# Challenges to developing lightweight safety helmets:

## *A computational approach to modelling real world head impact accidents*

**Michael.Gilchrist@ucd.ie**
**University College Dublin**

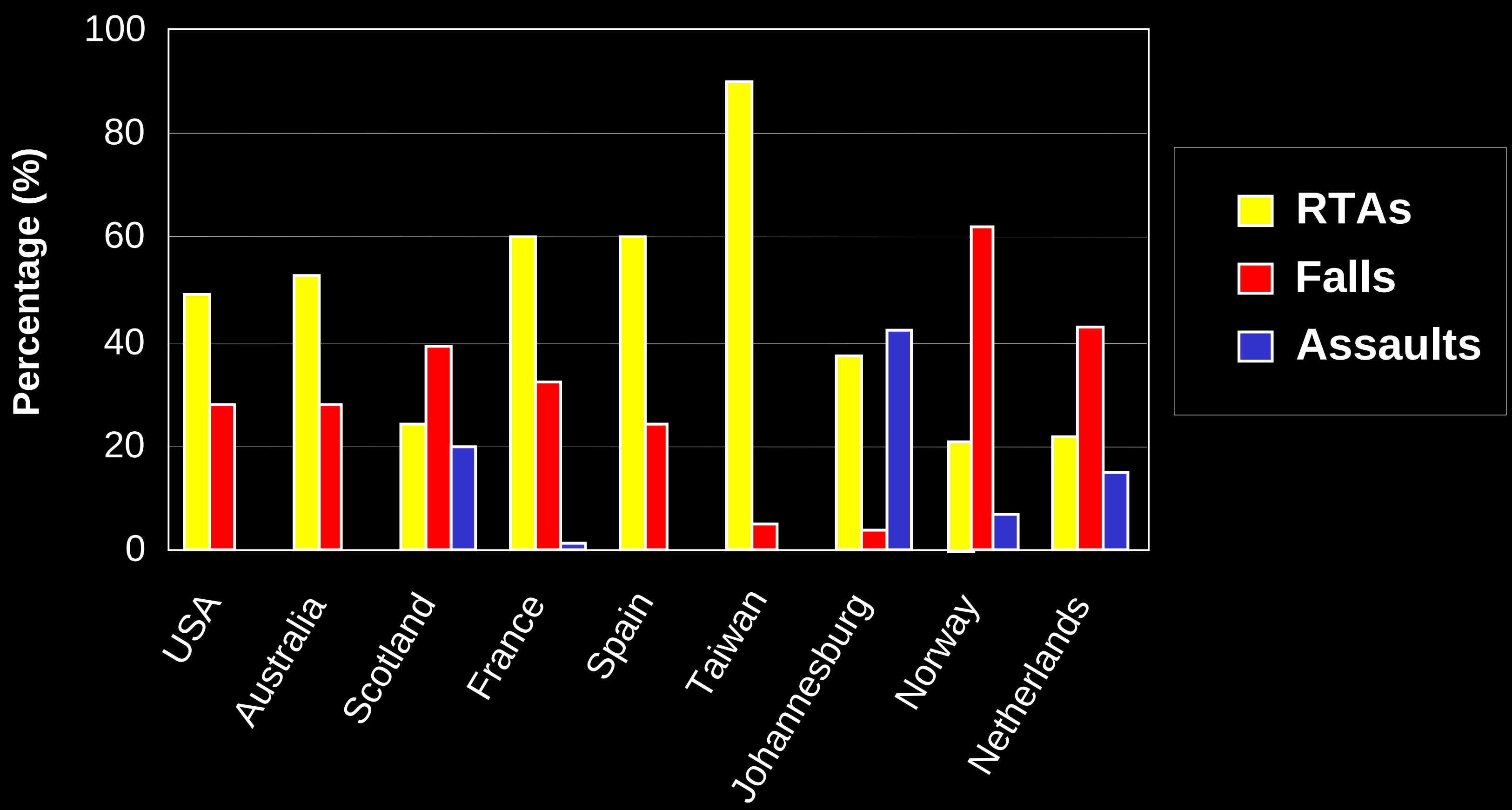
**Porto, July 28th 2005**

# Research Question

*Under what mechanical load conditions will particular lesions of head impact injury occur?*

- Performance of polymer matrix composites
- Behaviour of bituminous road pavement mixtures
- Skull fracture, contusion, DAI, haematoma, etc.
- Severe Vs. fatal and single Vs. multiple lesions
- Analysis of accidental falls, RTAs, ...
- Design of occupation-specific safety helmets

# Epidemiology of Head Injury





Jennett, B. (1996). J. Neurol. Neurosurg. Psychiatry, **60**, 362-9.

Mortensen, K. et al. (1999). Tidsskr. Nor. Laegeforen, **119**, 1870-3.

Meerhoff, S. R. et al. (2000). Ned. Tijdschr. Geneeskd., **144**, 1915-8.

Vazquez-Barquero, A. et al. (1992). Eur. J. Epidemiol., **8**, 832-7.

# Statistics of Irish Head Injury

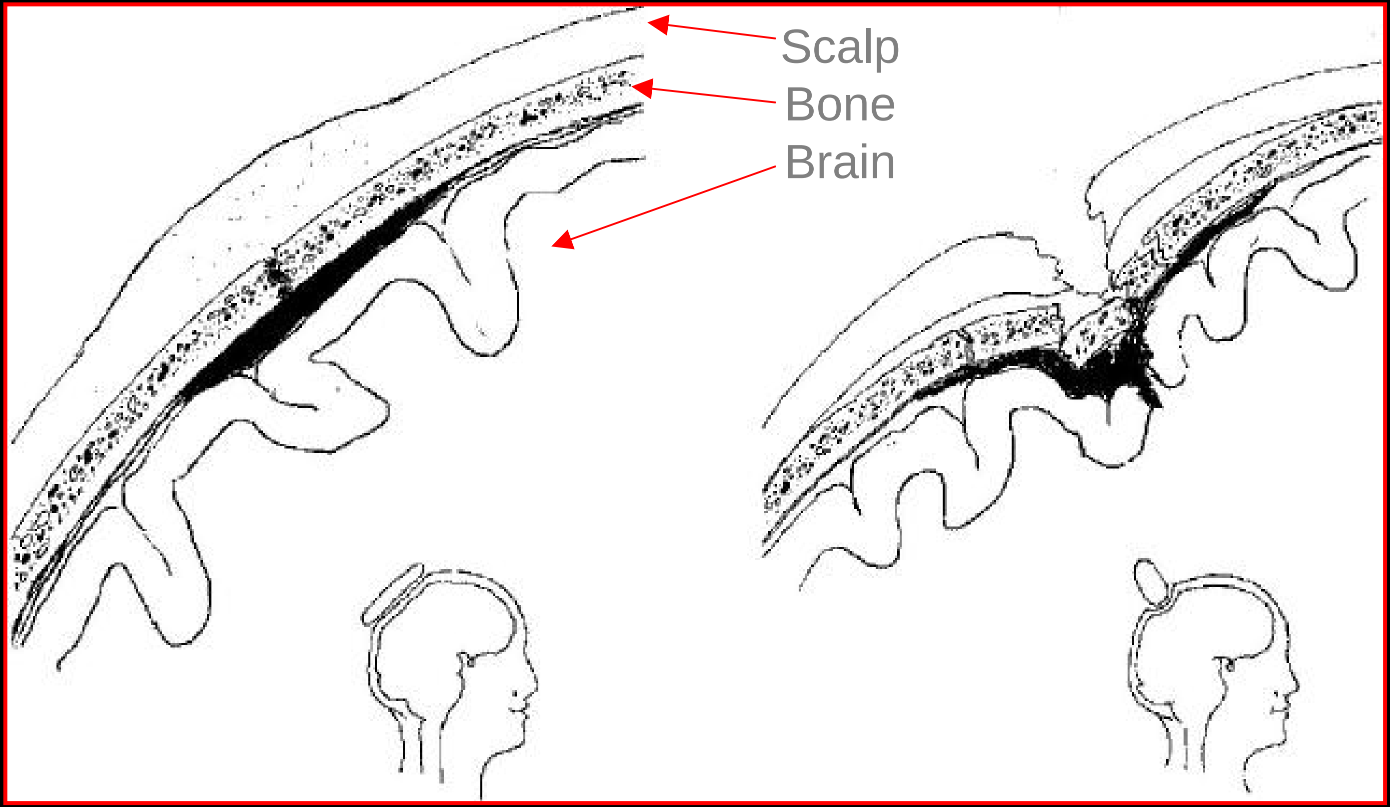
- Irish RTAs in 2002 : 376 fatalities (86 pedestrians, 18 cyclists, 44 motorcyclists) and 9206 injured
- 96 Vs 161 (Portugal) fatalities per $10^6$ of population
- Irish Horse Riding Concussions (2000-04):
  - Point-to-Point = 60 / 3848 falls
  - Flat Racing = 16 / 163 falls (1 fatality)
  - National Hunt = 101 / 4244 falls (1 fatality)

# UCD Approach to H.I. Research

- Use multibody dynamic and finite element simulations
- Develop unique 3D FE simulation models
- Predict occurrence of contusion and haematoma
- Explain energy absorption of cerebrospinal fluid
- Quantify severity of specific injury mechanisms
- Develop tissue-level criteria for non-fatal injuries
- Design personal protective equipment and helmets

# Hard Tissue Injury: Skull Fracture

**Linear Fracture** | **Depressed Fracture**

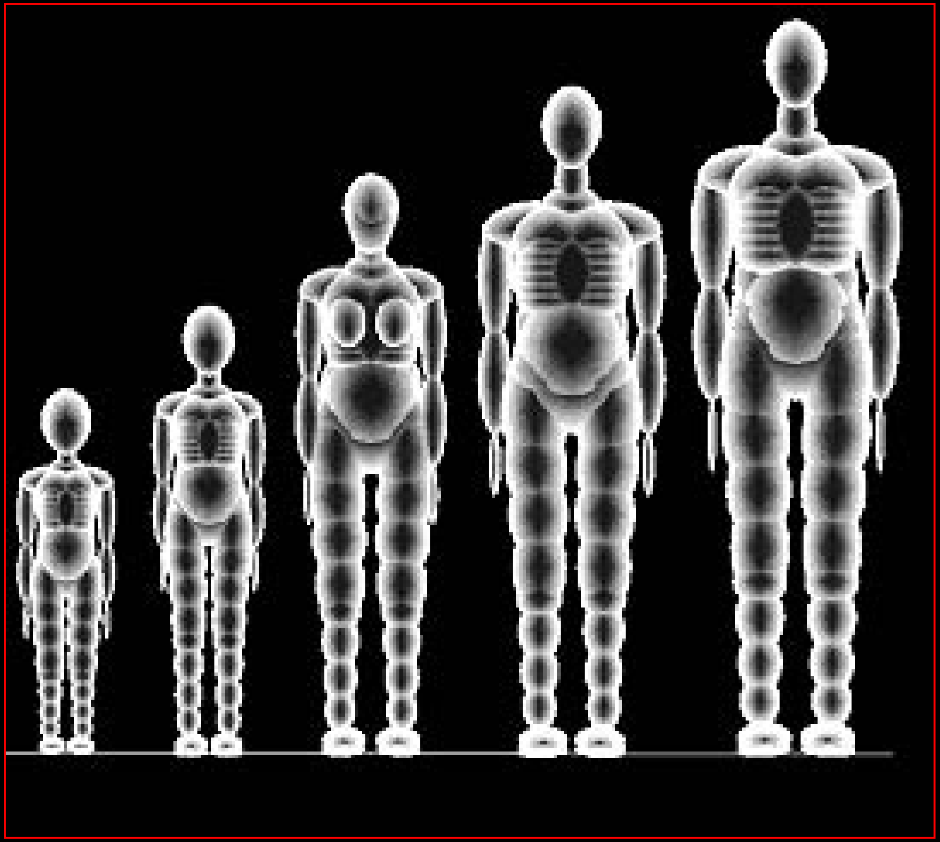


# Soft Tissue Injury: Brain Injury

**Extra Dural Haematoma**

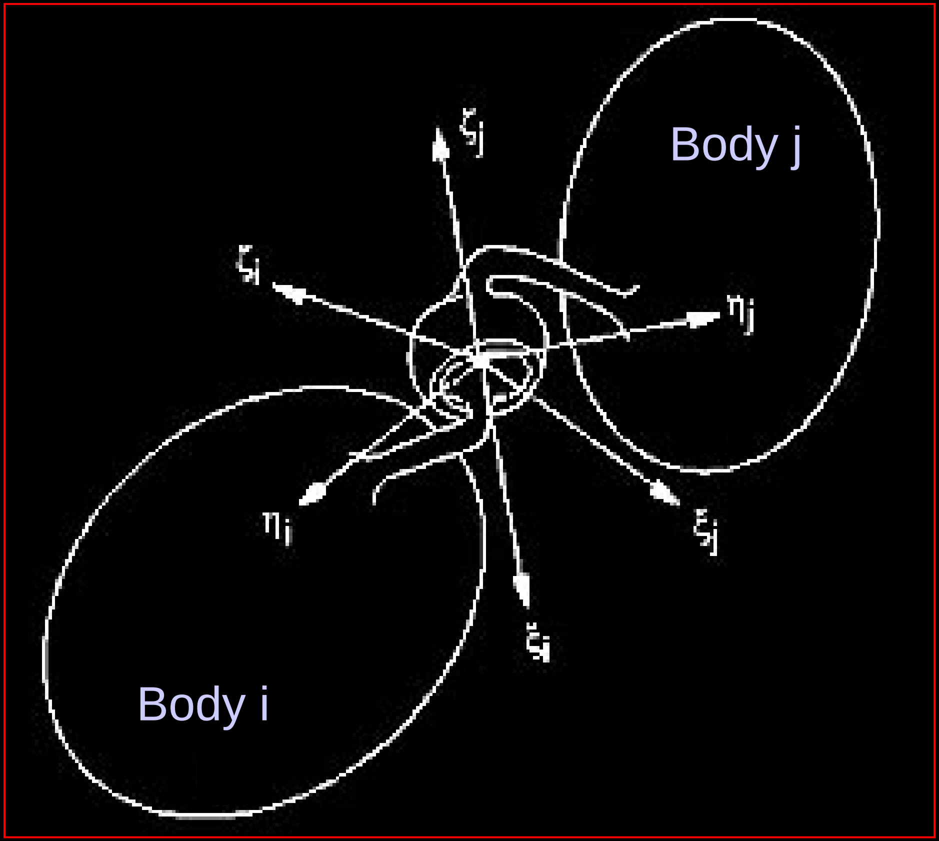

**Penetrating Injury**

# Multibody Dynamics Simulations



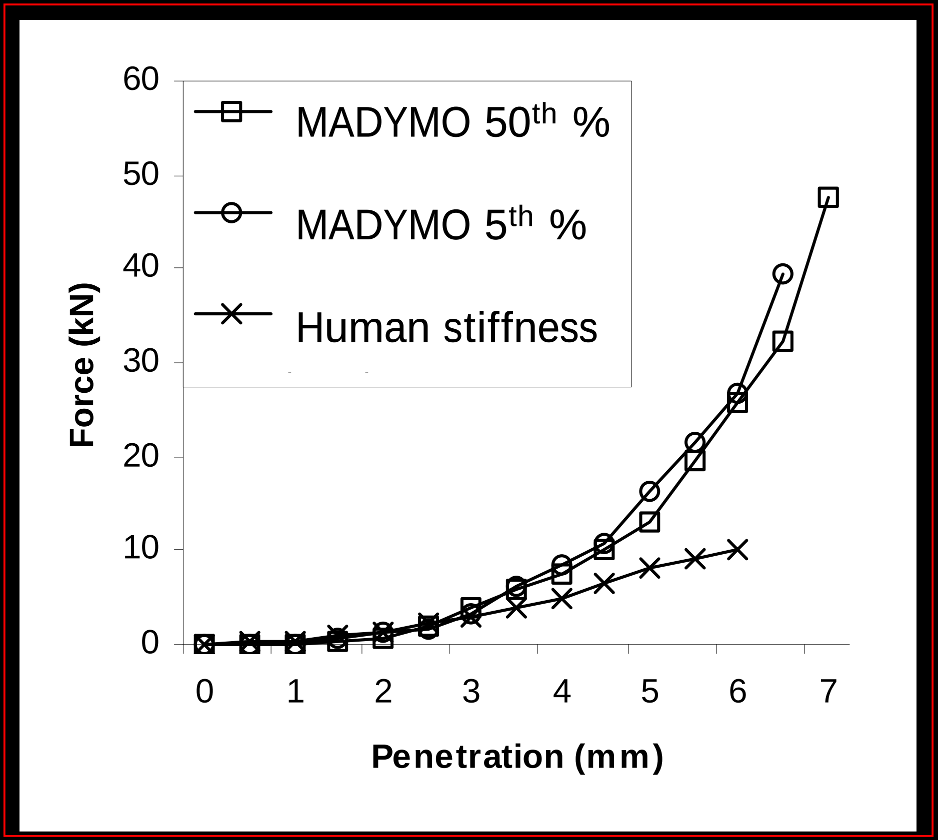
MADYMO pedestrian models: 64 ellipsoidal bodies

# Multibody Dynamics Simulations




Spherical joint (ball & socket); kinematic stiffness

# Multibody Dynamics Simulations



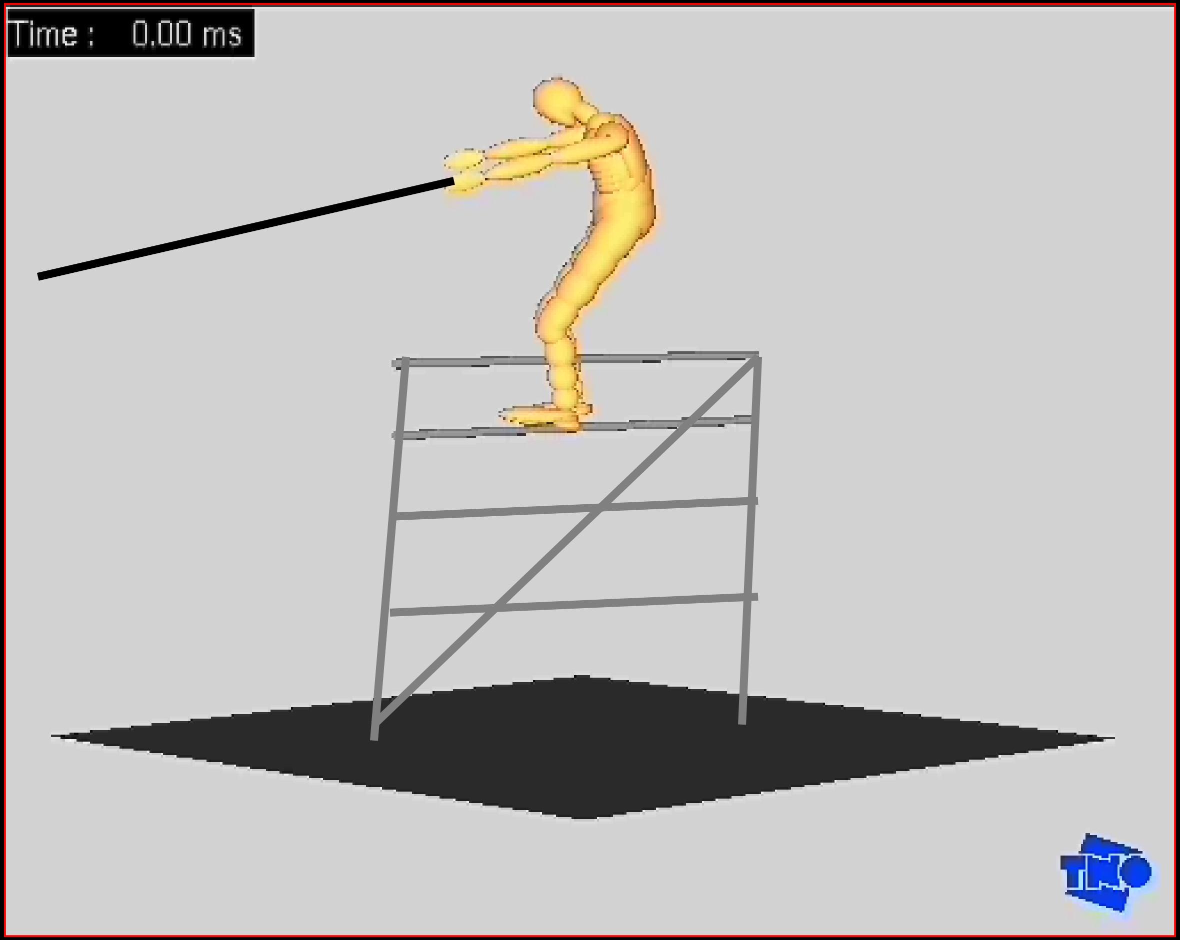

Head-ground contact characteristics

# Multibody Dynamics Simulations

- Simple falls from National Neurosurgical Unit
- Clinical examination of head injury
- Physical details of accident circumstances
- Appropriate choice of pedestrian model

O'Riordain, K., Thomas, P.M., Phillips, J.P. and Gilchrist, M.D. (2003). Reconstruction of real world head injury accidents resulting from falls using multibody dynamics. Clinical Biomechanics, **18**, 590-600.

# Multibody Dynamics Simulations




37 yr old male (178cm, 80kg) straddling gate

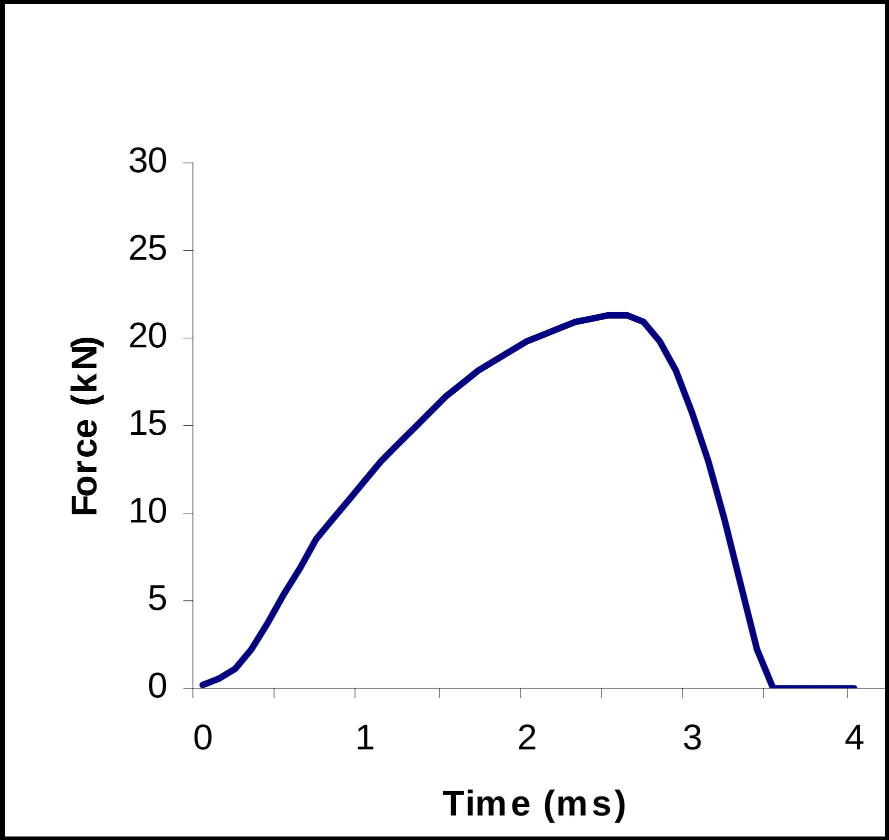
Fell 138cm, struck left shoulder and head against concrete

# Multibody Dynamics Simulations

*Injuries and Outcome:*

- scalp laceration + 5cm linear fracture + extradural haematoma (left temporo-parietal region)
- Left upper limb abrasions
- Emergency craniotomy: evacuate haematoma

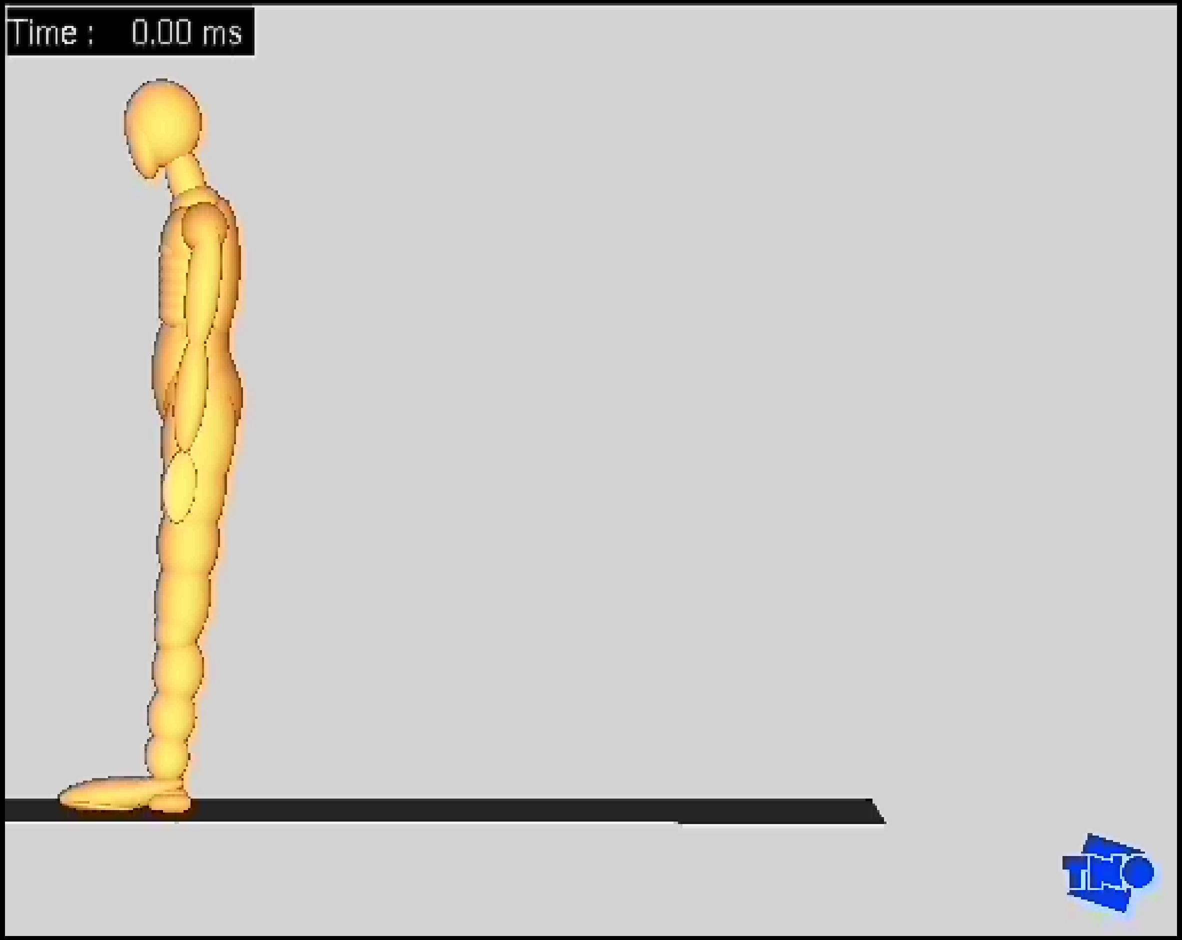
# Multibody Dynamics Simulations





Skull fracture: ~11.9kN (Yoganandan); ~12.4kN (Allsop)

# Multibody Dynamics Simulations




11 yr old boy (152cm, 37kg) fainted at water fountain.

Occipital impact of head against concrete.

# Multibody Dynamics Simulations

Clinical Observations:

- Brief LOC
- GCS 14/15
- Right lateral frontal intracerebral haemorrhagic contusion
- Blood in right Sylvian Fissure (traumatic sub-arachnoid haemorrhage)

# Multibody Dynamics Simulations

| Force (kN) | Duration |
|---|---|
| 12.1 | <2.5ms |

| Linear Velocity, $x'$ (m/s) | Angular Velocity, $\theta'$ (rad/s) |
|---|---|
| Resultant: 6.9 | Resultant: 30.2 |

| Linear Accln., $x''$ (g) | Angular Accln., $\theta''$ (krad/s$^2$) |
|---|---|
| Resultant: 587.0 | Resultant: 20.7 |

Peak Results for Datum

# Multibody Dynamics Simulations

## Force for Skull Fracture: 12.1kN

- Yoganandan *et al*[1] measurements:

  8.8 – 14.1kN; Average = 11.9kN

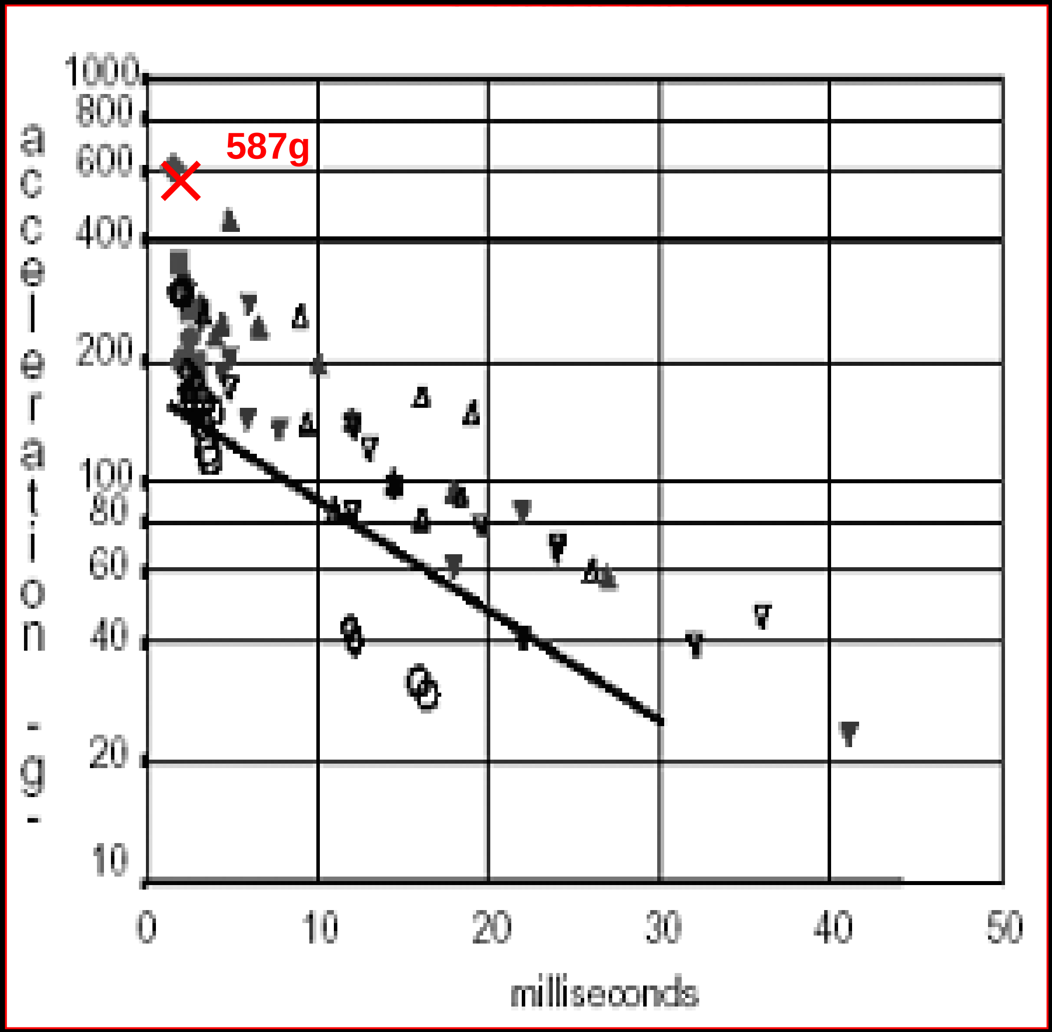
- Allsop *et al*[2] measurements:

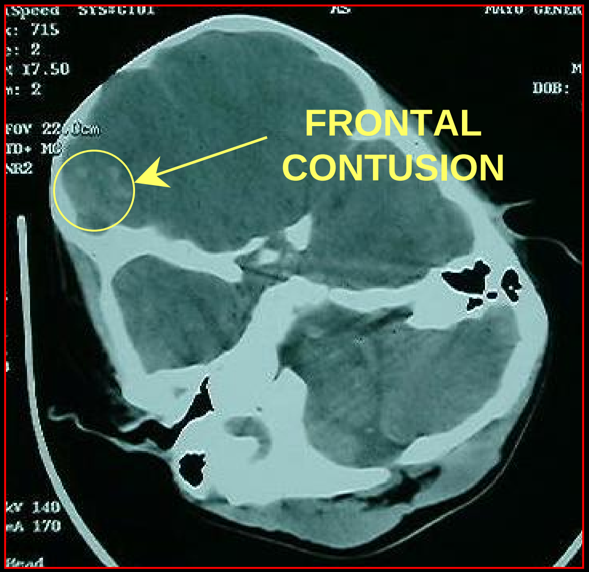
  Average = 12.4kN

- More compliant bone in children

1. Yoganandan, N. *et al*, (1995). J. Neurotrauma,**12**, 659-68.
2. Allsop *et al*, (1991). Proc. 35th Stapp Car Crash Conf., 269-78.

# Multibody Dynamics Simulations

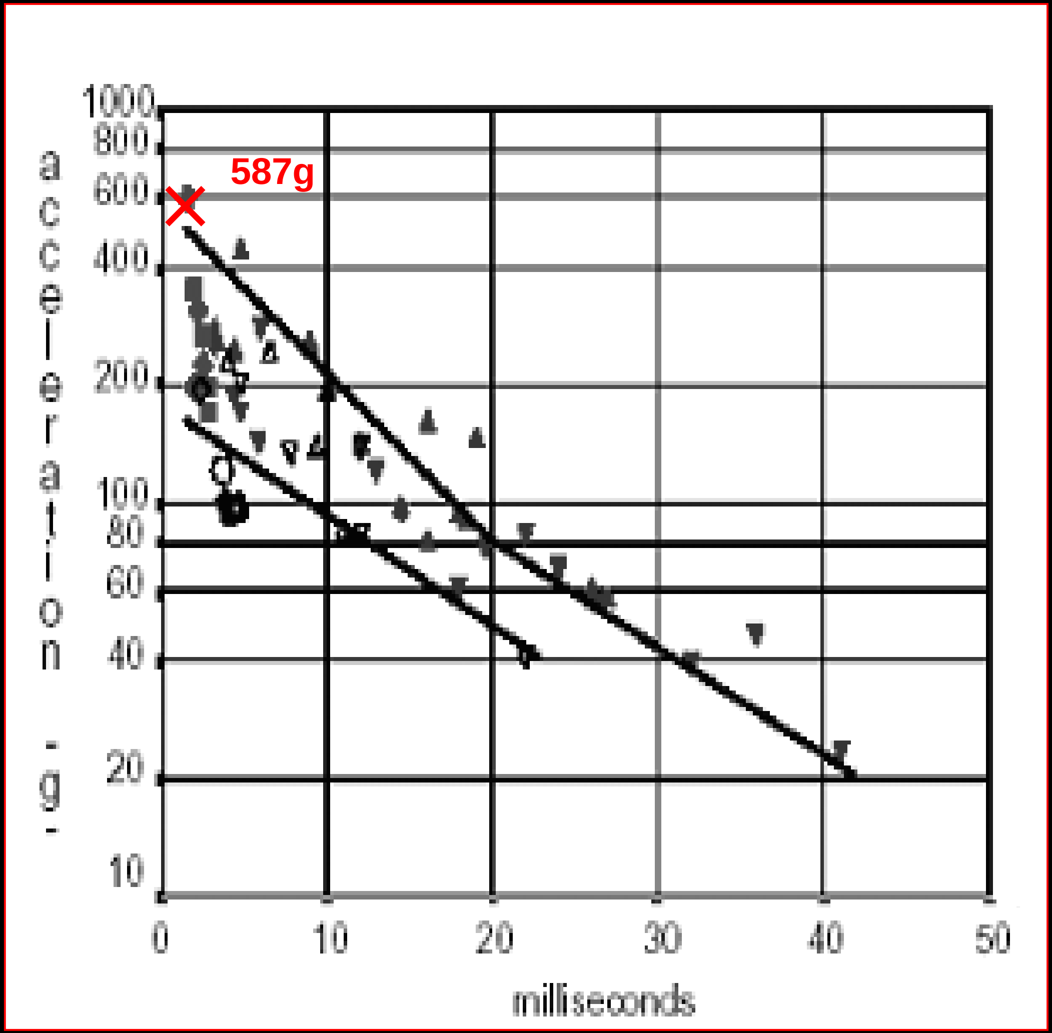


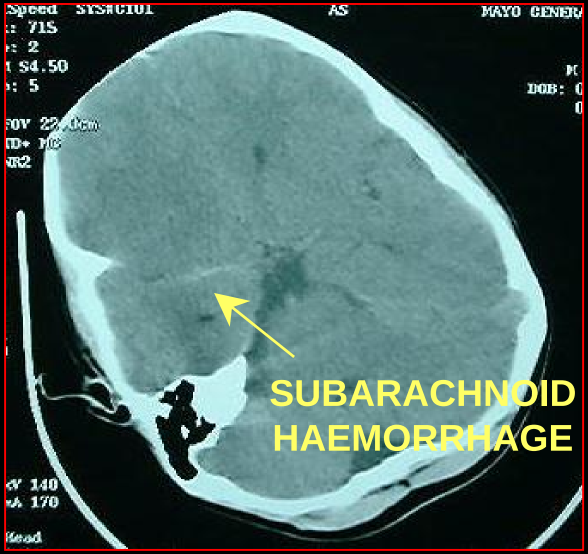




Frontal Contusion

Auer et al., Proc. XVIII Congress Int. Soc. Biomechanics, Zurich, Switzerland, 2001.

# Multibody Dynamics Simulations

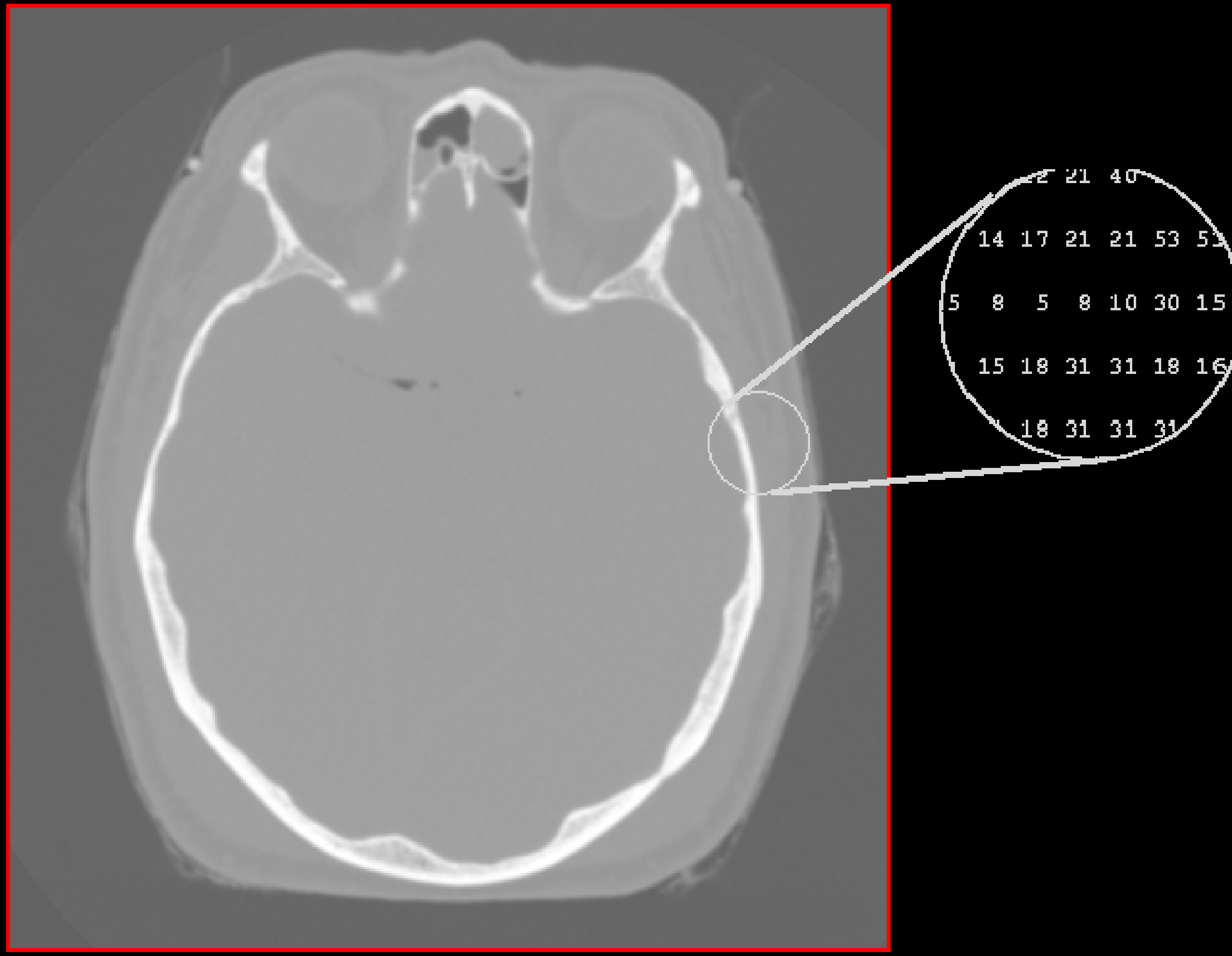



Subarachnoid Haemorrhage

Auer et al., Proc. XVIII Congress Int. Soc. Biomechanics, Zurich, Switzerland, 2001.

# Finite Element Simulations




Automatic creation of 3D FE models from CT scans

# Finite Element Simulations

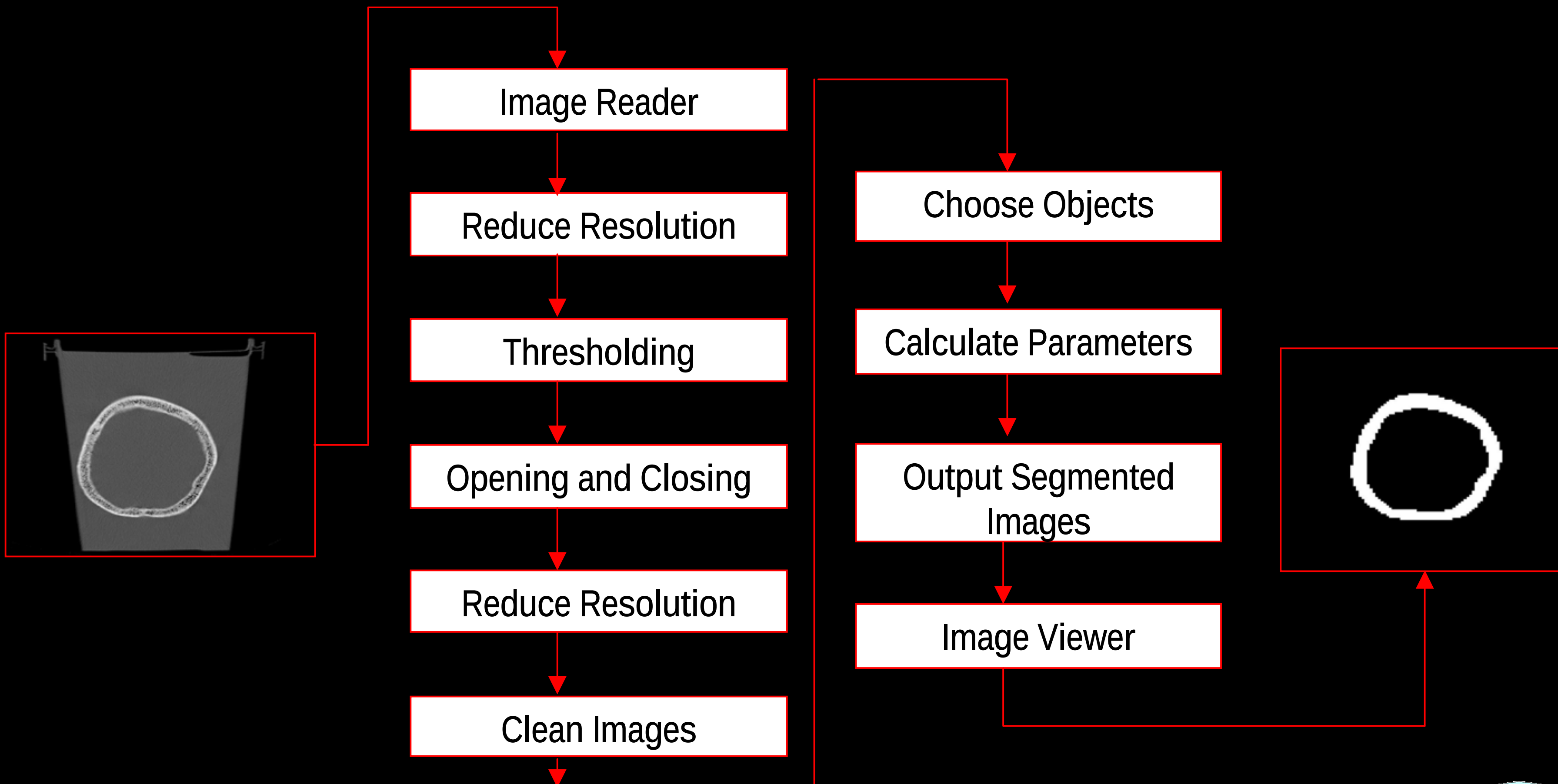
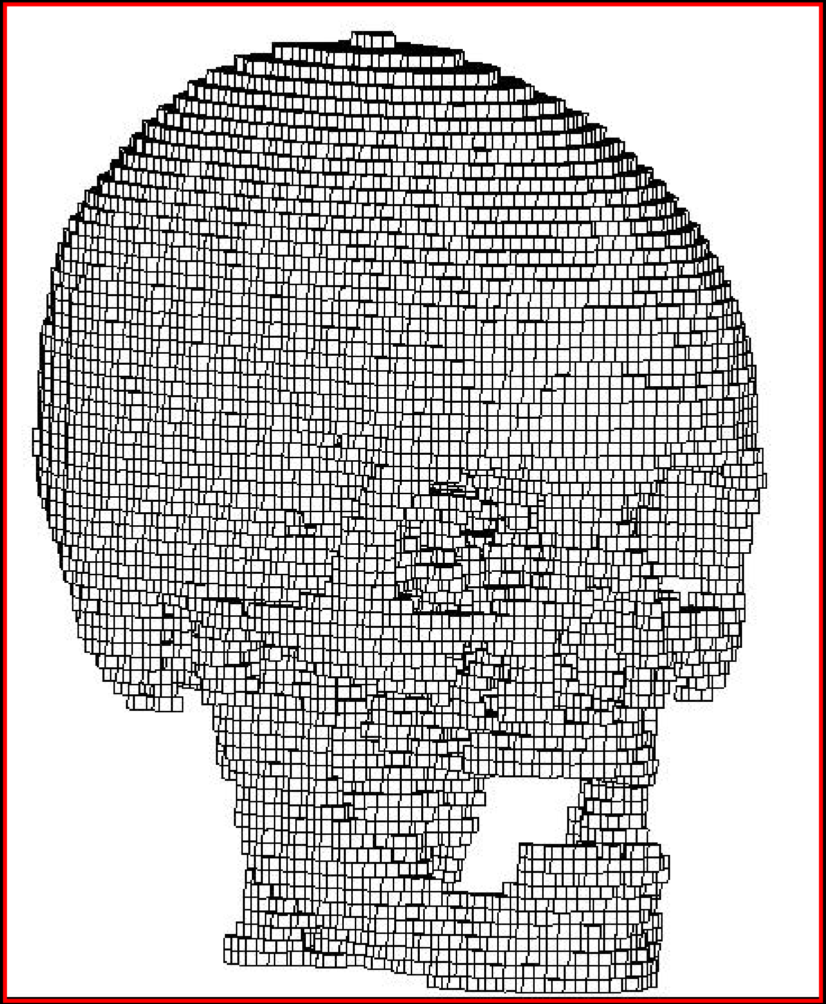
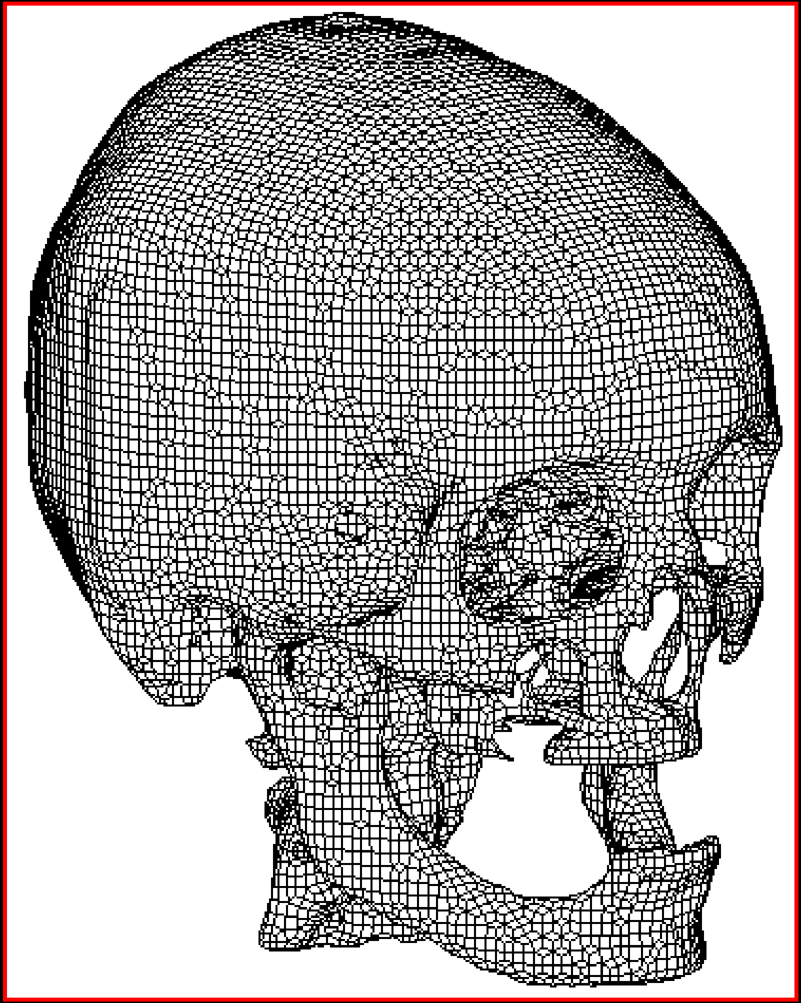



Image processing ‘pipeline’

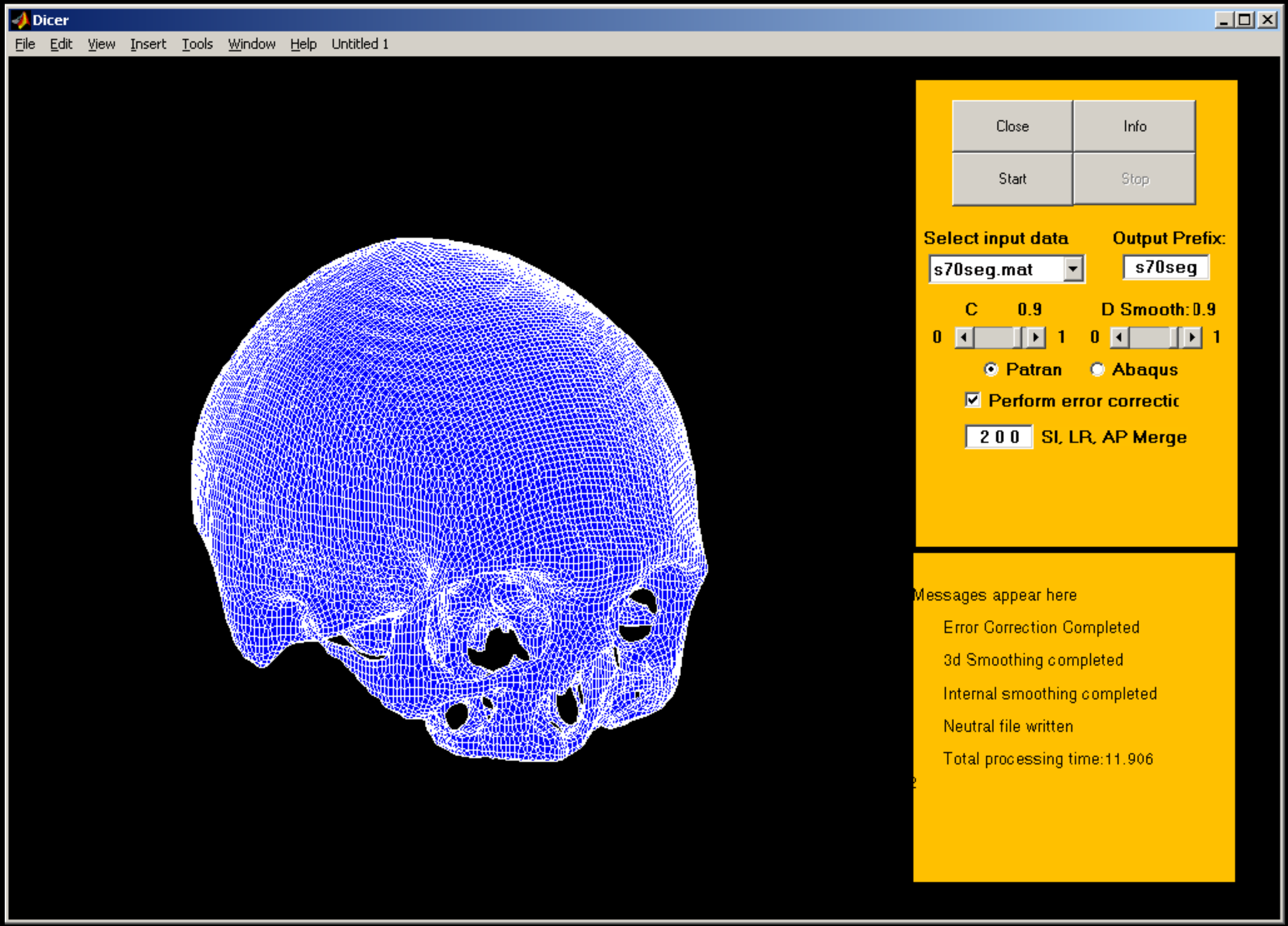
# Finite Element Simulations



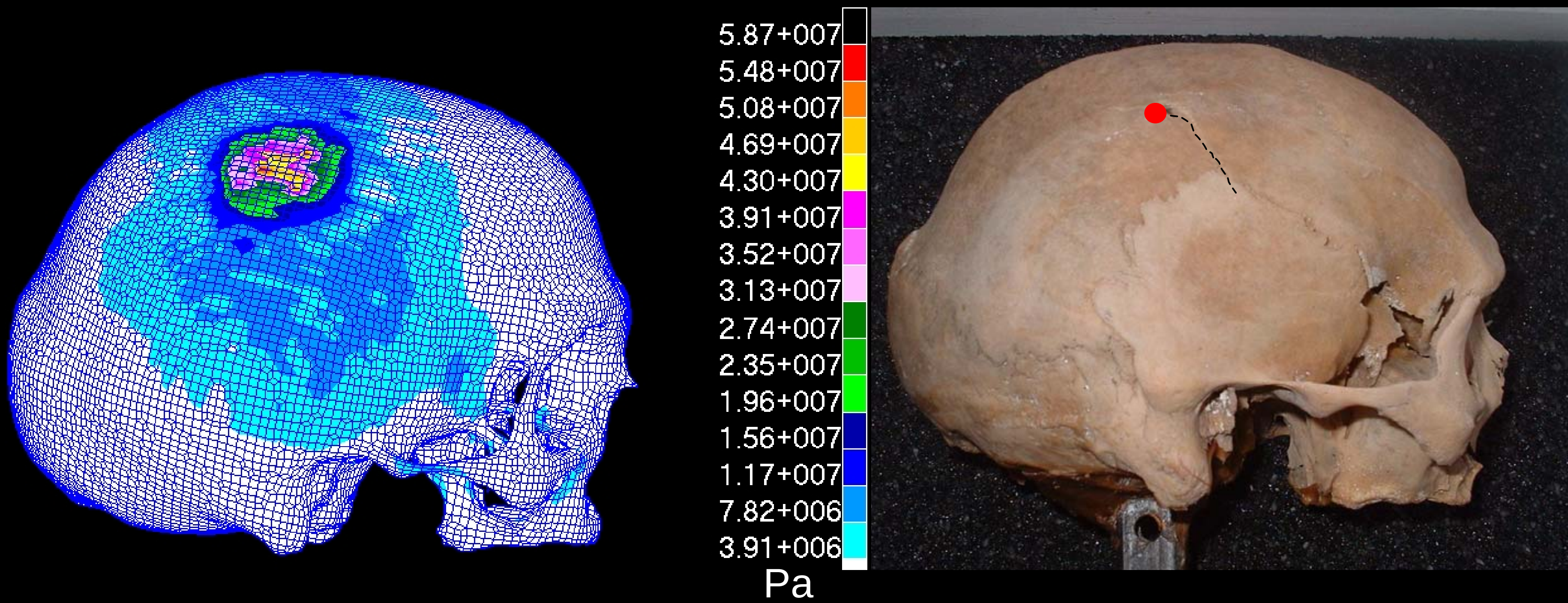


Canton, B. and Gilchrist, M.D. An automated system to generate patient specific meshes of biological objects. In preparation.

# MATLAB Interface

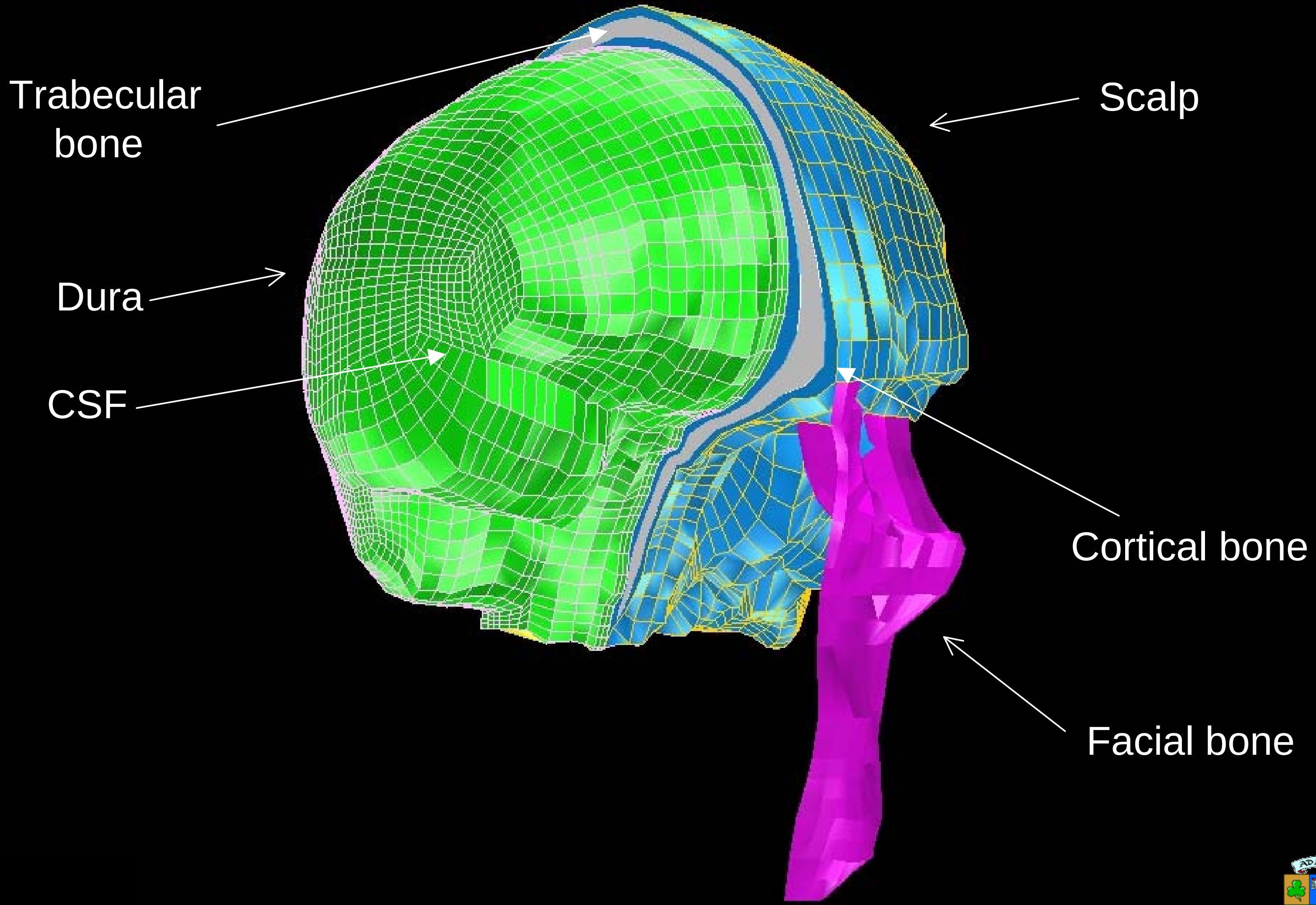


# Finite Element Simulations



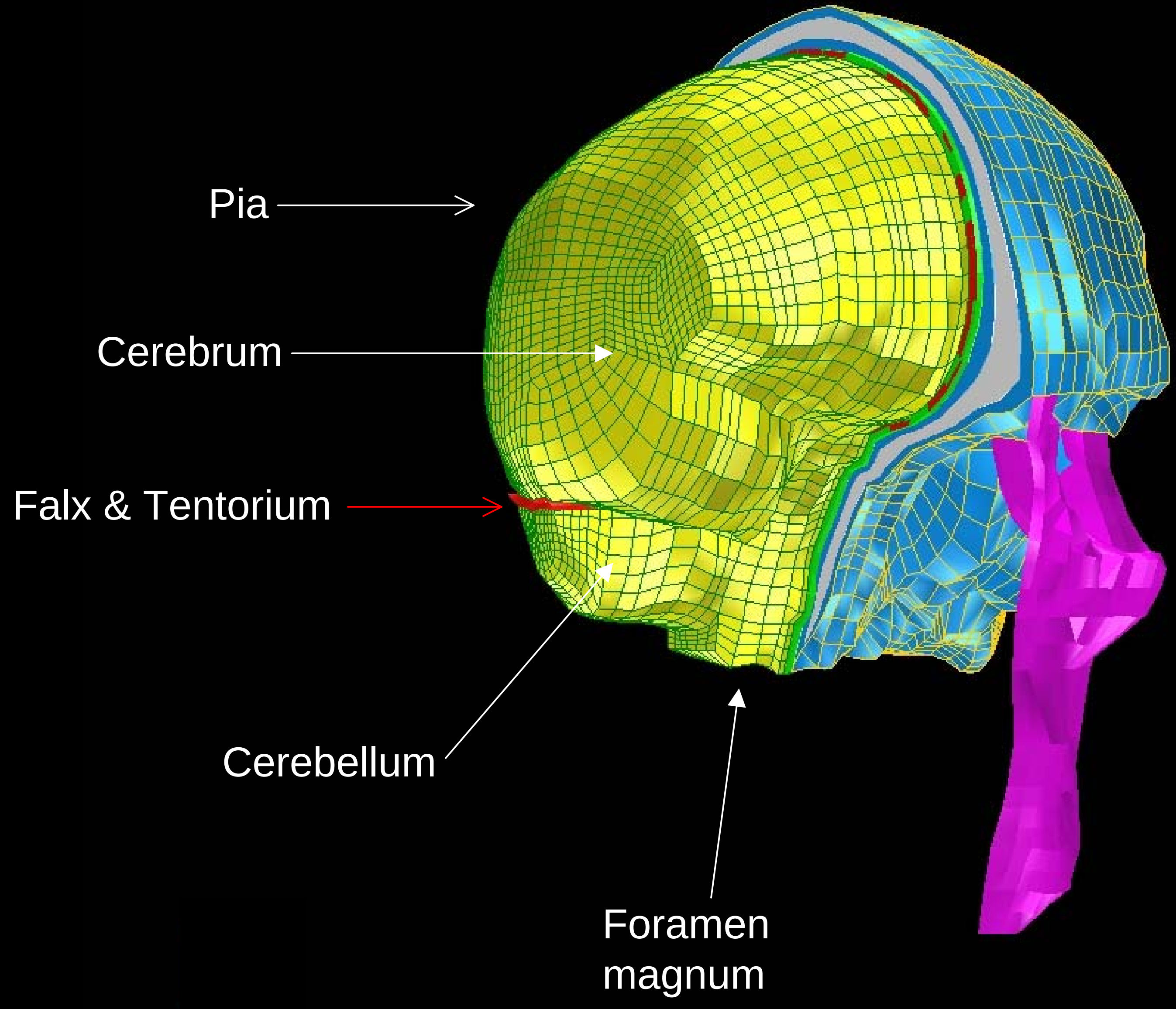

Skull impact simulation: Von Mises stress (experiments by KU Leuven)

# Finite Element Simulations

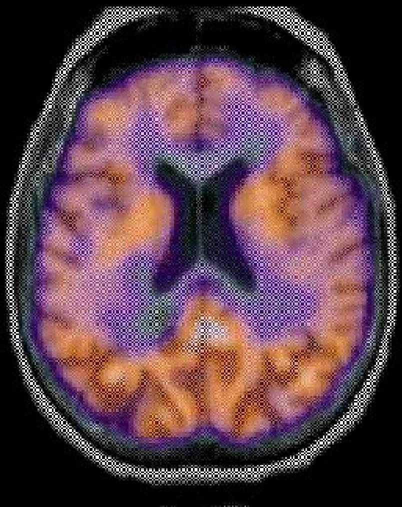


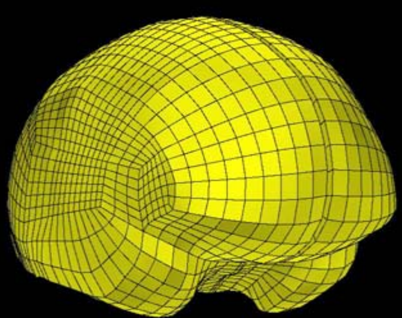

Horgan, T. J. and Gilchrist, M.D. (2003). The creation of three-dimensional finite element models for simulating head impact biomechanics. Int. J. Crashworthiness, Vol. 8 (4), pp. 353-366.

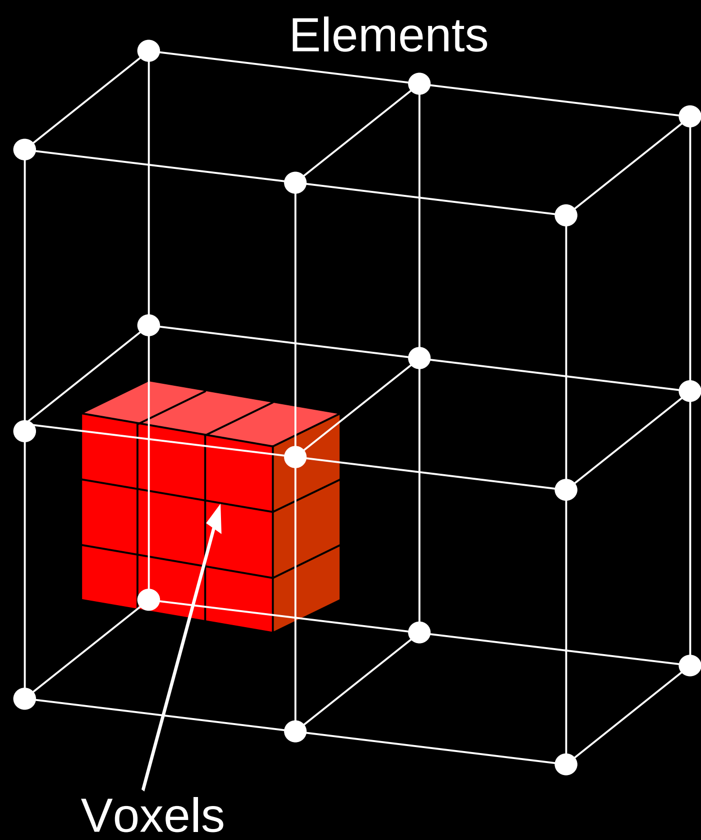
# Finite Element Simulations

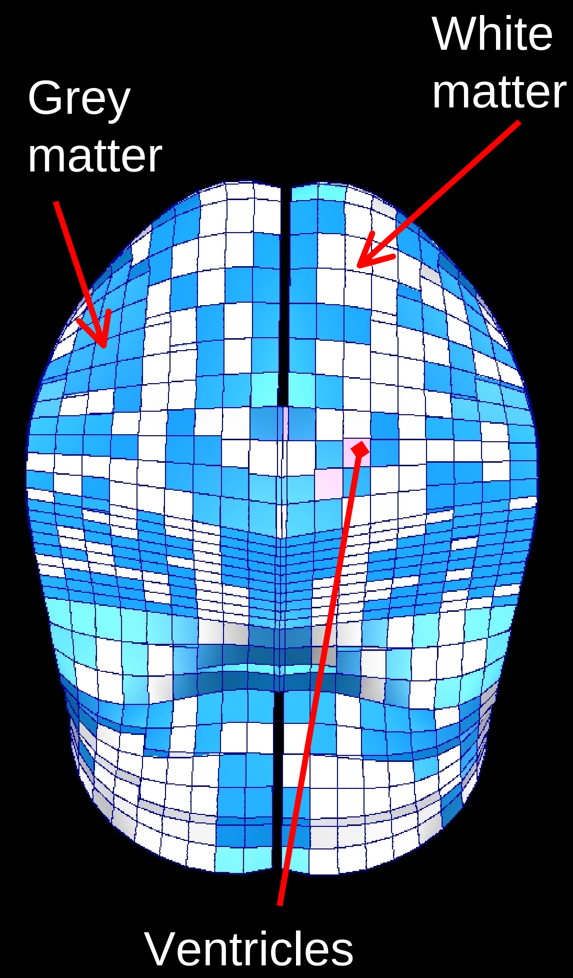


# Finite Element Simulations





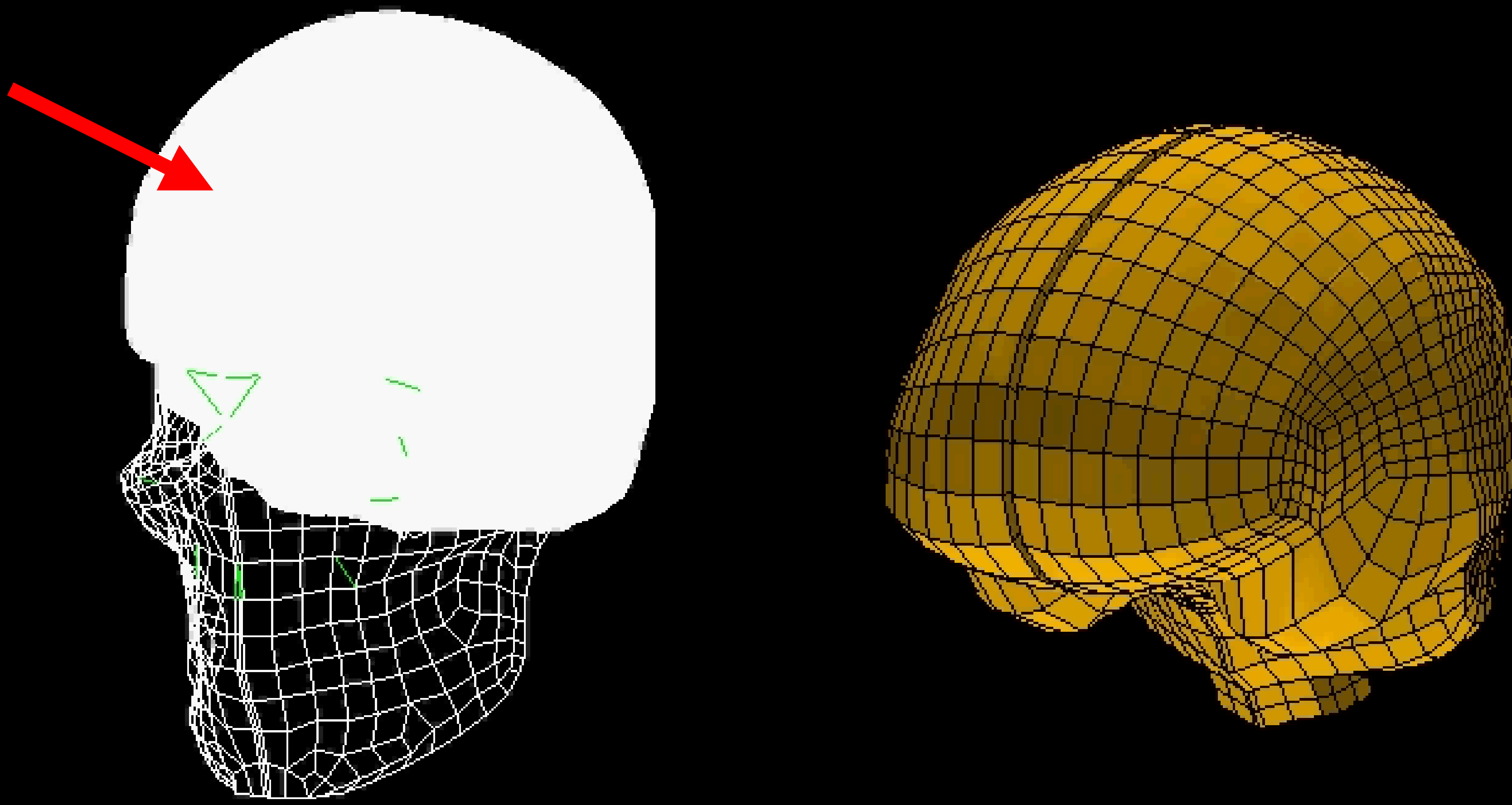



Automated assignment of material properties to elements

# Finite Element Simulations

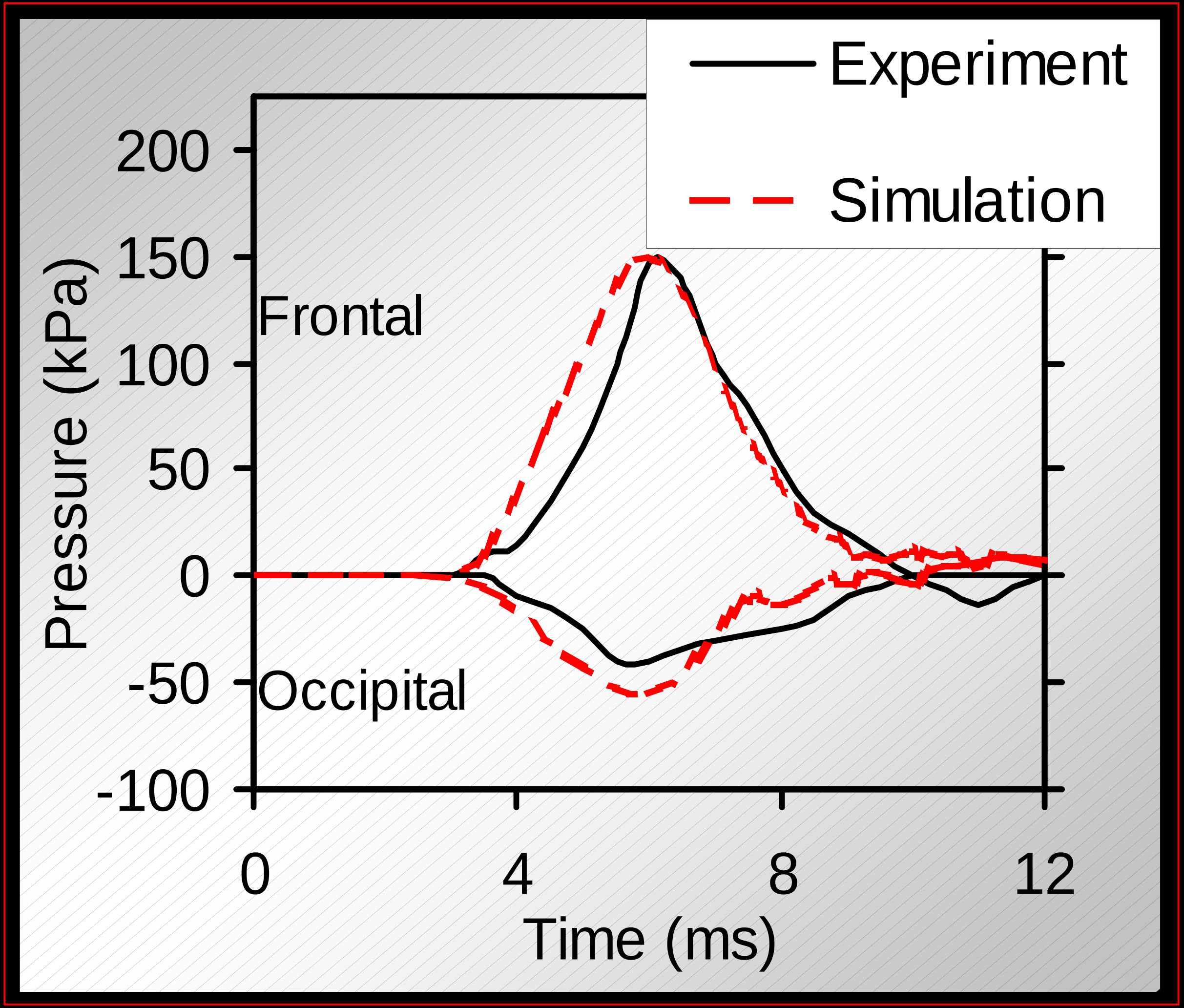
150 kPa -60 kPa Pressure



190 kPa 15 MPa Von Mises stress

Seated cadaver impact 45° frontal impact (experiments by Nahum)

# Finite Element Simulations



# Concluding Remarks

- Combined approach of multibody dynamics with finite element simulations can provide in-depth detail of impact injury mechanisms
- Combined experimental and computational approach offers scope to understand damage mechanics at tissue level and in clinical context – collaboration?
- Occupation specific safety helmets can be designed using virtual modelling approach – collaboration?