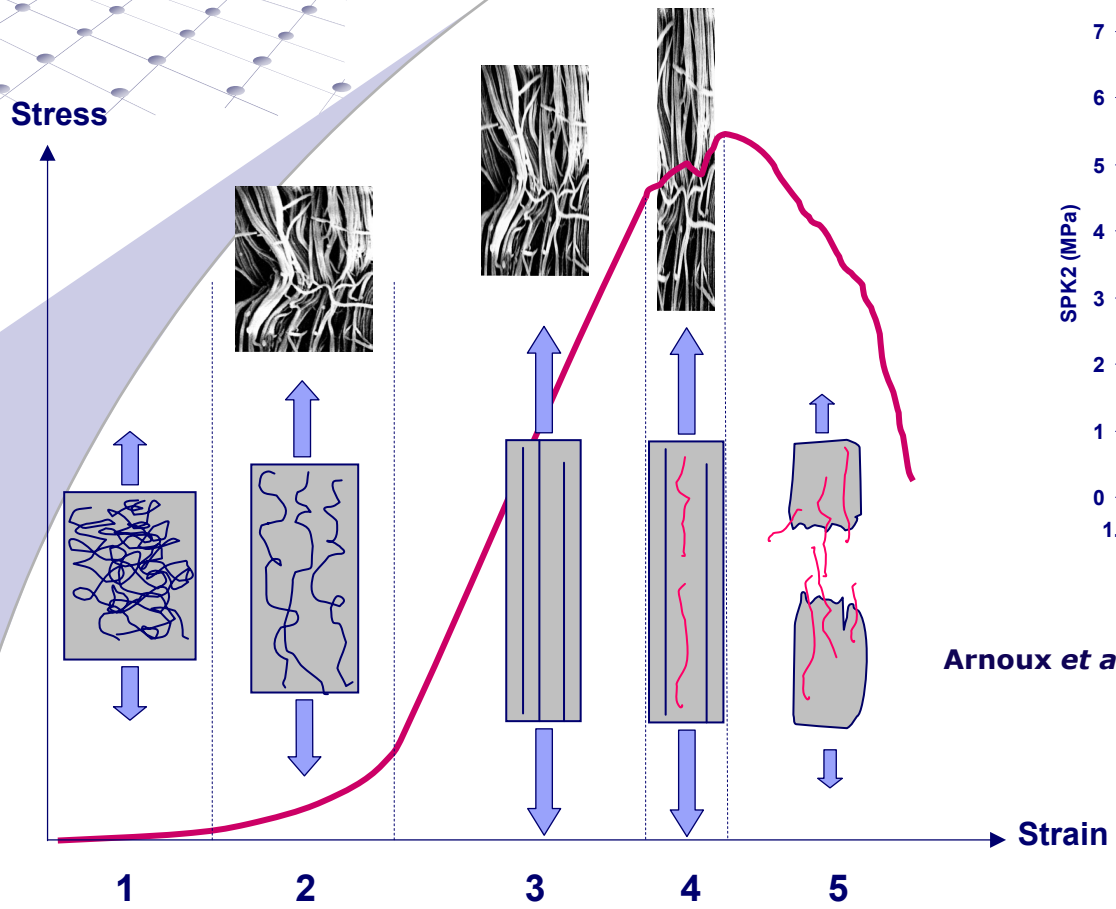
IMPACT / High strain rates

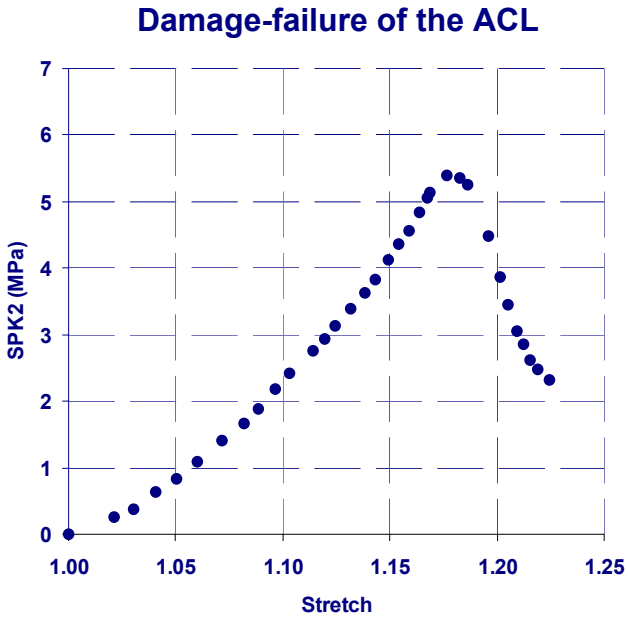






1D stress-strain curve





Arnoux *et al*., *Comp. Meth. Biomech. Bio.Eng., 2002*

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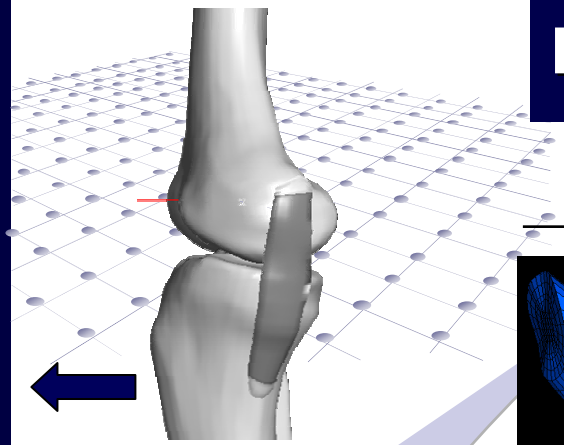
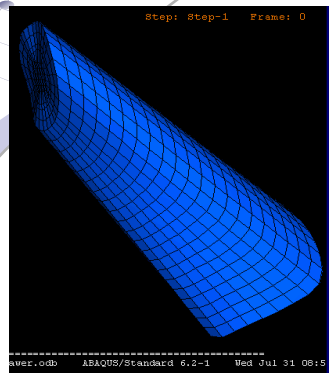
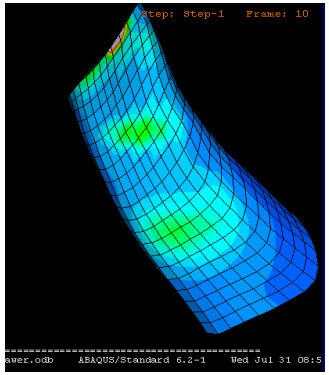


Knee modelling: clinical orthopaedics

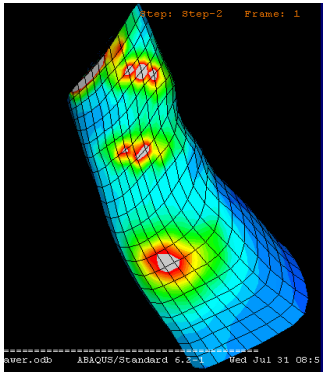
Drawer test



full knee extension

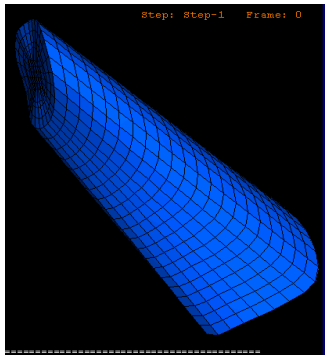


90^0 flexion

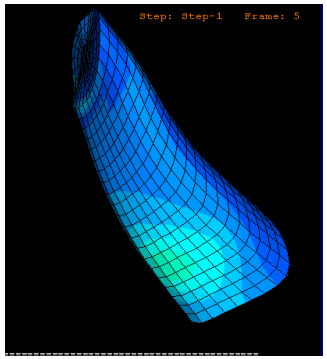


4 mm anterior displacement

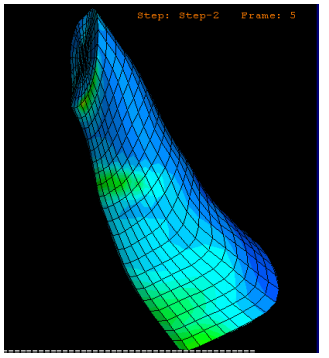
Lachman test



full knee extension



30^0 flexion



4 mm anterior displacement

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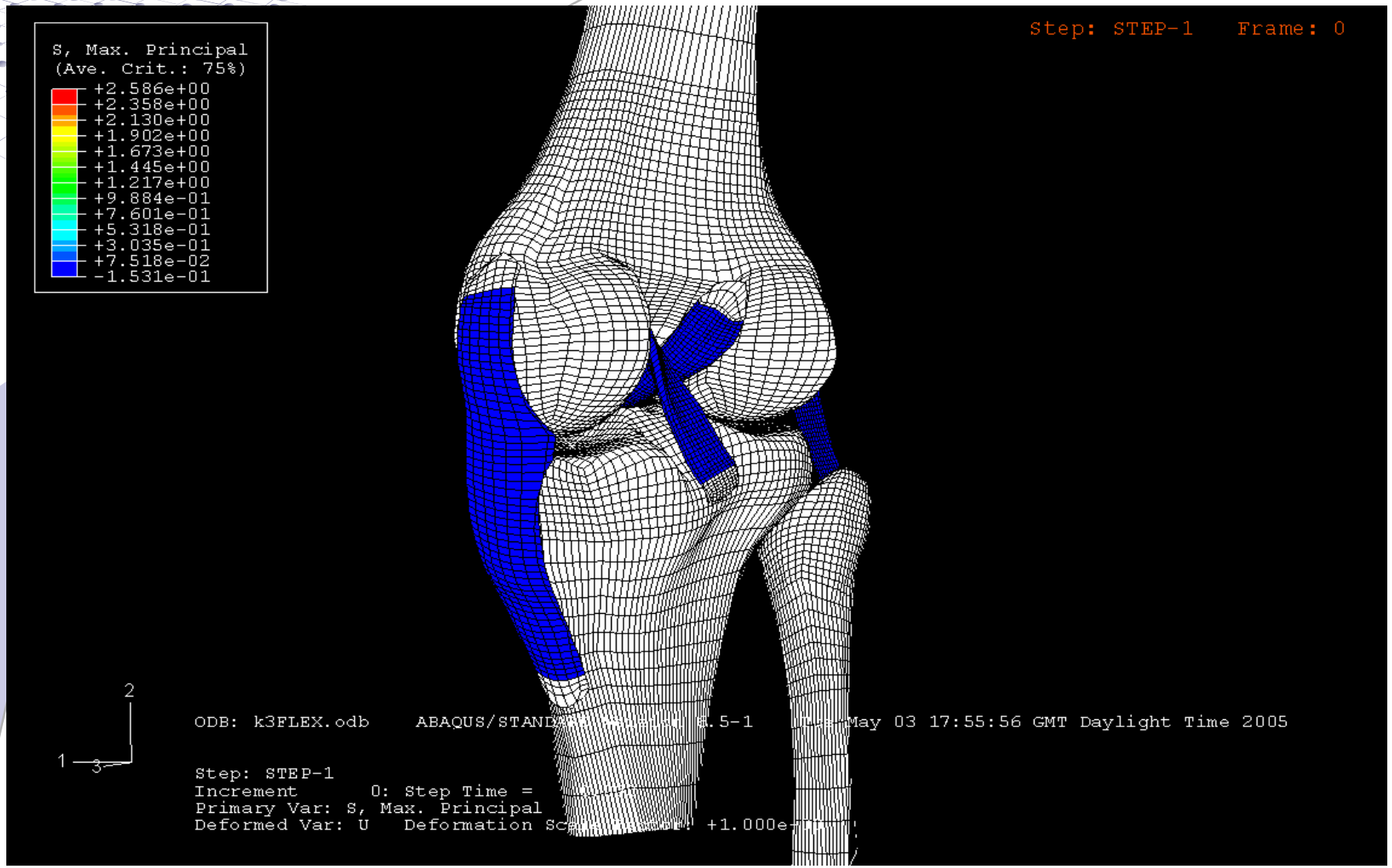
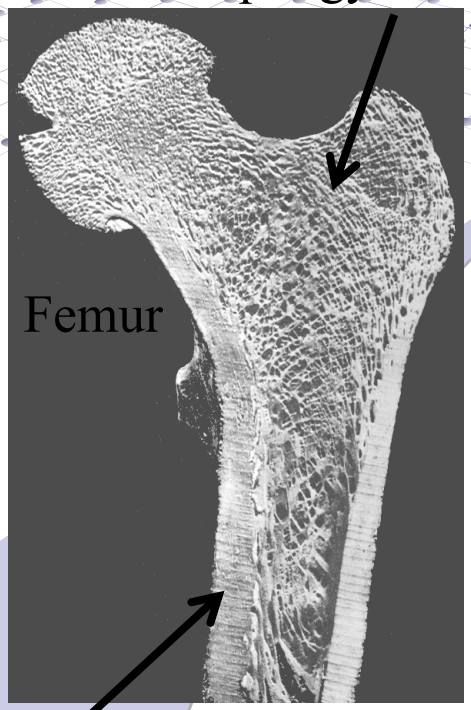
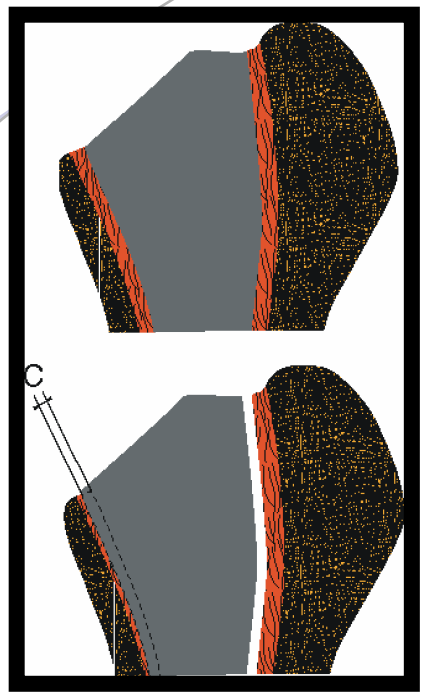
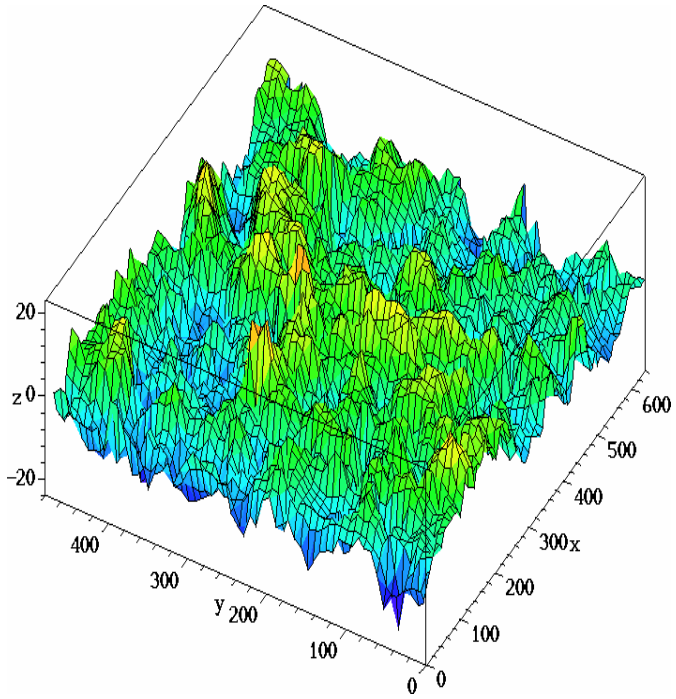
Knee Joint Passive Flexion



Secondary Stability



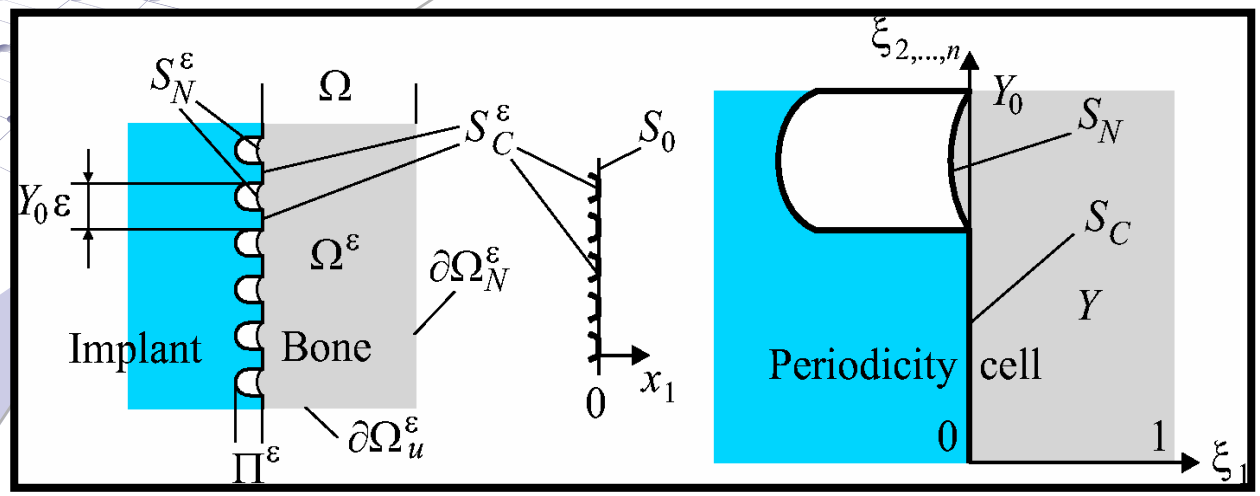




Soft tissue and bone ingrowth → enhanced (secondary) stability

Formation of fibrous tissue → loosening of the implant

Homogenisation of the Interface



- Direct FE simulation on the micro and macro levels simultaneously is prohibitively costly
- Homogenisation provides macro-mechanical parameters of bone-implant contact interaction
- Homogenisation allows avoiding micro-modelling of the contact interaction

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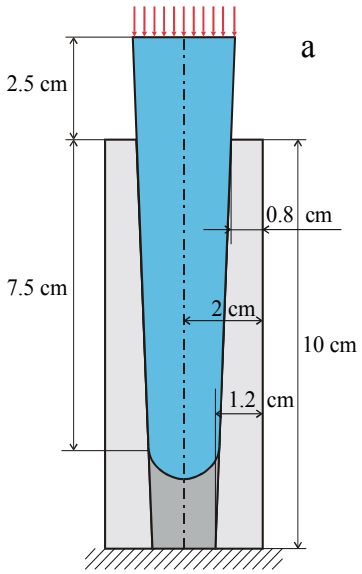
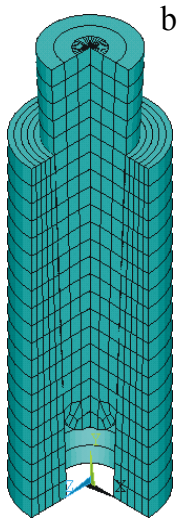
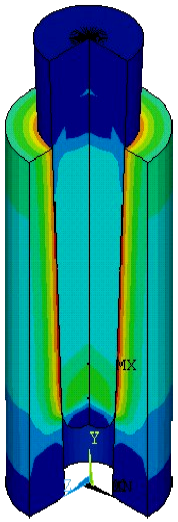
Sensitivity Analysis



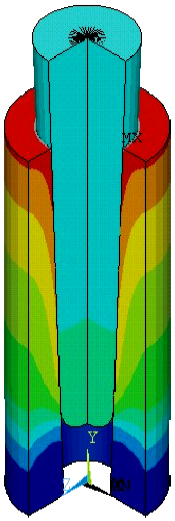
Model



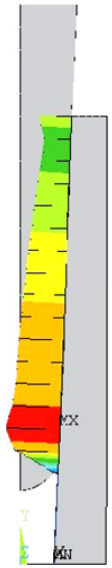
FE mesh



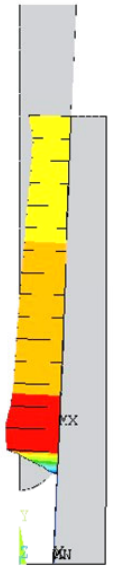
Von Mises stress



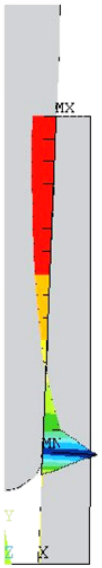
Total displacement



Penetration

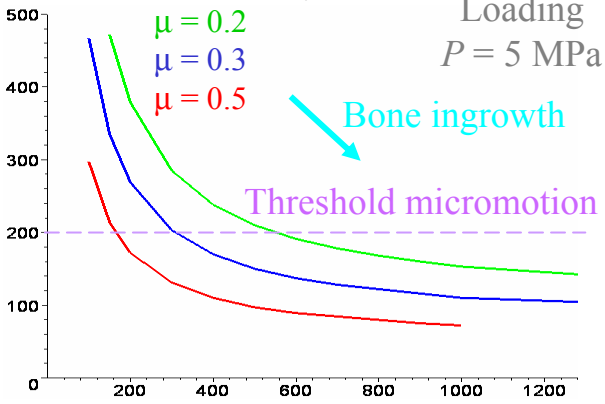


Contact pressure



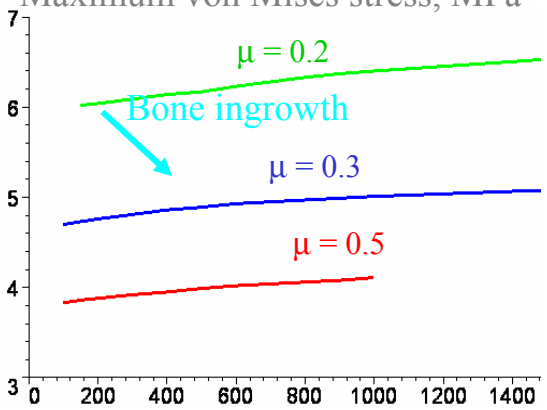
Sliding

Interface micromotion, µm



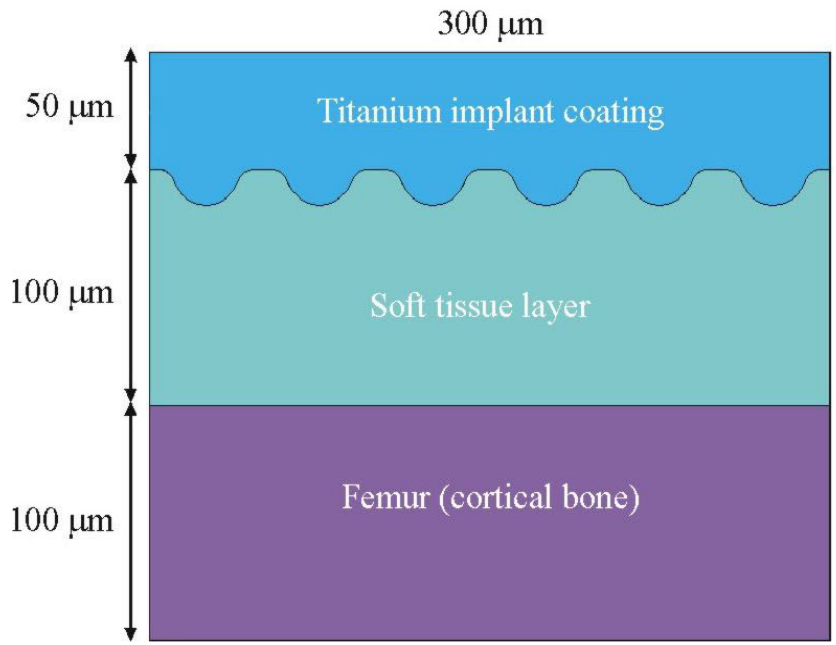
Normal contact stiffness, GPa/m

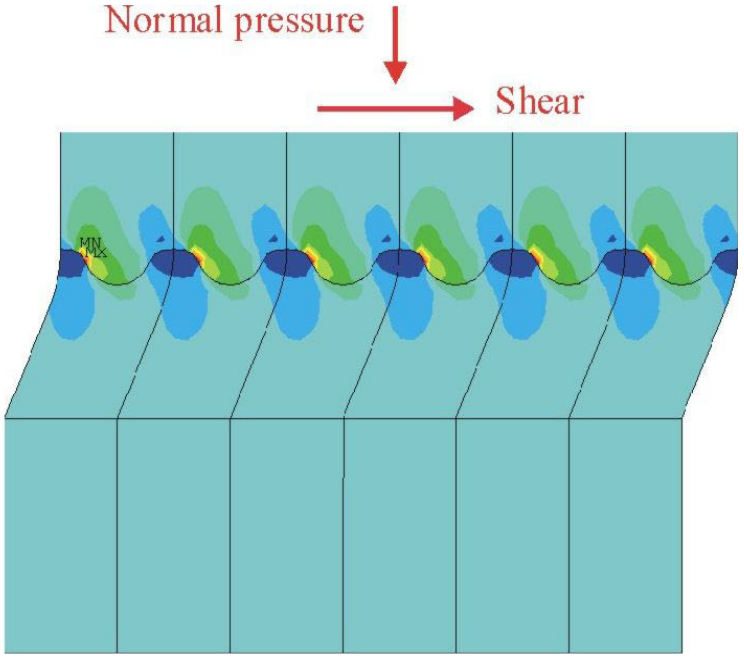
Maximum von Mises stress, MPa



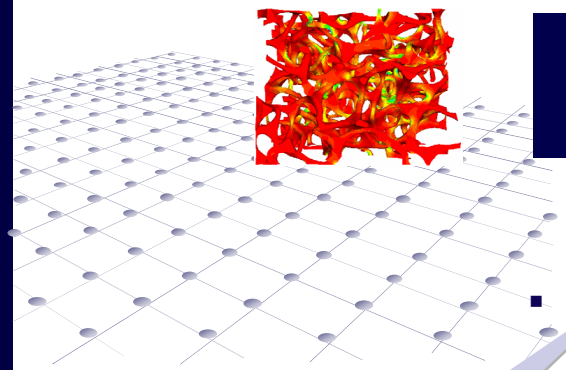
Normal contact stiffness, GPa/m

Micromodelling of the Interface





Micromodelling of the interface allows obtaining values of essential macro parameters for finite element analyses taking into account secondary stability.



Example: medical auxetic foam

- Unique structural properties: negative Poisson's ratio
  - expands when stretched
  - contracts when compressed
- Shock-absorbing and sound-proofing properties

- In BIOMEDICAL ENGINEERING:
  - Tunable filters (e.g. flow of drugs possible in 1 direction but blocked in the other directions)
  - other biomedical applications in development
- Numerical simulations used to explore structural behaviour and optimise structural characteristics of auxetic foam

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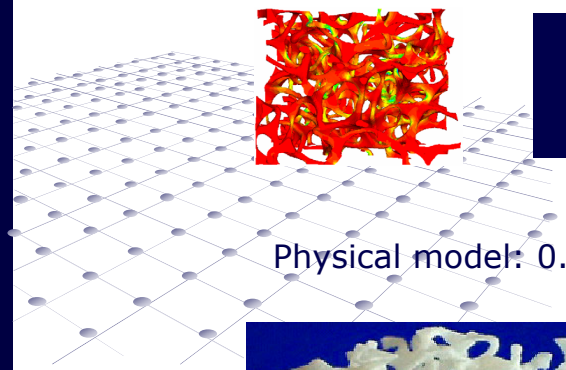
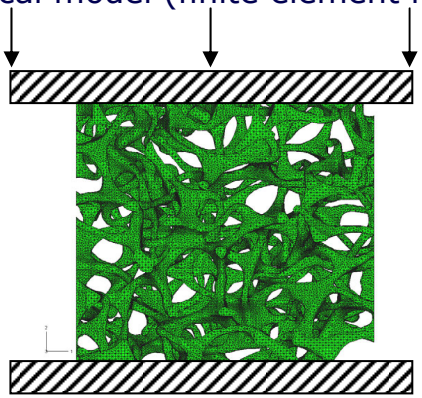


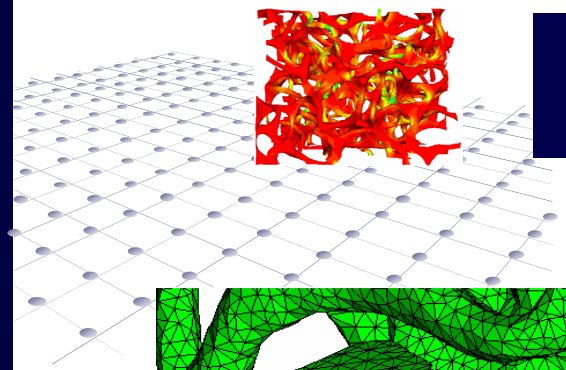
Finite element simulation

Physical model: 0.1 mm x 0.1 mm x 0.1 mm

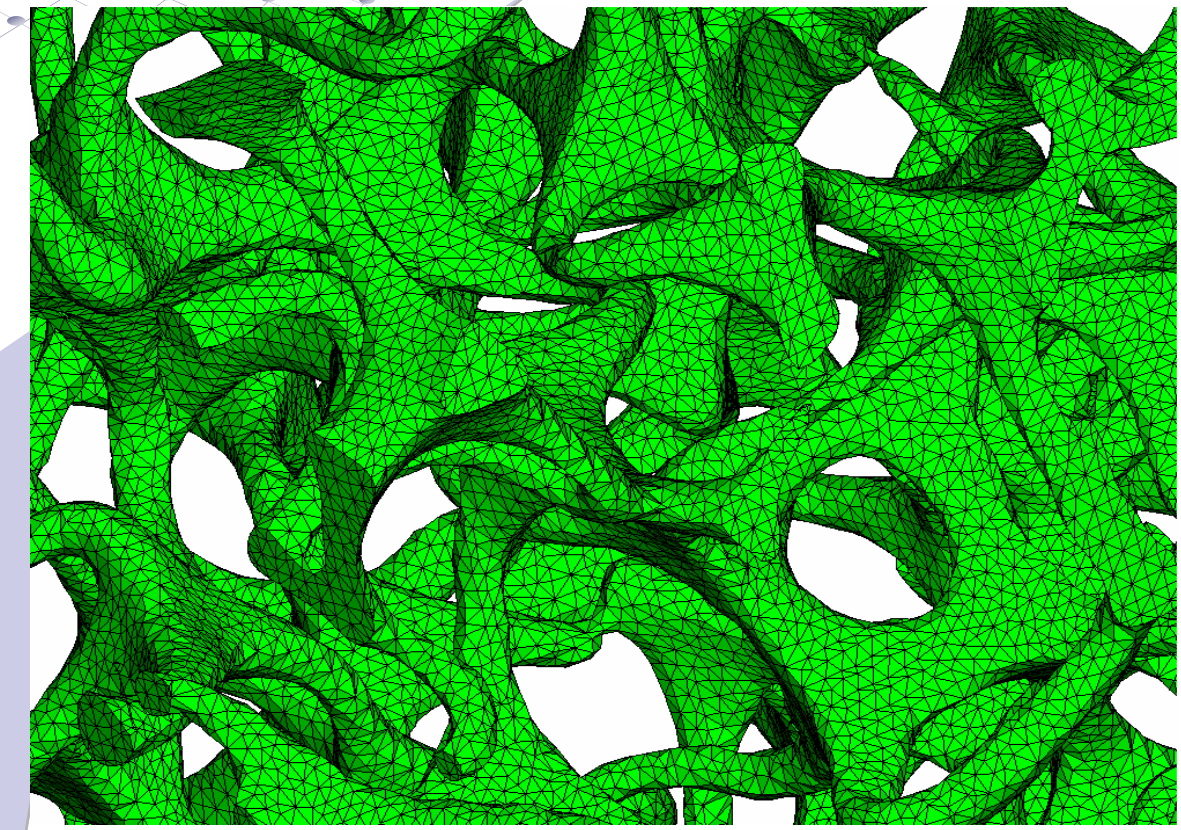
Numerical model (finite element mesh)

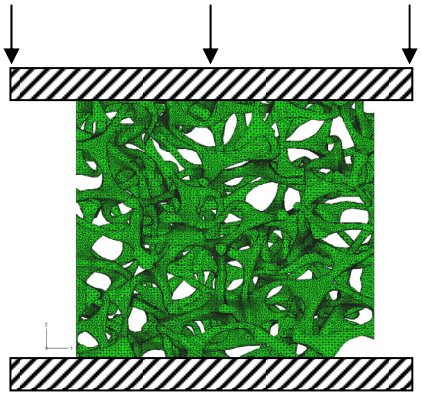


- High resolution synchrotron scanning of auxetic sample (Argonne National Laboratory, IL, USA)
- Image processing / Segmentation
- Generation of finite element mesh (> 600,000 elements)



Finite element analysis





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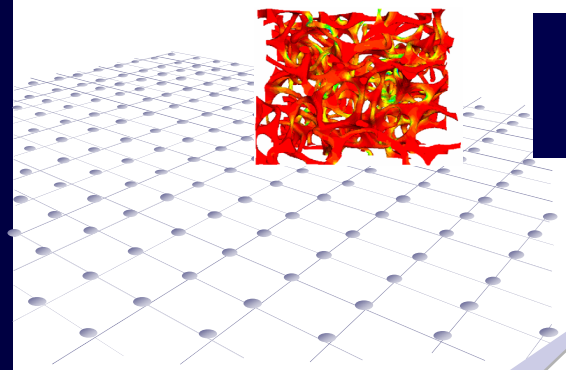
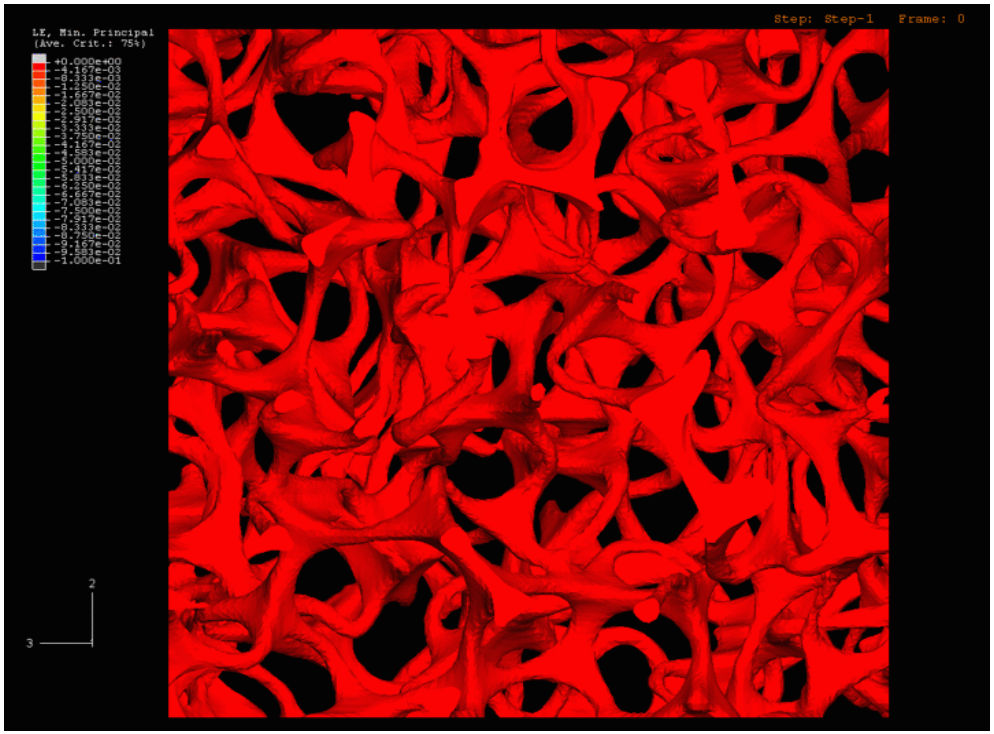


Non-linear finite element analysis

Computation time: 27 hours on a dual- Intel Xeon processors PC 2.8 GHz

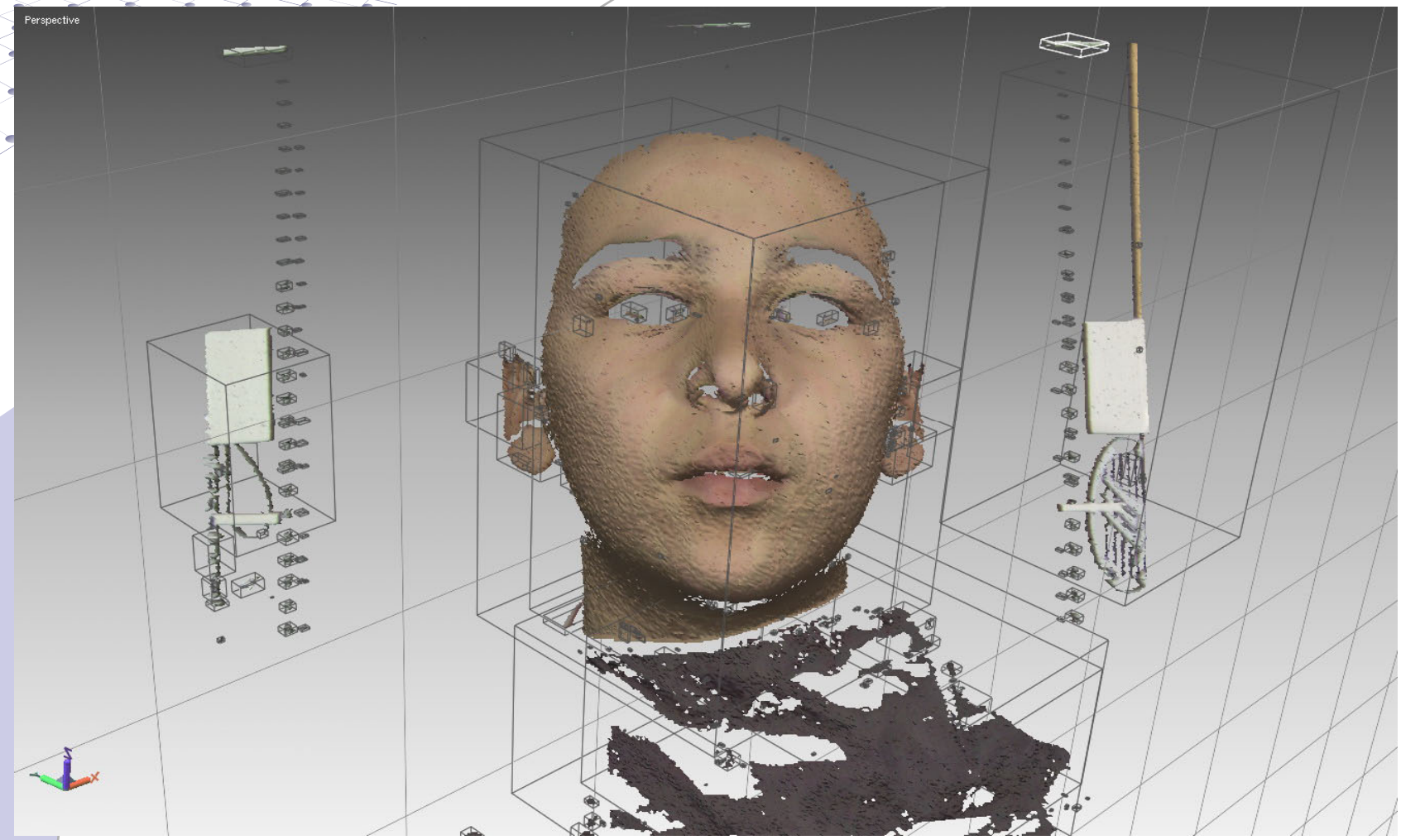


FACIAL IMAGING CLINICAL APPLICATIONS

Current applications:

- **Facial growth study**
- **Study of twins (growth parameters)**
- **Computation of average face**
- **Study of facial anomalies**
- **Surgical planning**

Dividing the raw data shells into many separate shells (the total number of shells is usually 300 to 400)



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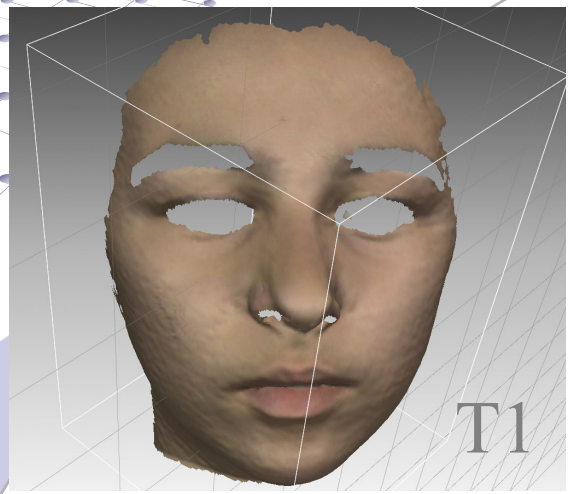
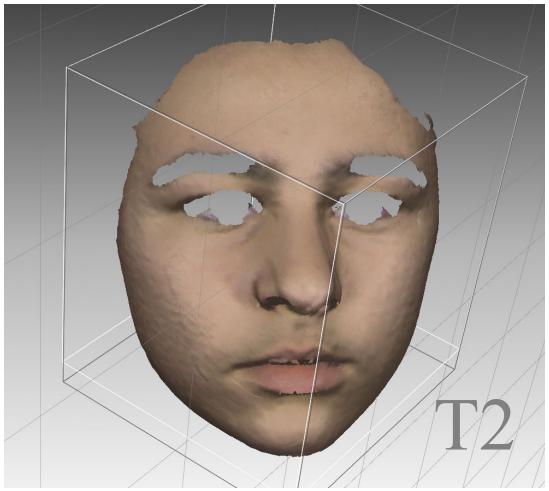
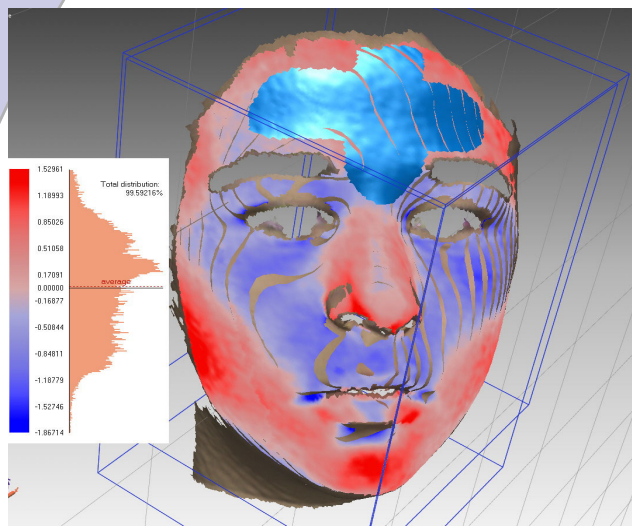
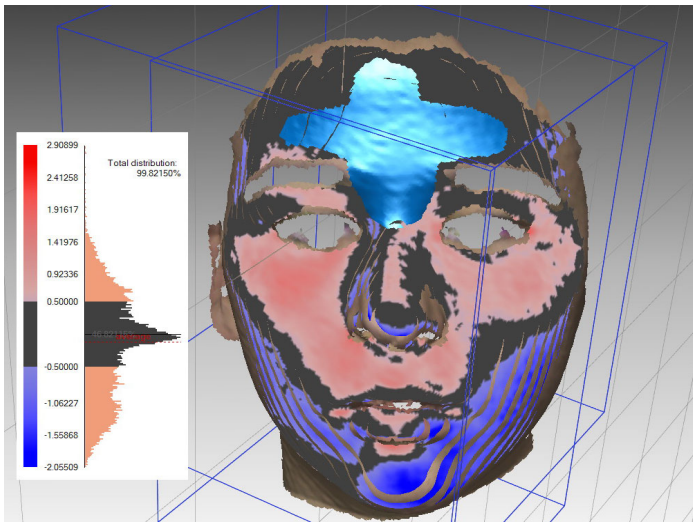
CLINICAL APPLICATIONS

The study of growth (T1 - T2 six months growth)





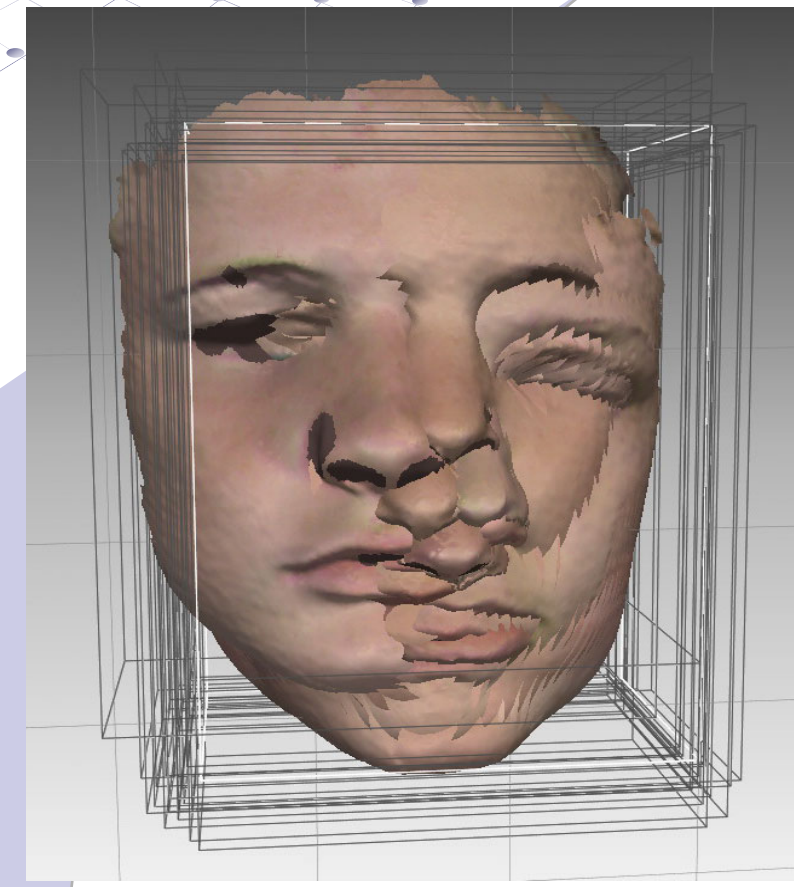




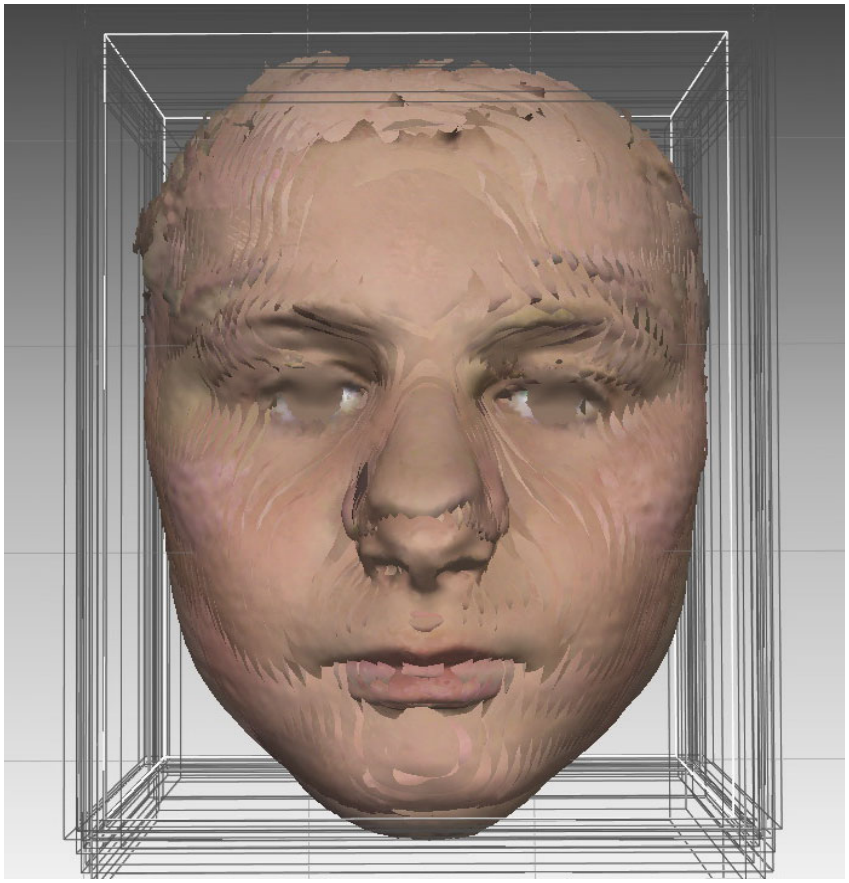
CLINICAL APPLICATIONS

The average face (40 faces)

Not aligned



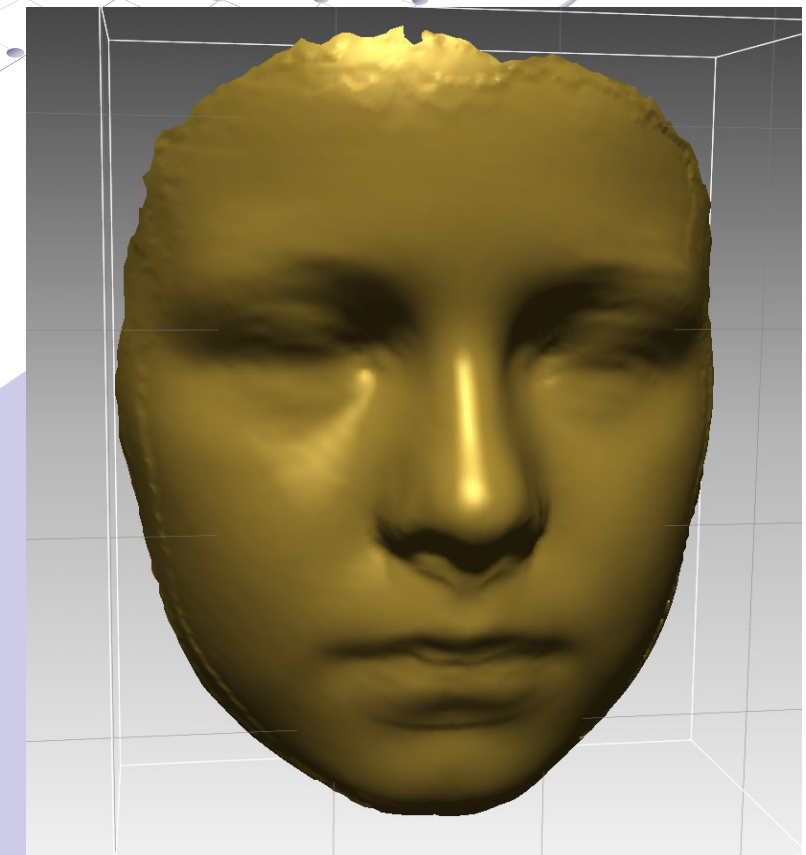
Aligned (best fit)



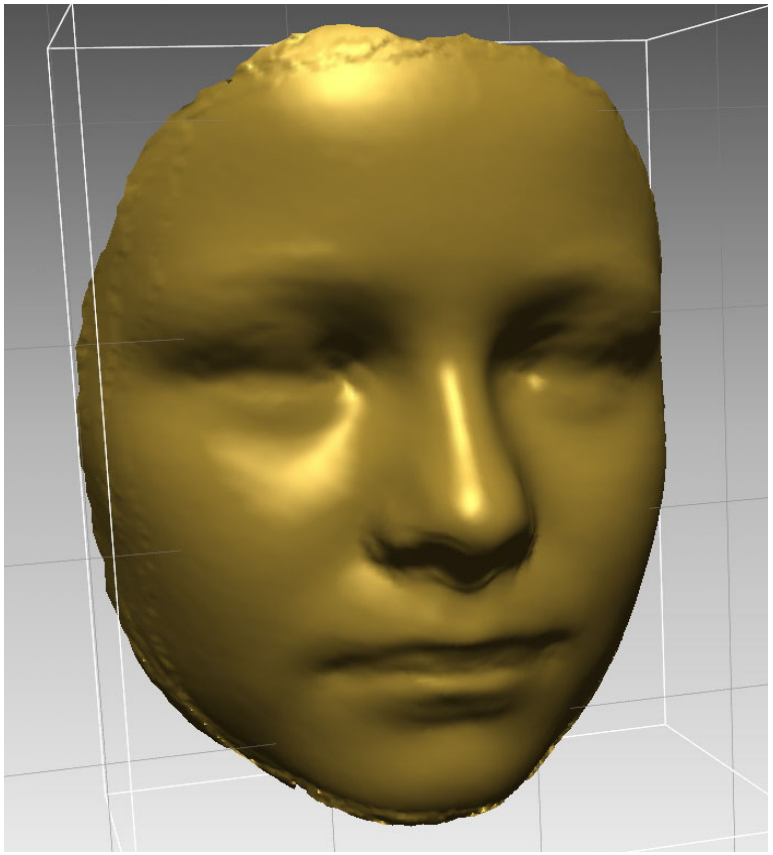
CLINICAL APPLICATIONS

The average face

Male (n = 20)



Female (n = 20)



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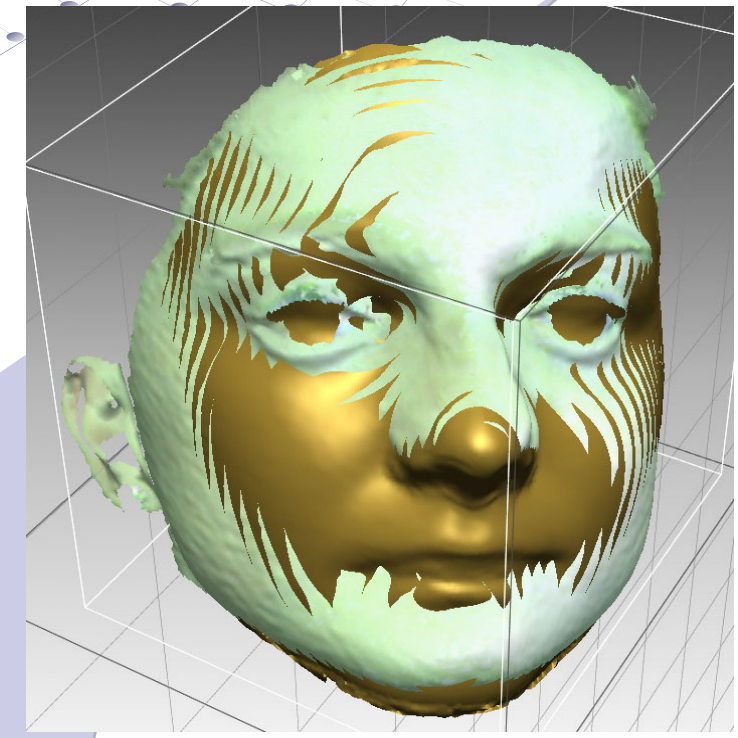
CLINICAL APPLICATIONS

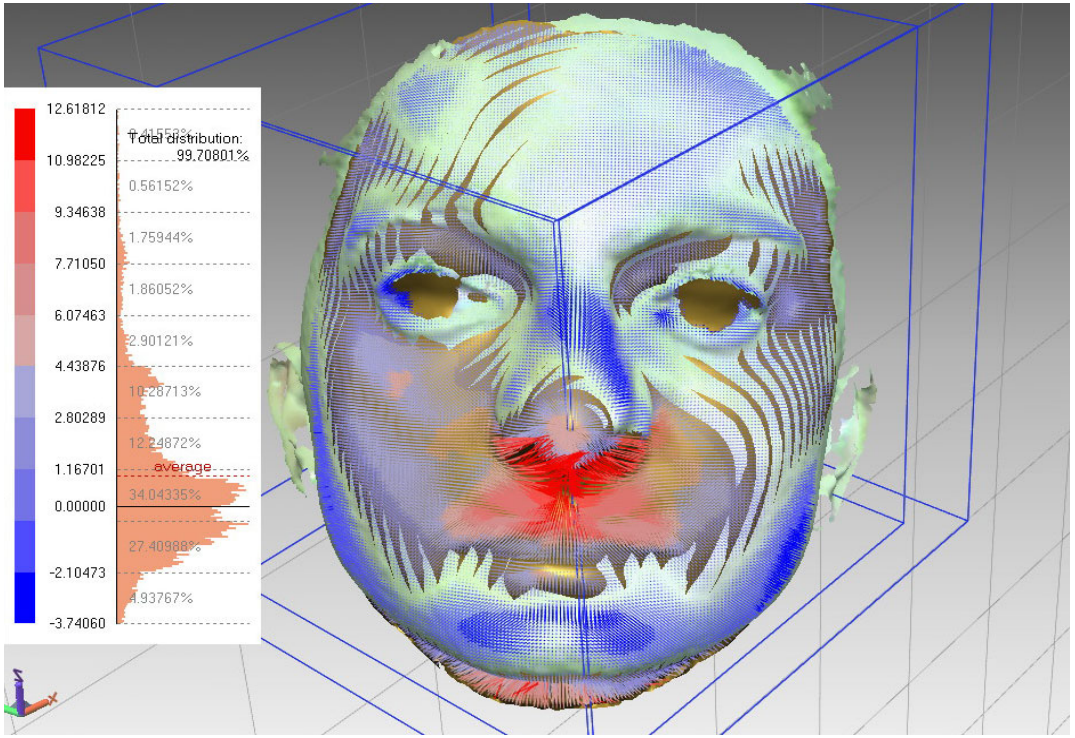
Study of facial anomalies

CLINICAL APPLICATIONS

Study of facial anomalies

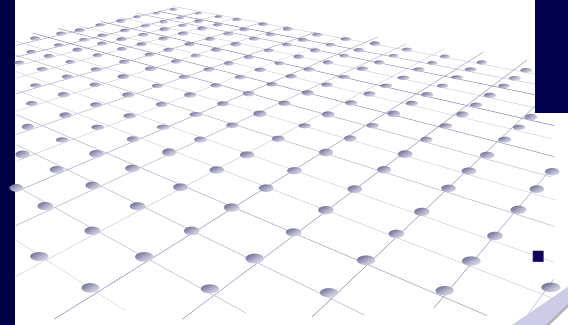
Comparison with the average face





FUTURE DEVELOPMENT

- Measurement of surface and volume changes
- Quantification of facial anomalies
- Analysis of post-treatment changes
- Prediction of post-treatment changes
- Development of new software tools
- 3D facial recognition



Example: Dental implant

- Implant shape optimisation
- Immediately loaded implants
- Interaction of bone/tissue interface
- Bone adaptation and growth (simulation)
- Pre-clinical assessment

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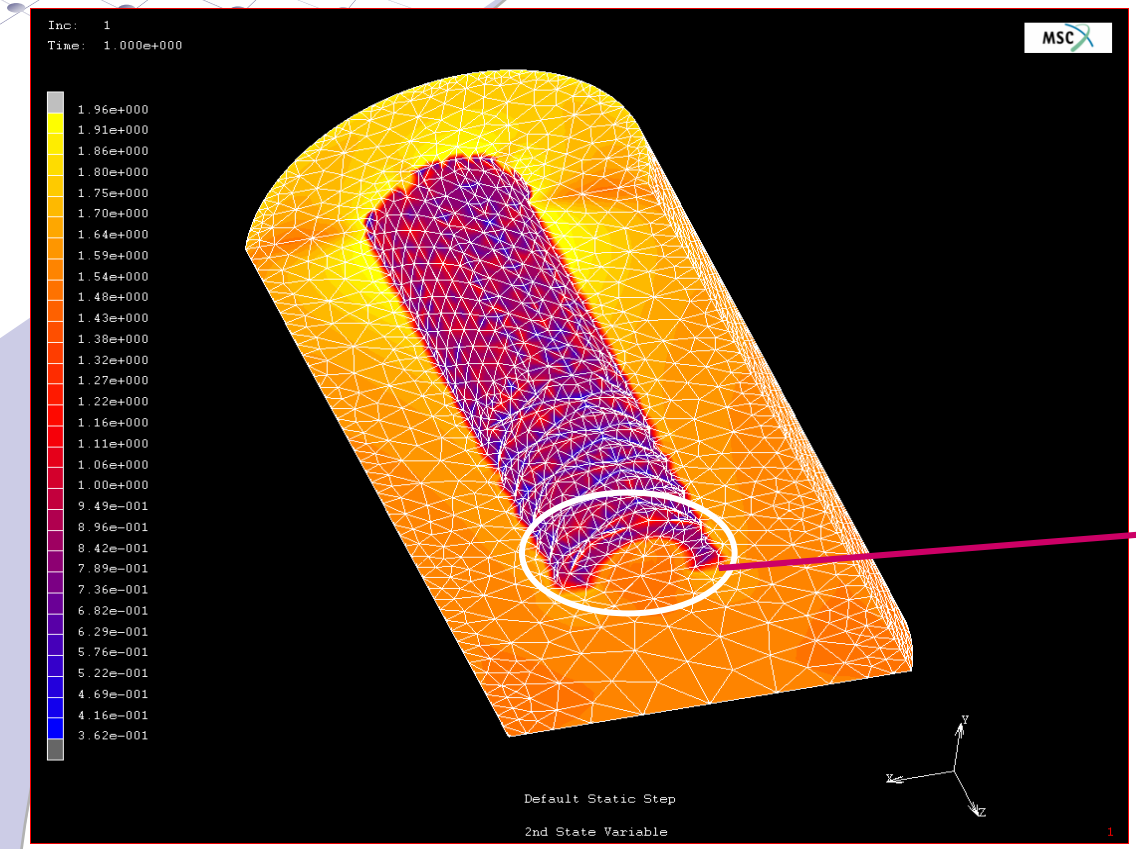
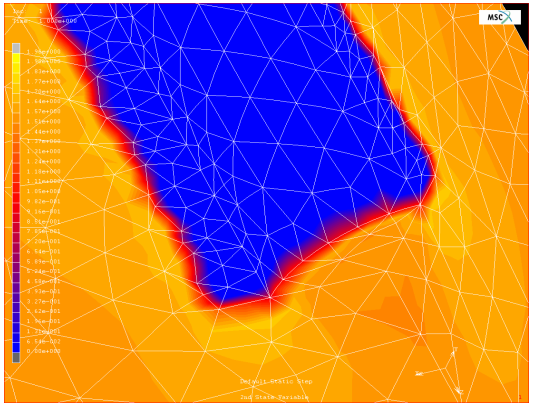
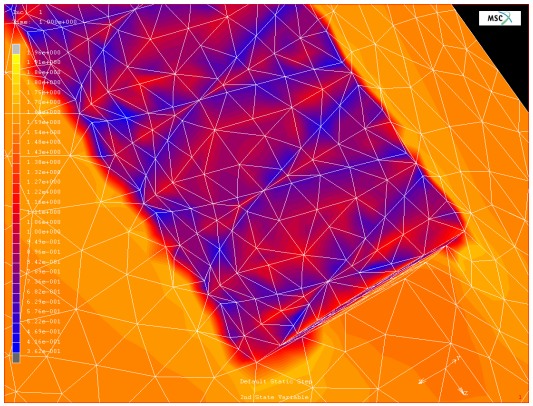
Simulating of bone adaptation







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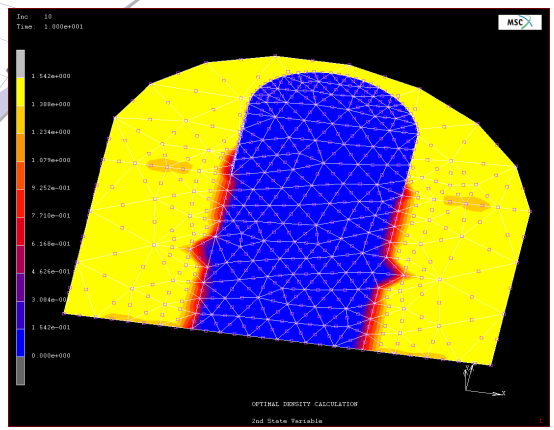
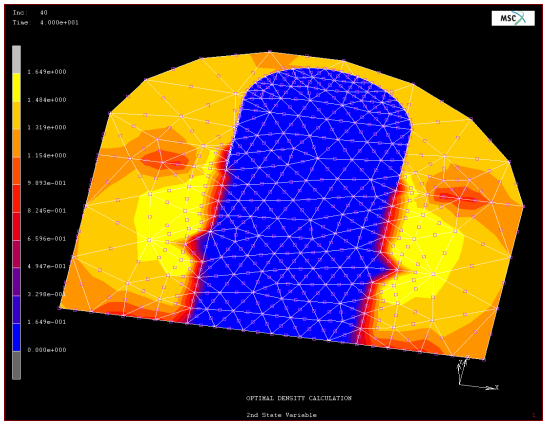
Evolution of bone density

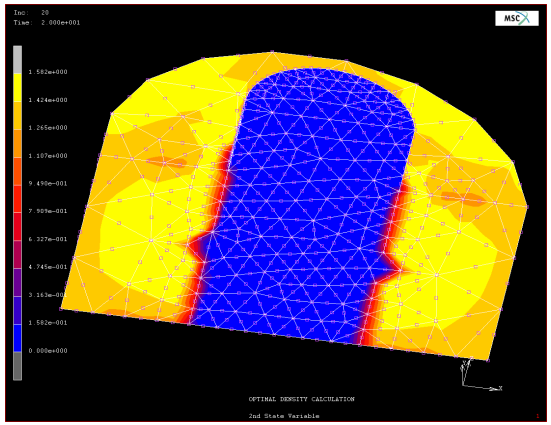
10 days



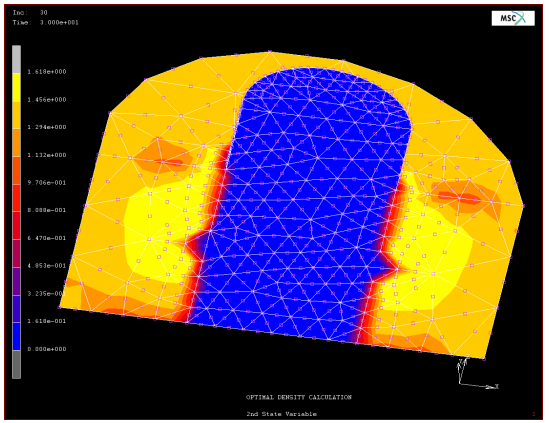
20 days



30 days



40 days



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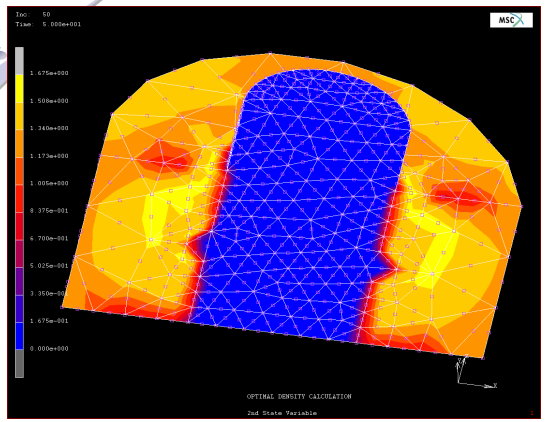
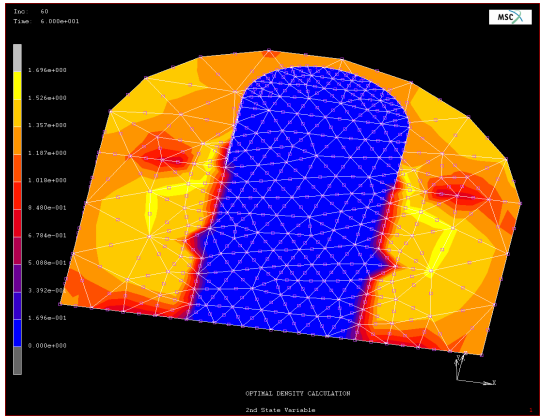
Evolution of bone density

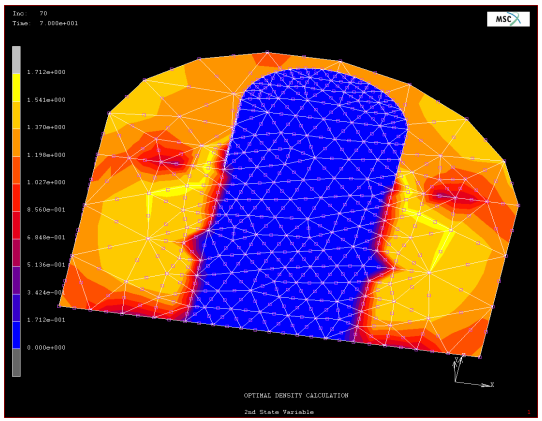
50 days



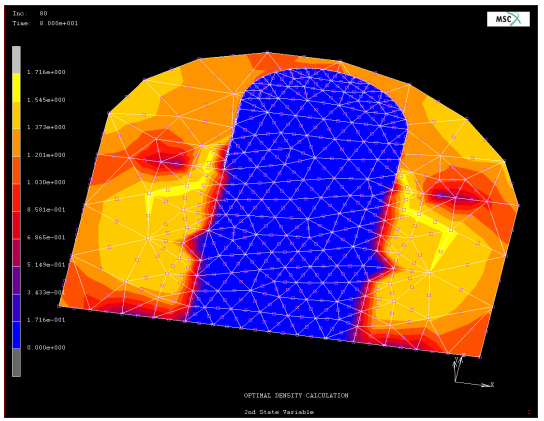
60 days

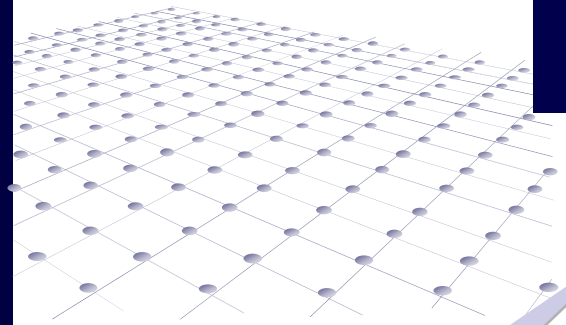


70 days



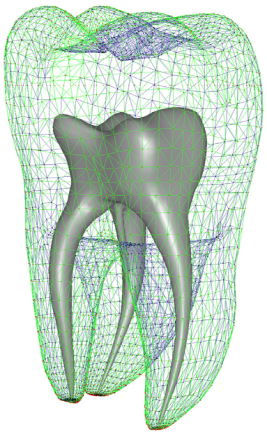
80 days

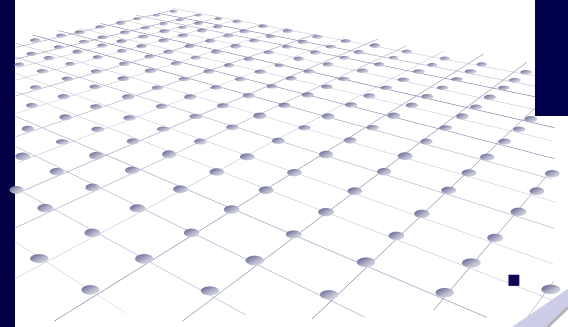




Other topics in dental mechanics

- Development of new biomaterials (skin substitutes, etc)
- Oral care products, dentures
- Maxillo-facial surgery
- Smart materials: shape memory alloys
- Polymerisation of dental cements
- Rapid prototyping
- Computer-aided surgery
- Simulating clinical trials

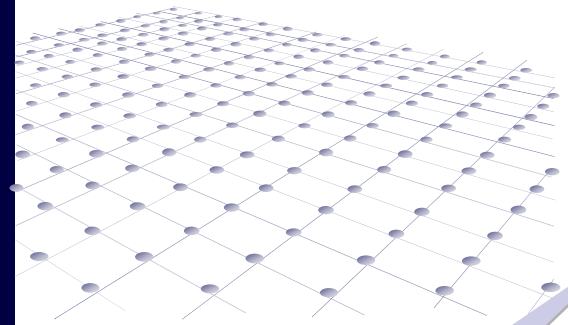




The future of biosimulation

- Improve the current capabilities (constitutive models and tissue structure characterisation – difficult but advancing)
- Complex multi-physics simulations of complete biological structures (in combination with new medical imaging techniques and systems biology)
- A framework of biocomputational techniques, tissue engineering, micro CFD, mechanotransduction,
- Molecular mechanics modelling (how molecular structures and short-scale atomic interactions affect macroscopic properties of tissues)
- Multi level techniques, macro – micro – nano, for biological simulation of biological structures, 'the digital human'

'Necessity is the mother of invention'



Acknowledgements

- Argonne National Laboratory, USA
- Astratech, Sweden
- DePuy International Ltd, UK
- DuPont, USA
- ESI Group, France
- The Welsh Development Agency
- Dr. Philippe Young, Simpleware Ltd, UK
- Prof. Jerry Seidler, University of Washington, USA
- Dr. Georges Limbert, Biomechanics Research Unit
- Dr. Alex Zhurov, Biomechanics Research Unit

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