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Analysis of Traumatic Brain Injuries Using A Rat Brain Finite Element Model

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Objective of the present study

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The objective of the present study is to improve knowledge on traumatic brain injuries due to different impact scenarios based on a FEM of the rat's head

Rat’s head geometry obtention

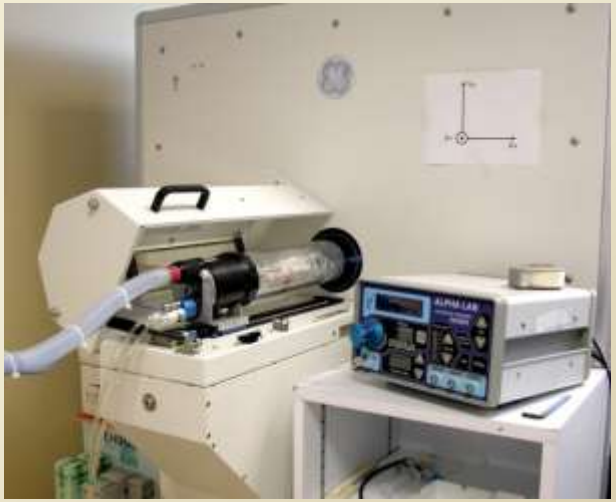
Rat's head geometry obtention: tools

Rat's head prepared for MRI magnet

MRI apparatus

- Resistive 0.1 T magnet

Micro CT system

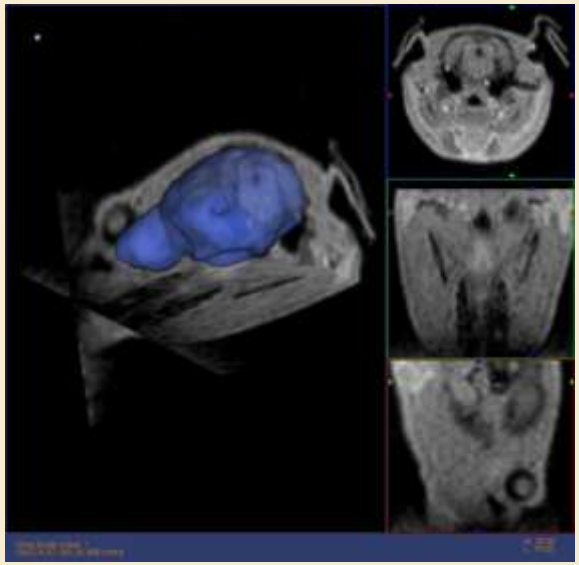


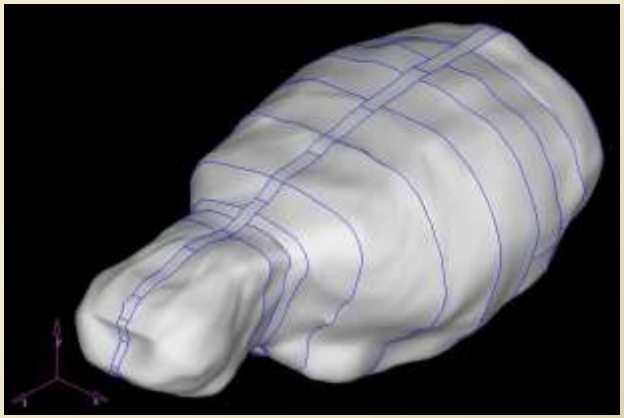
Rat's head geometry obtention: brain surface rendering

Rat's brain selection
- Micro CT tools

Rat's brain rough meshing
- Micro CT tools

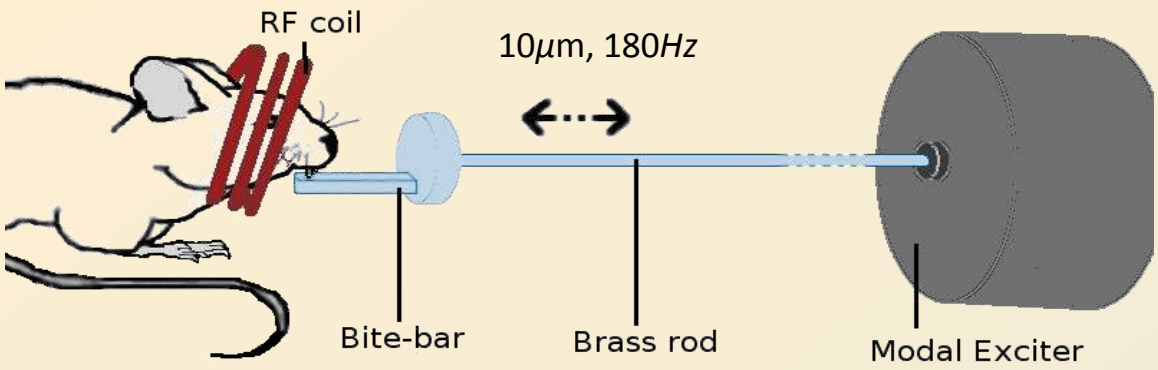
Rat's brain surface rendering
- Altair Hyperworks 9.0

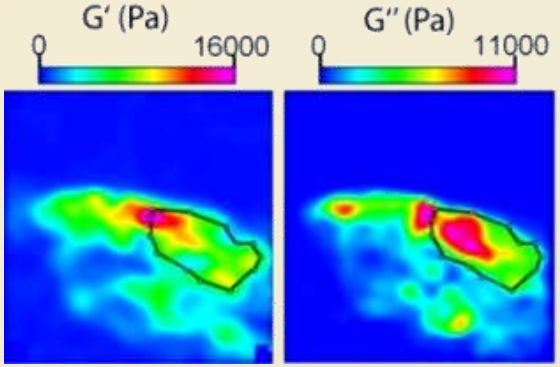


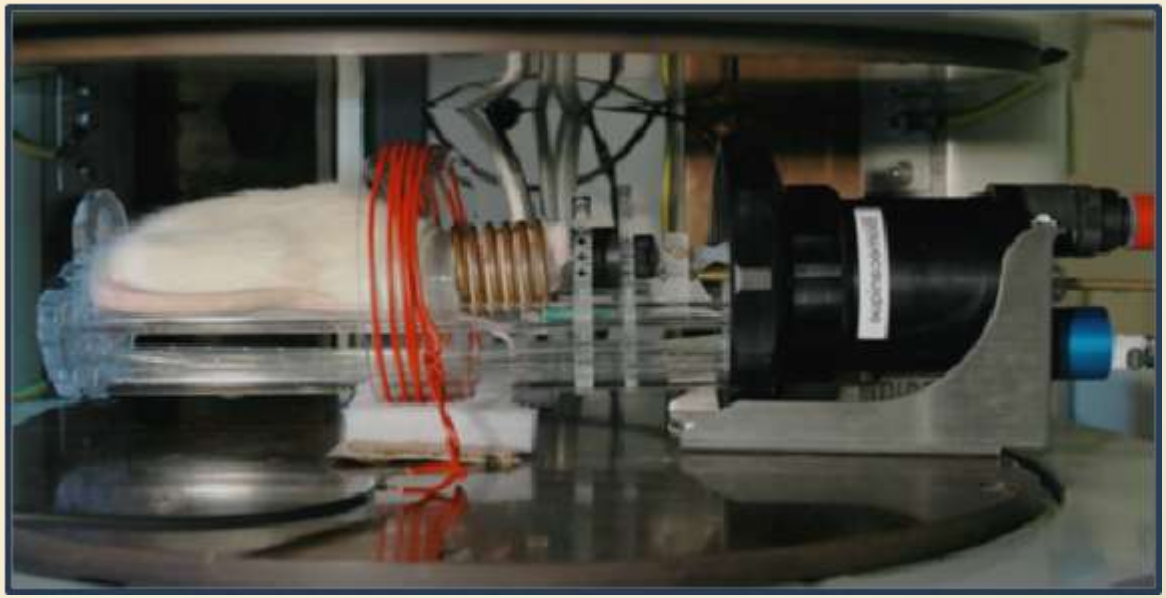


Rat's brain mechanical properties obtention

Rat's brain mechanical properties obtention: MRE







Mean shearing moduli at 180 Hz for the 7 tested rat's by Vappou et al. 2008

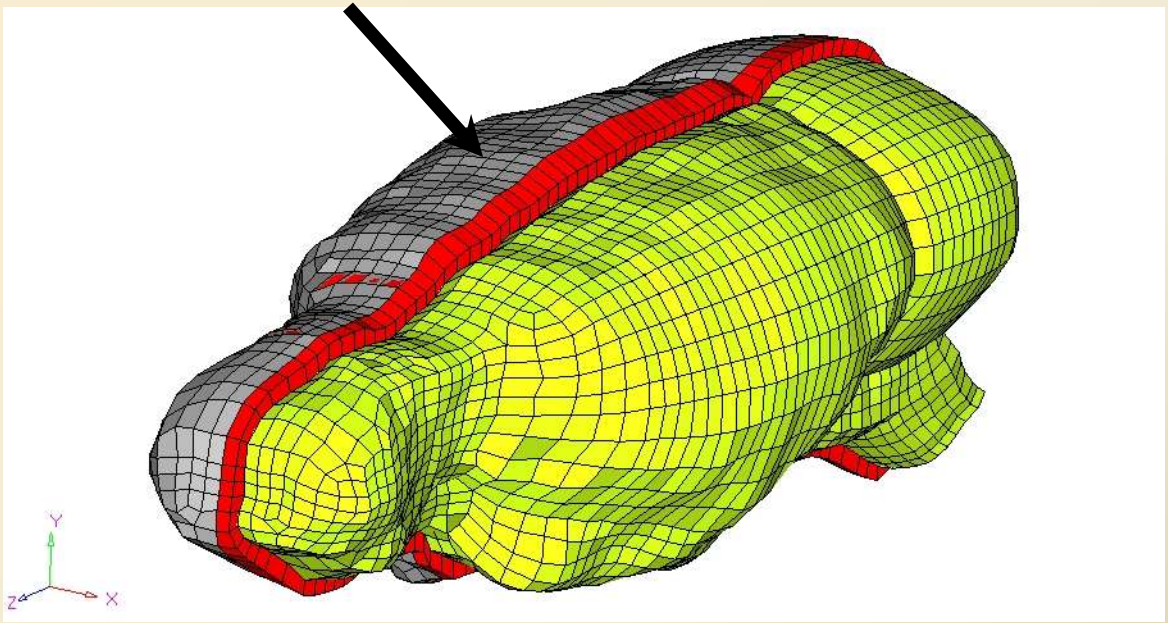
- G'=7,600+/-650 Pa
- G''=7,500+/-1,600 Pa

FEM of the rat's head

FEM of the rat's head: skull and general view

Skull

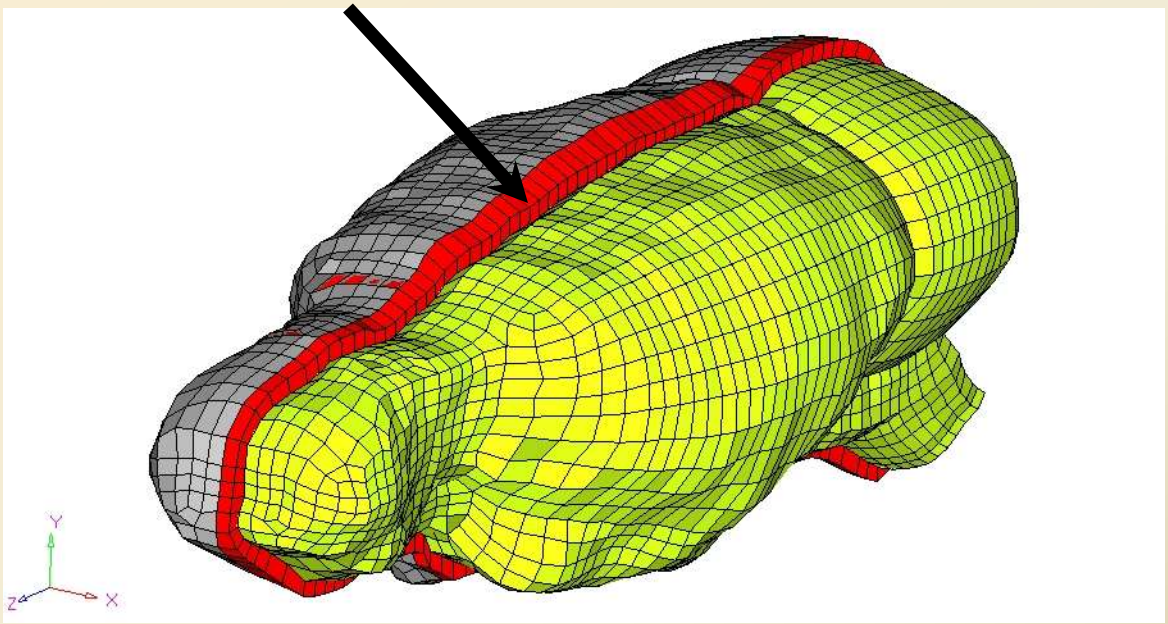
- 3,220 shell elements – e=0.1 mm
- Linear elastic
  - ρ=1,800 kg/m^3 – E=15,000 MPa – ν=0.21 (Baumgartner et al. 2004)



FEM of the rat's head: brain/skull interface and general view

Brain/skull interface

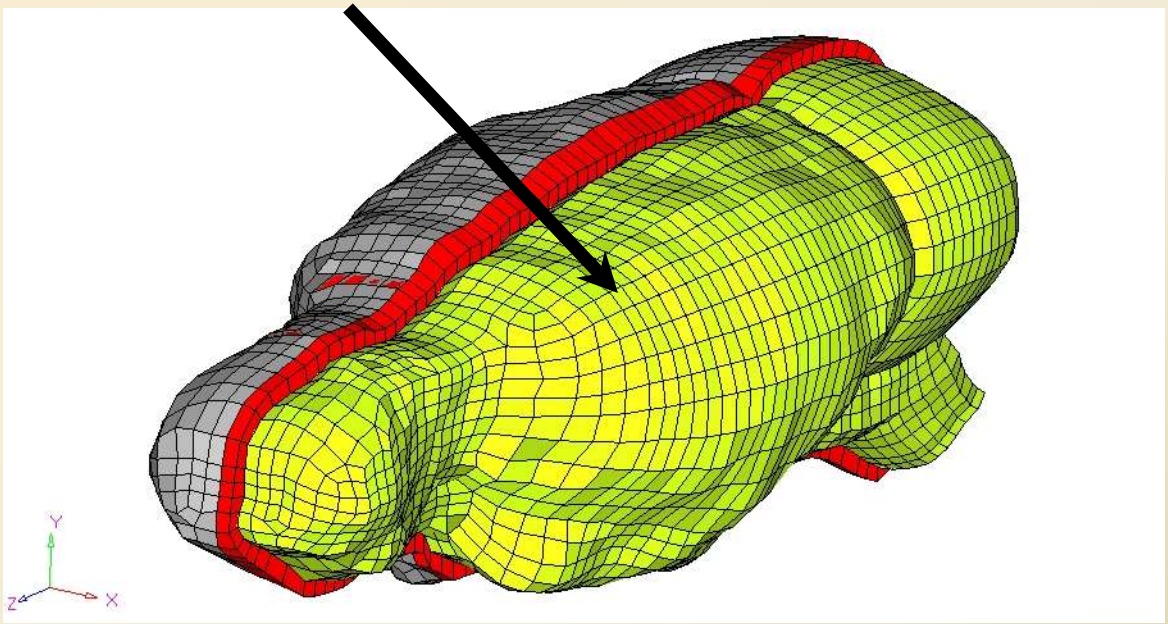
- 3,220 hexahedral elements
- Linear elastic
  - ρ=1,130 kg/m^3 – E=20 MPa – ν=0.45 (Zhang et al. 2001 and Mao et al. 2006)



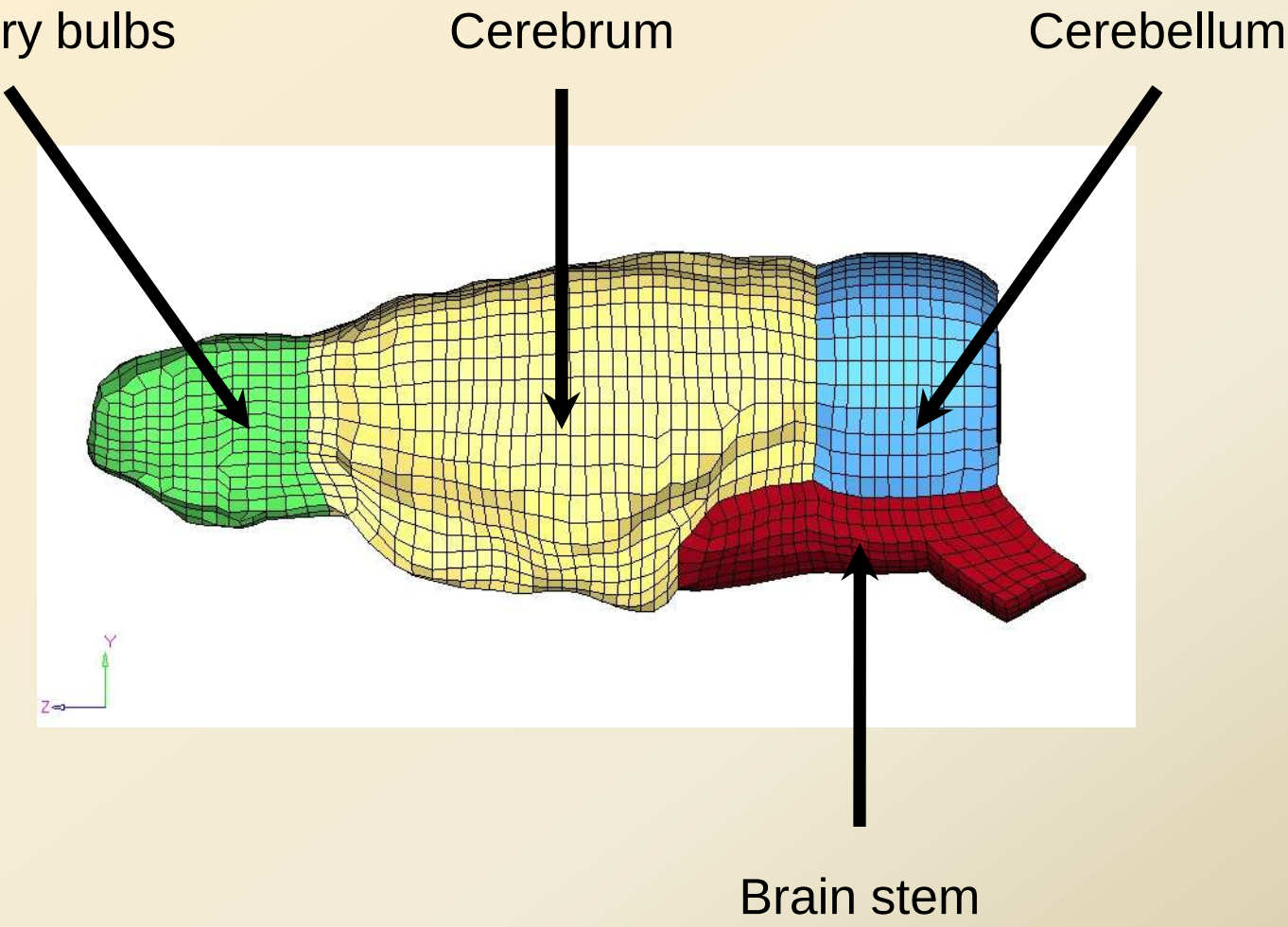
FEM of the rat's head: brain and general view

Brain

- 14,752 hexahedral elements
- Viscous elastic
  - ρ=1,040 kg/m^3 – K=2.19 GPa (Zhang et al. 2001 and Mao et al. 2006)
  - G_0=1.721 kPa – G_{inf}=0.508 kPa (Gefen et al. 2003)
  - β=0.125 s^{-1} (Levchakov et al. 2006)



FEM of the rat's head: brain general view



FEM of the rat's head: summarizing

Software used
- Altair Hyperworks 9.0 pre processor

Number of elements
- 3,220 4-nodes shell elements
- 17,972 8-nodes hexahedral elements

Edges' average size
- 0.45 mm

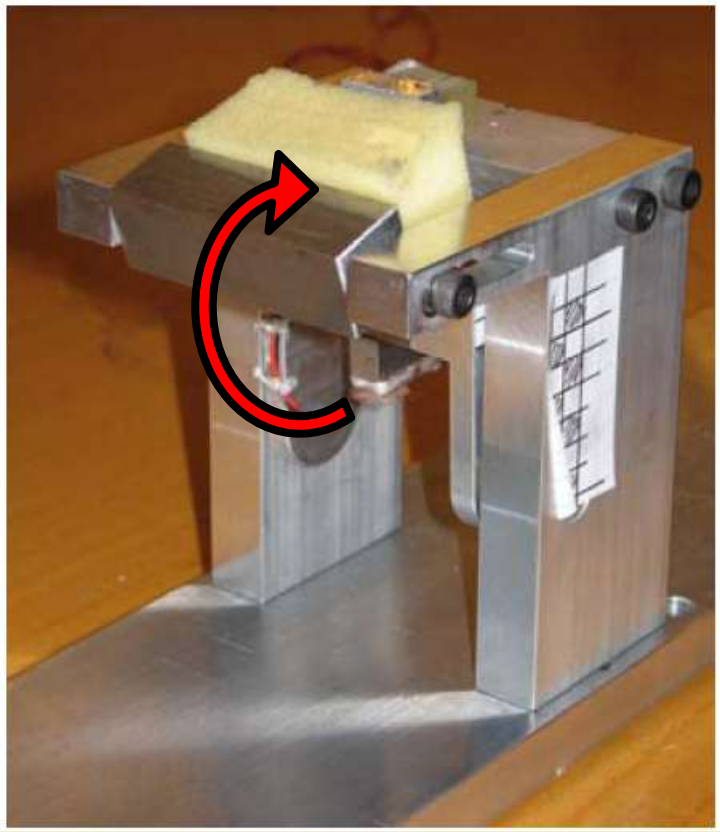
Total mass of the head
- 14.1 g

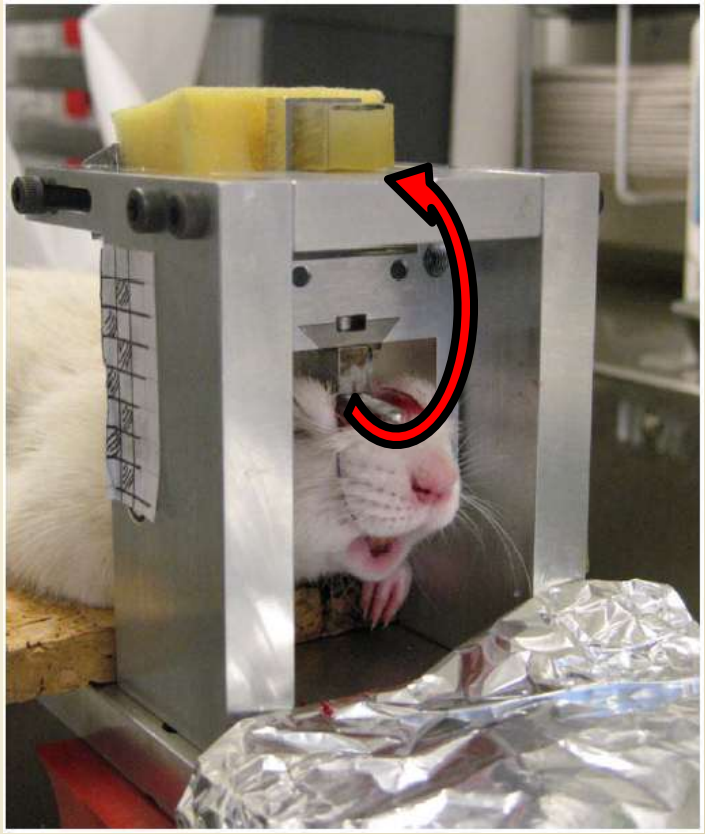
Experimental impacts on the rat's head

Experimental impacts on the rat's head (Davidsson et al. 2009)

Impact conditions and apparatus

- Rat's head exposed to a rearward rotational acceleration in the sagittal plane (43 rats)

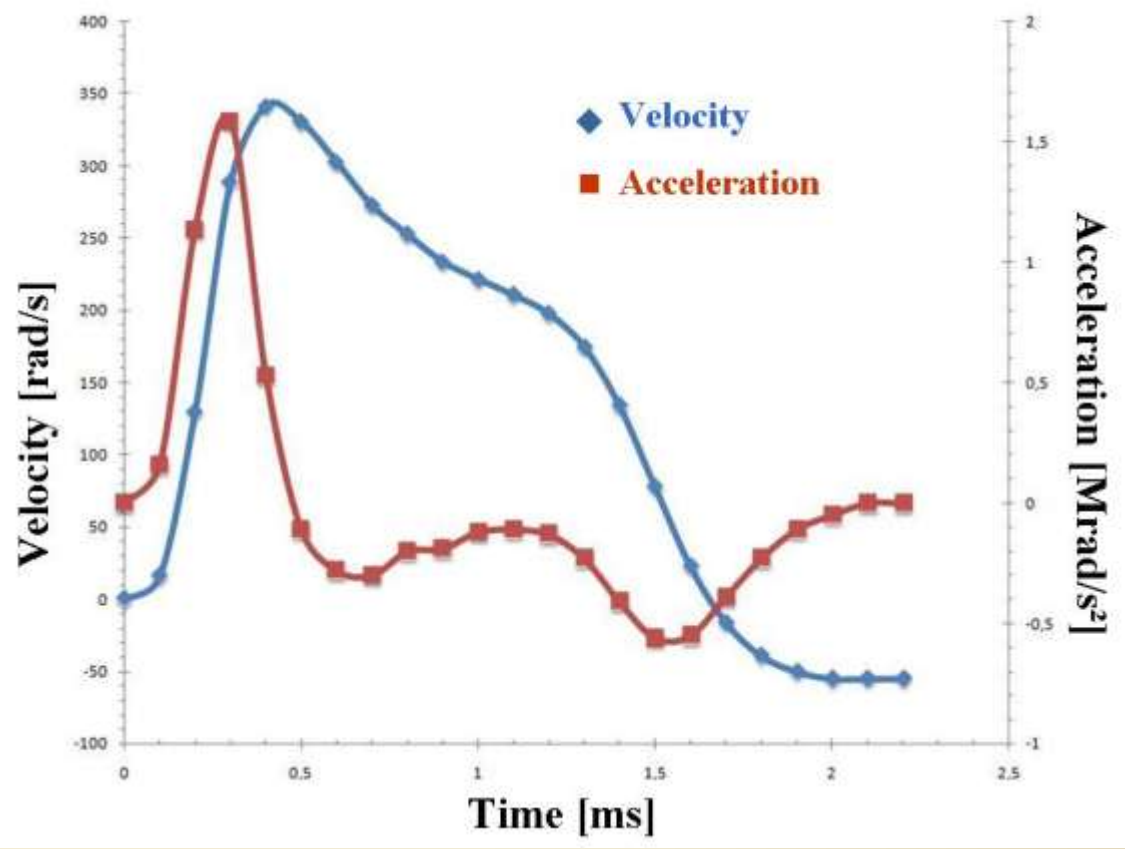




Experimental impacts on the rat's head (Davidsson et al. 2009)

Sustained acceleration level

- Up to 2,000,000 rad/s² during 0.4 ms



Simulation of the experimental impacts on the rat's head

Simulation characteristics

Software

- Altair Hyperworks 9.0 engine and post processor

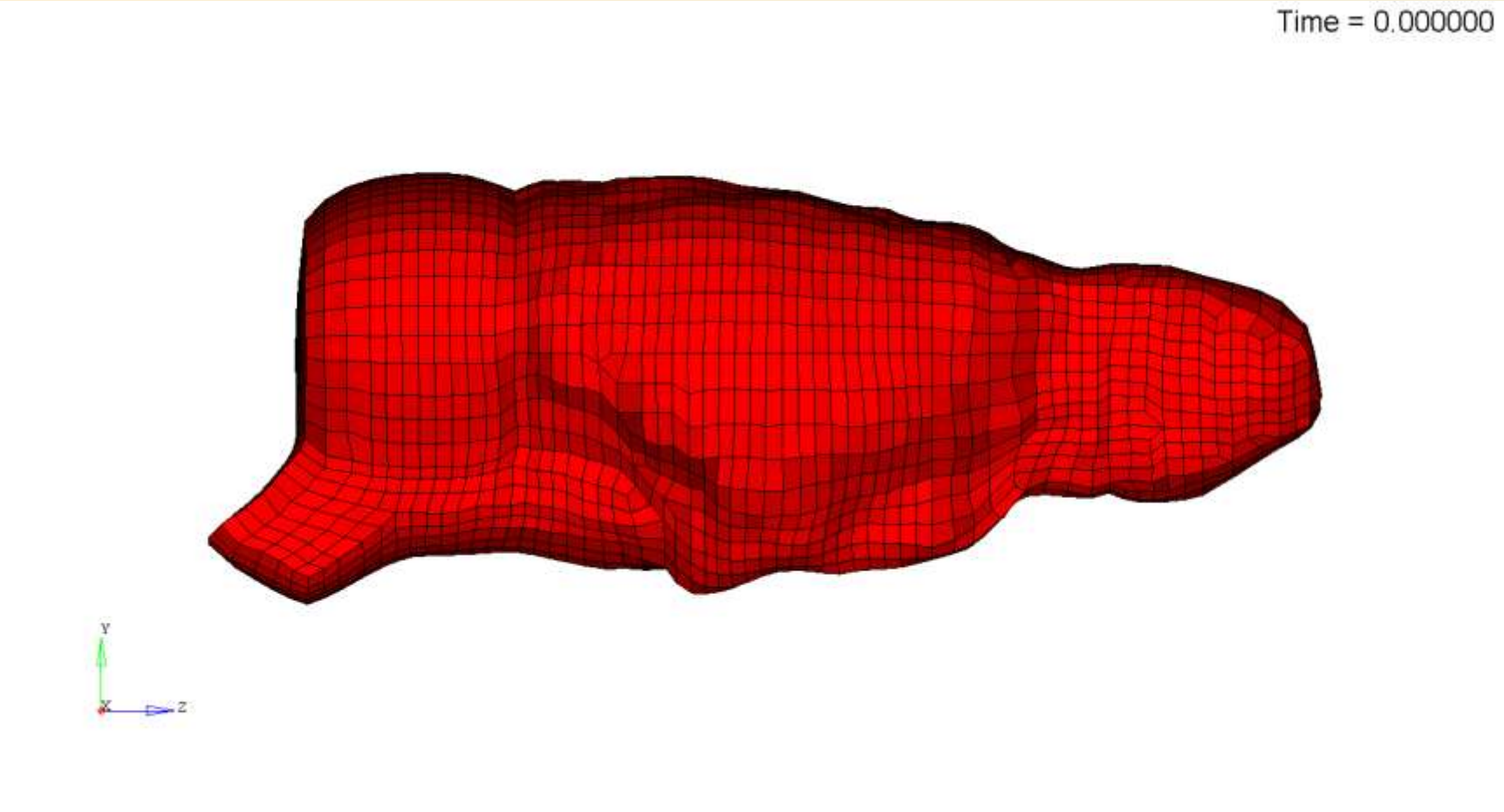
Computer

- Personnal computer
  - Intel Centrino Duo – 2 GHz CPU – 2 Go RAM

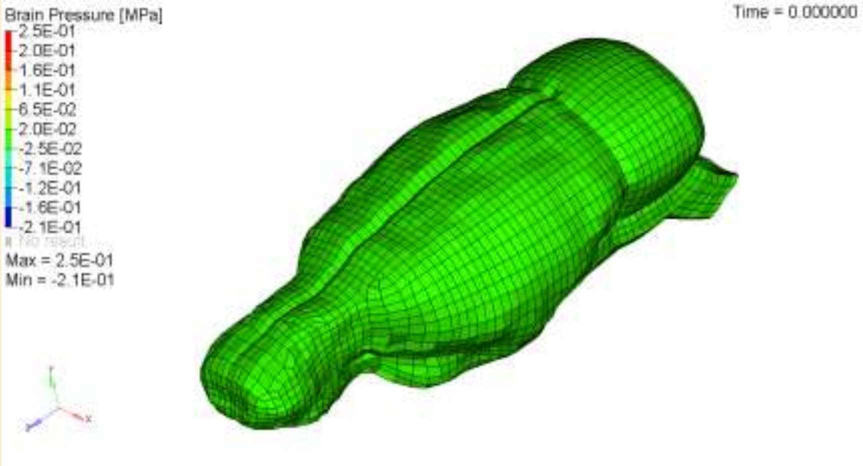
Simulation

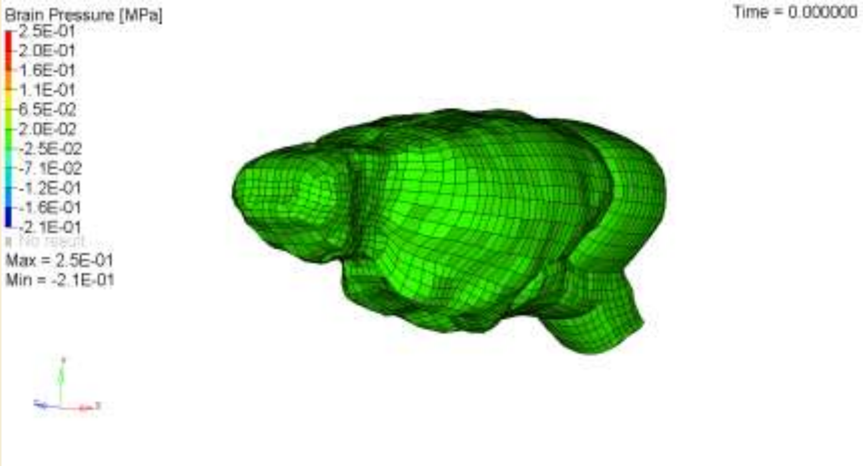
- Characteristics
  - Time=50 ms – Duration= ~1 hour – Time step= ~$10E^{-5}$ ms – Hourglass energy= ~5% Total energy

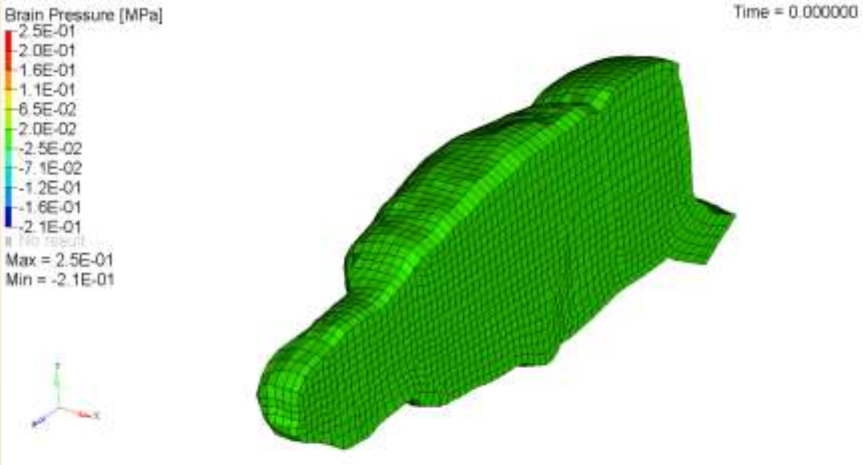
Rat's head motion during impact



Brain pressure during impact





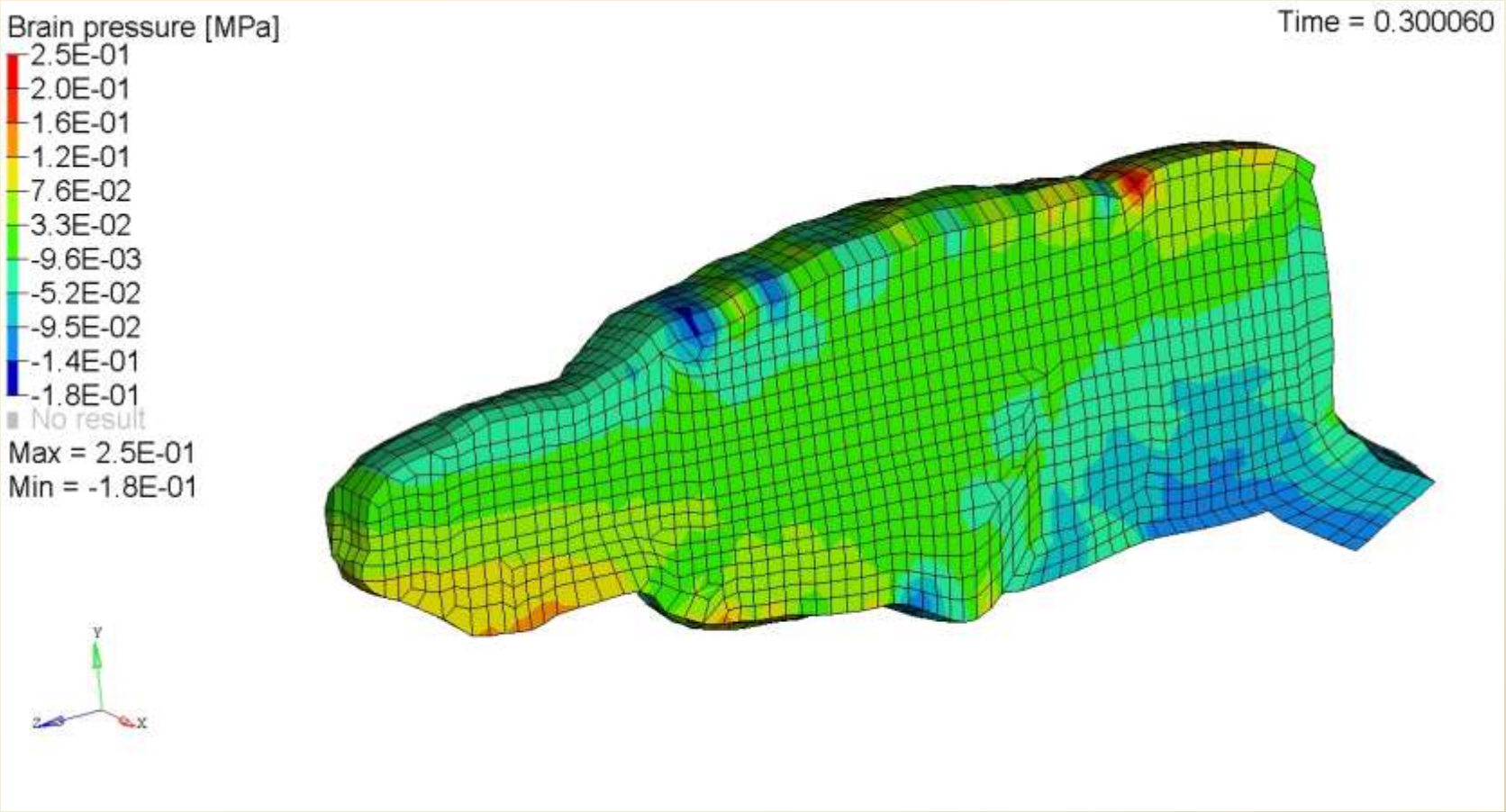


Maximum brain pressure

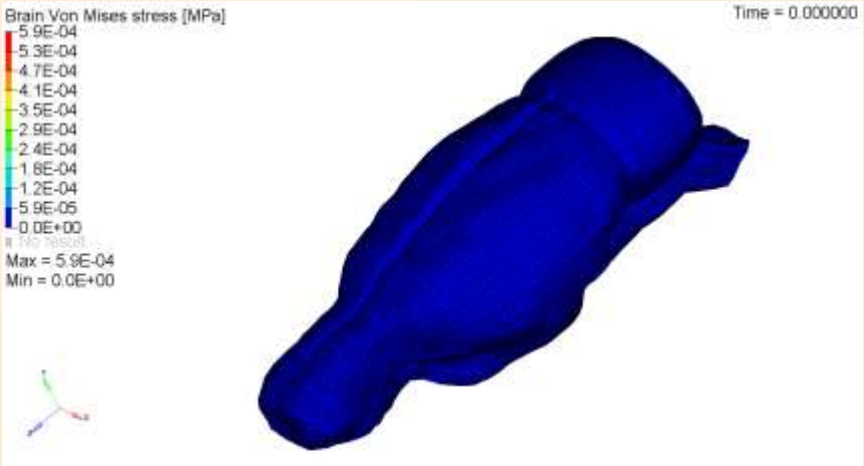
250 kPa

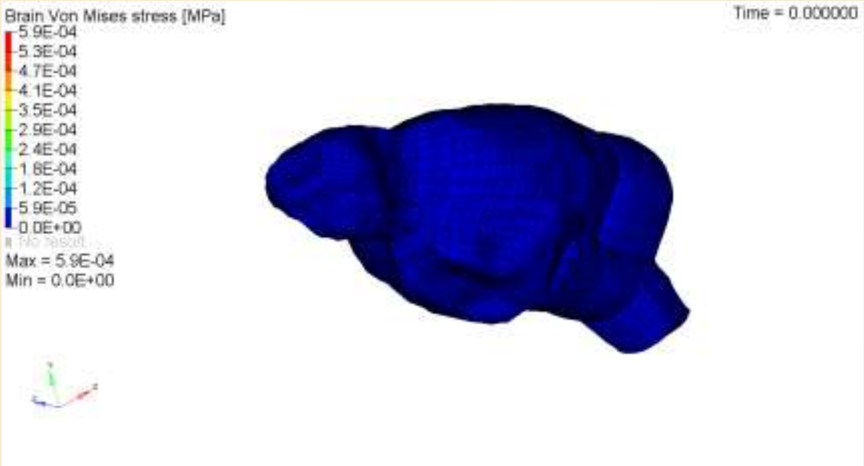
- Superior cortex
- Vicinity of the olfactory bulbs

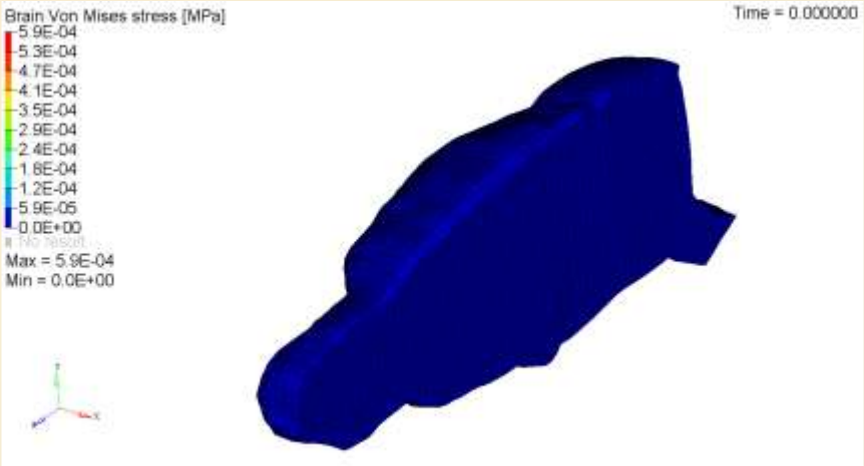
Brain pressure during impact



Brain Von Mises stress during impact





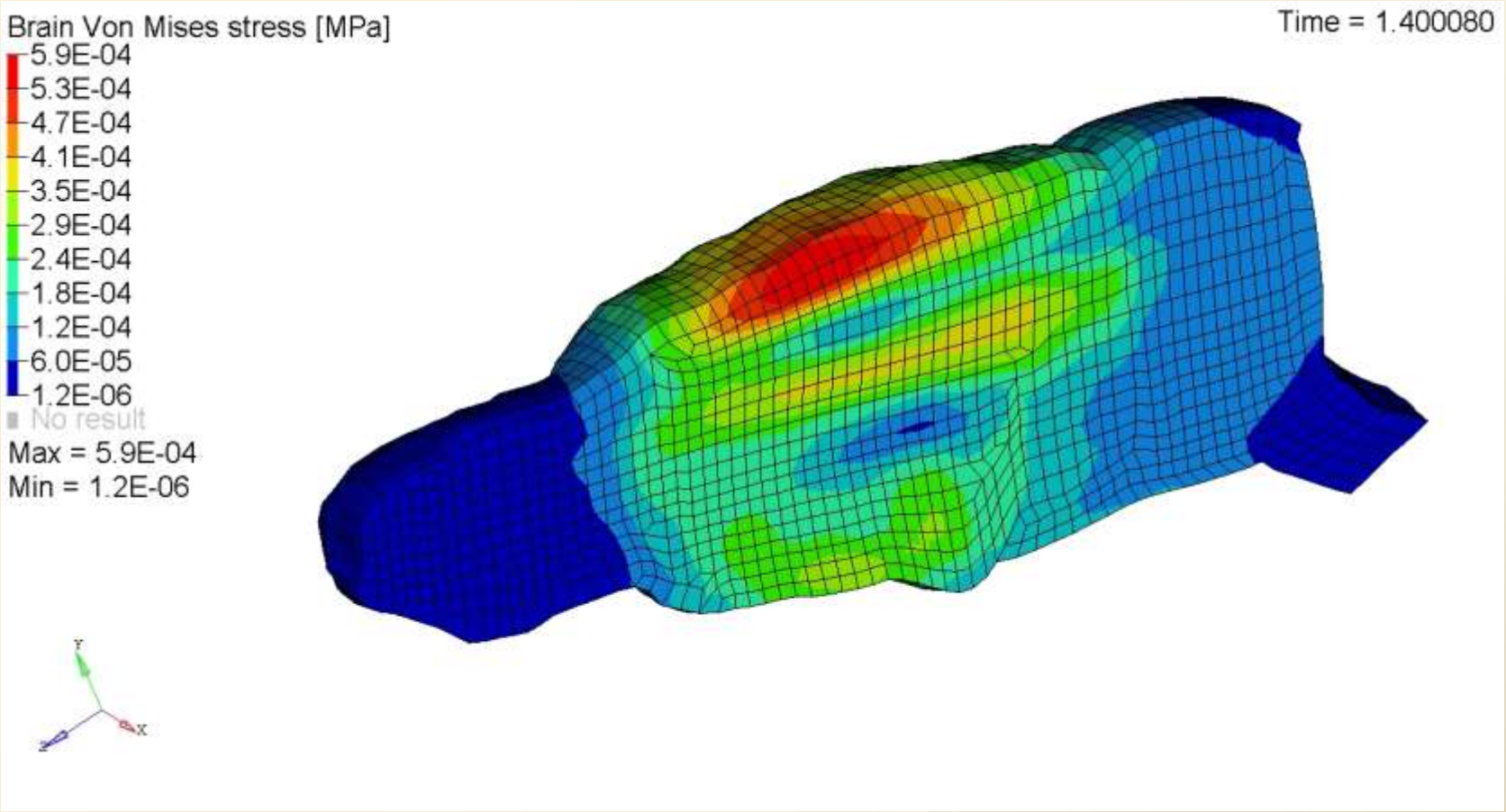


Maximum brain Von Mises stress

0.59 kPa

- Vicinity of the corpus callosum

Brain Von Mises stress during impact



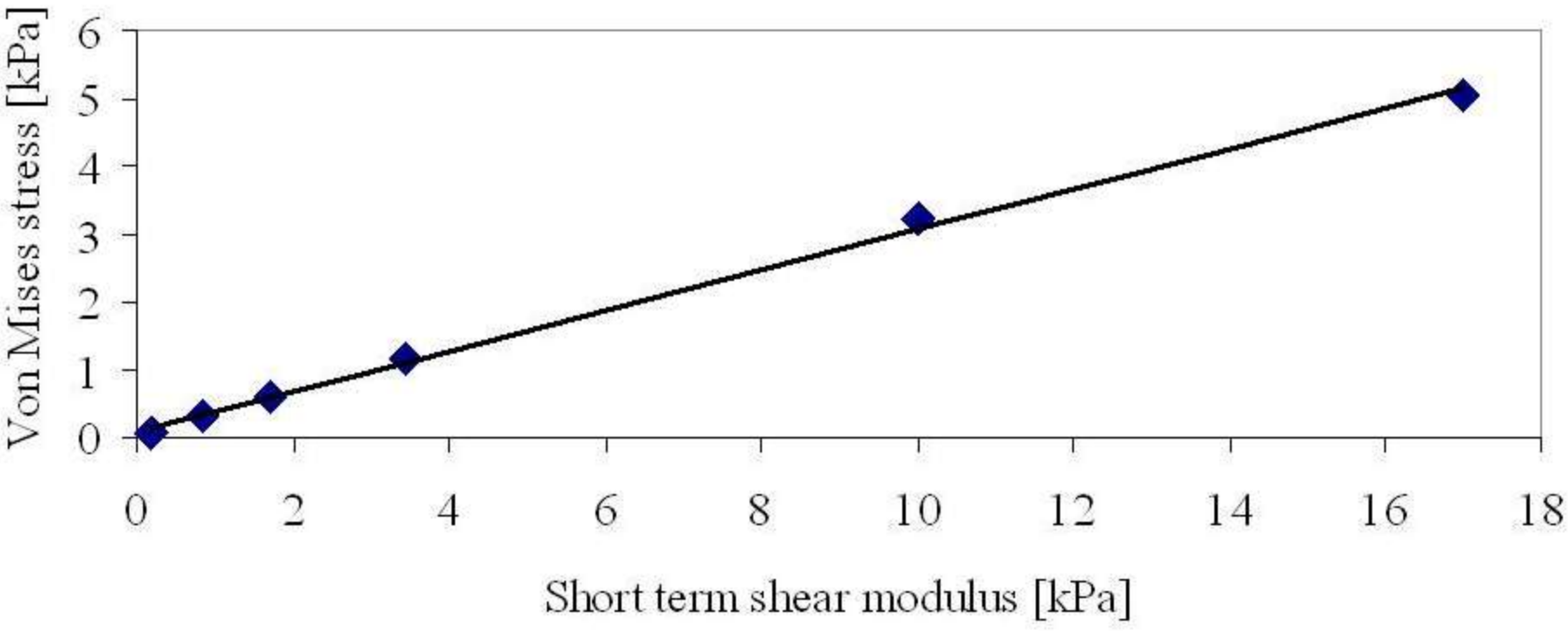
Parametric study of the rat's head FEM

Brain short term shear modulus, pressure and Von Mises stress

Variation
- 0.17 kPa to 17 kPa

Brain pressure → **112 kPa**

Brain Von Mises stress ↗ **Linear**

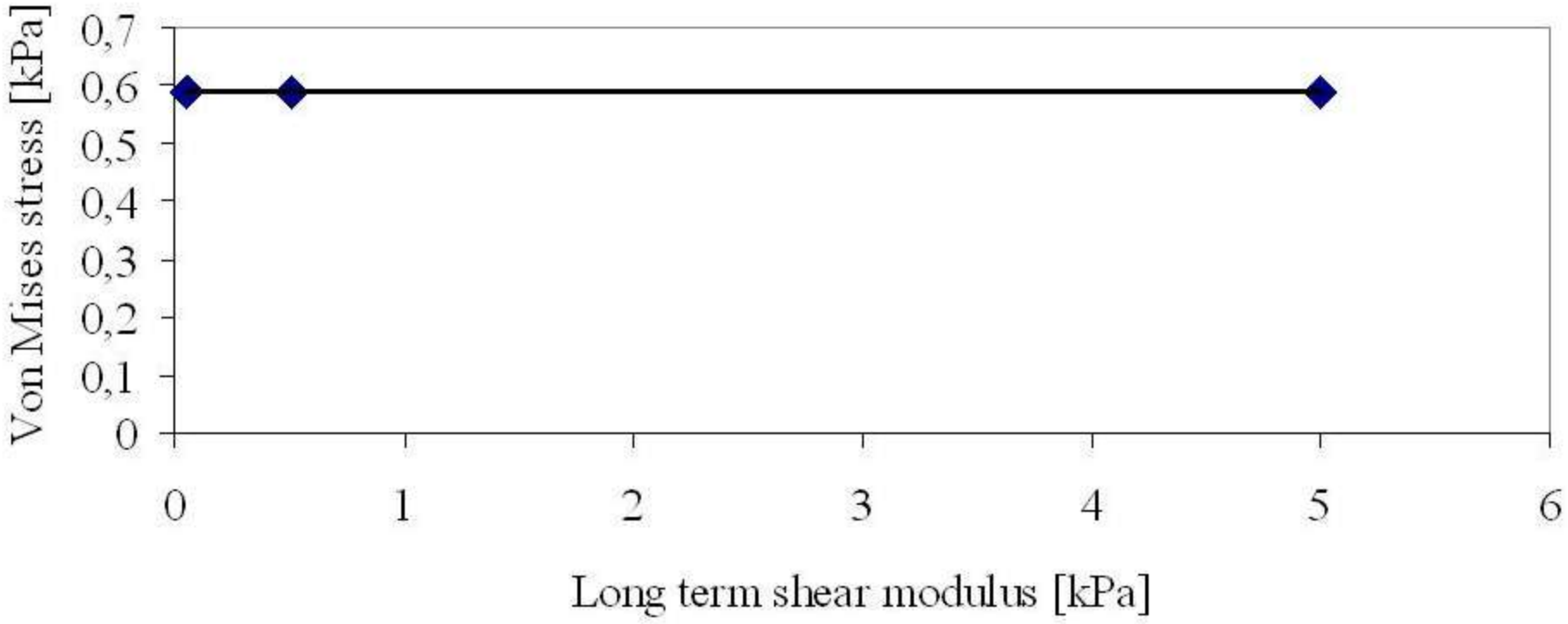


Brain long term shear modulus, pressure and Von Mises stress

Variation
- 0.05 kPa to 5 kPa

Brain pressure ⇨ **112 kPa**

Brain Von Mises stress ⇨ **0.59 kPa**

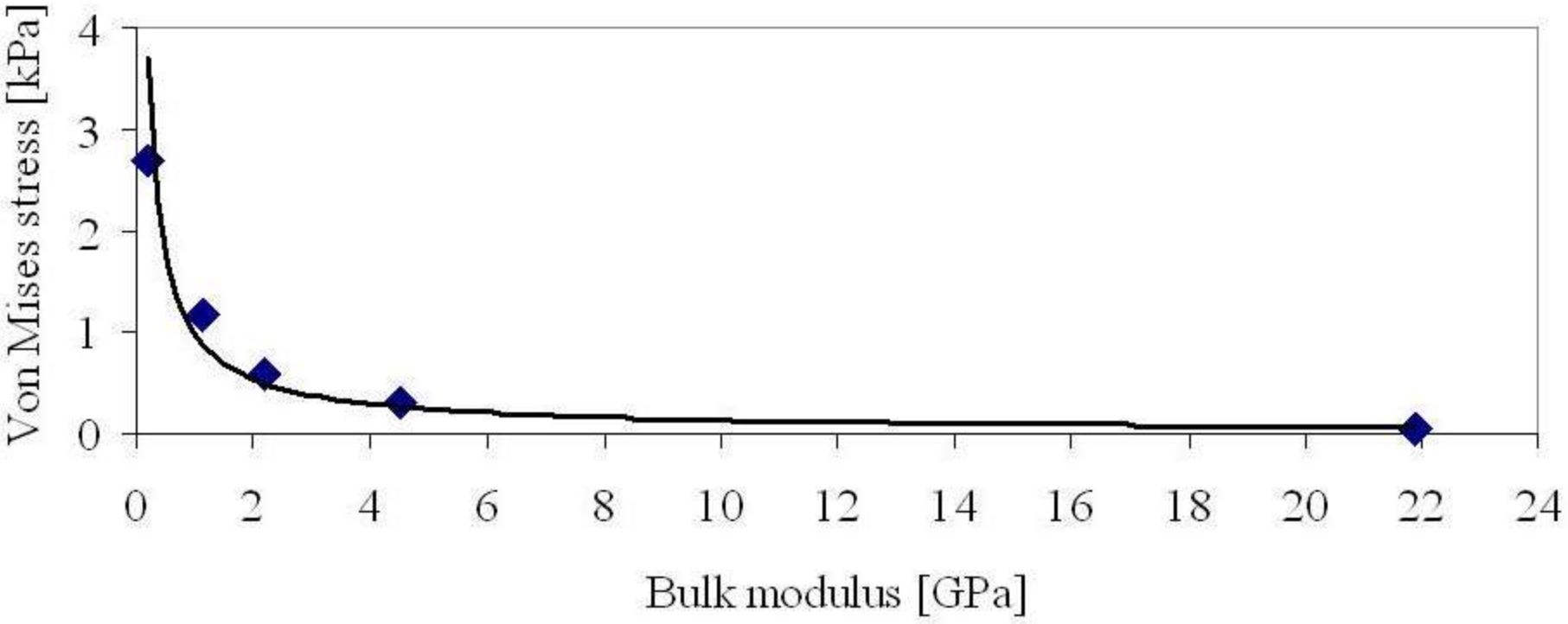


Brain Bulk modulus, pressure and Von Mises stress

Variation
- 0.219 GPa to 21.9 GPa

Brain pressure → **112 kPa**

Brain Von Mises stress ↘ **Power**



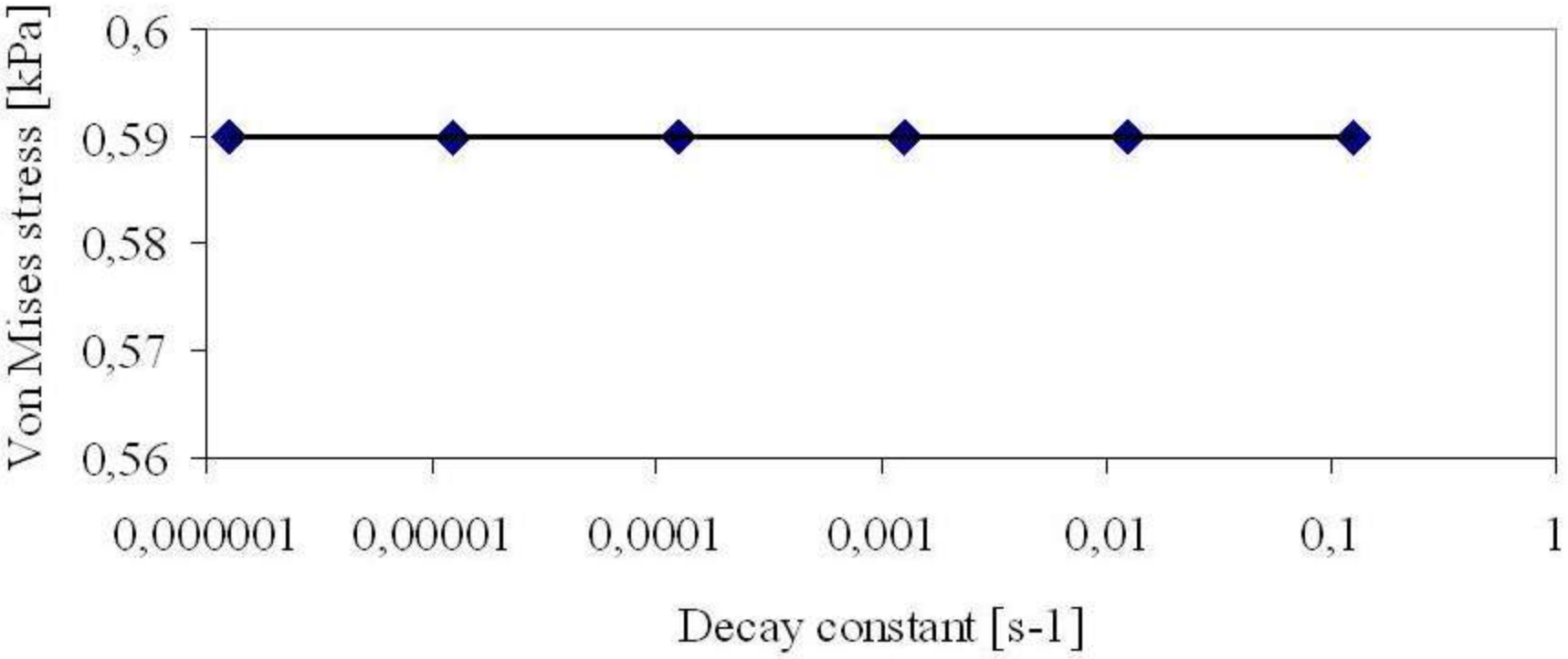
Brain decay constant, pressure and Von Mises stress

Variation

- $1.25E^{-6}$ ms^{-1} to 1.25 ms^{-1}

Brain pressure ⇨ **112 kPa**

Brain Von Mises stress ⇨ **0.59 kPa**

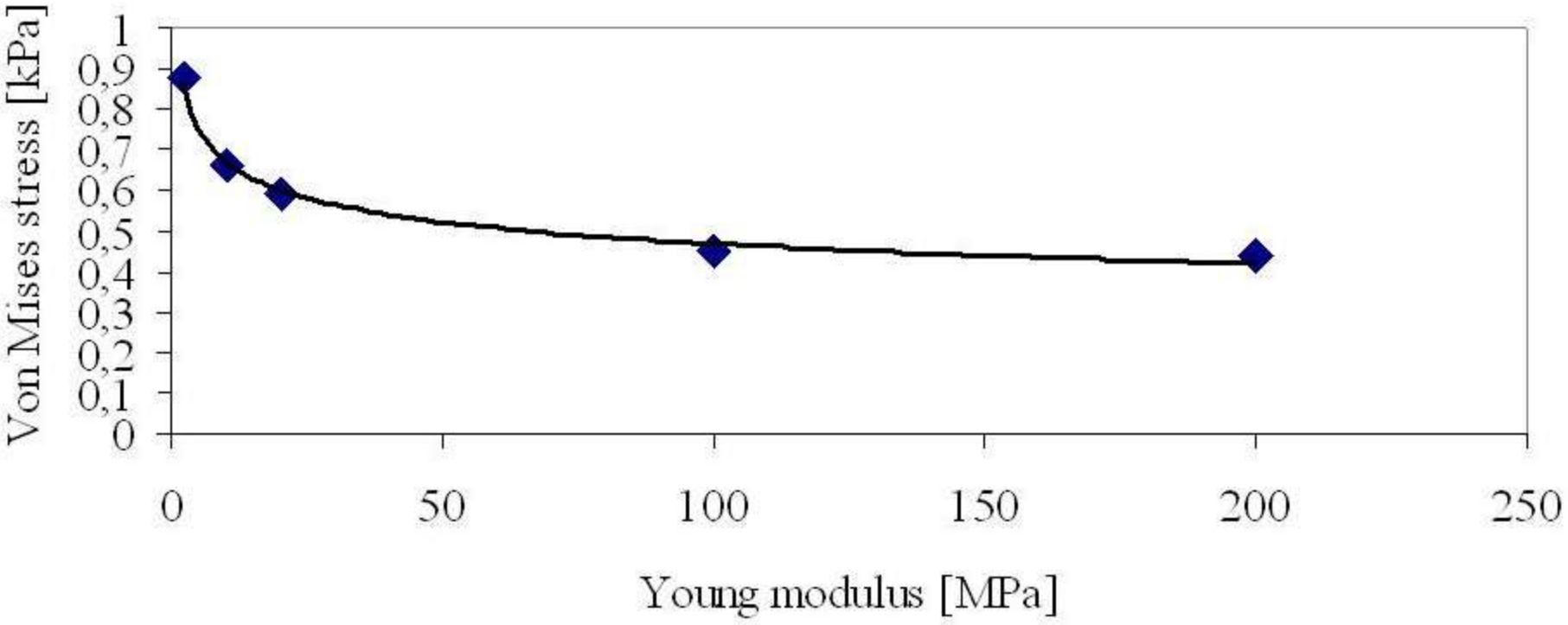


Brain/skull interface Young modulus, pressure and Von Mises stress

Variation
- 2 MPa to 200 MPa

Brain pressure → **112 kPa**

Brain Von Mises stress ↘ **Power**

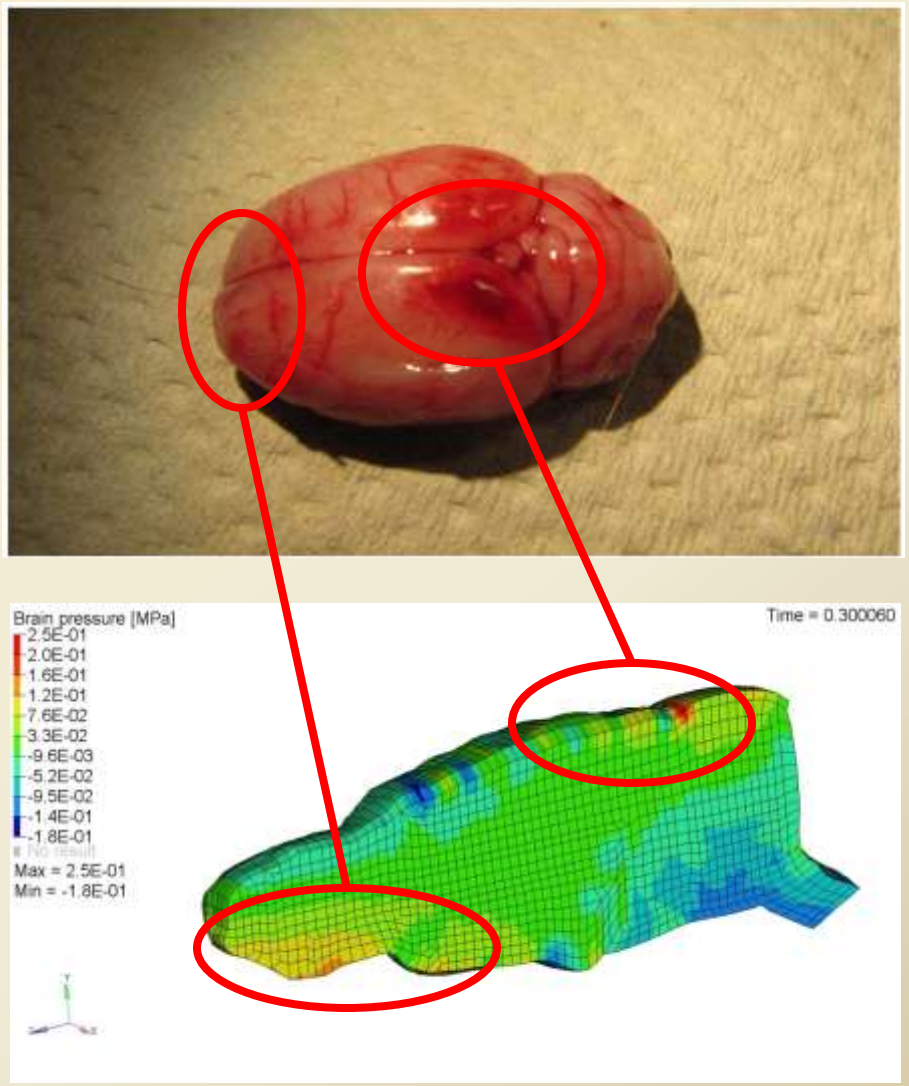


Comparison between observed and predicted injuries

Observed and predicted brain haemorrhages

Haemorrhages

- Superior cortex
- Vicinity of the olfactory bulb



Brain pressure

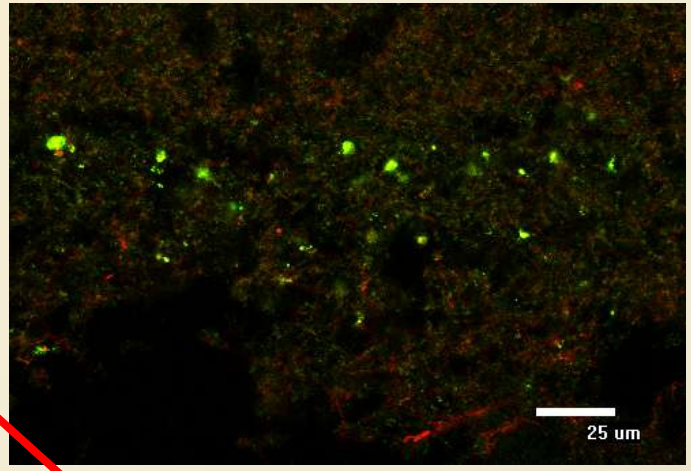
› 200 kPa

(Ward et al. 1980)

Observed and predicted diffuse brain injuries

Diffuse brain injuries

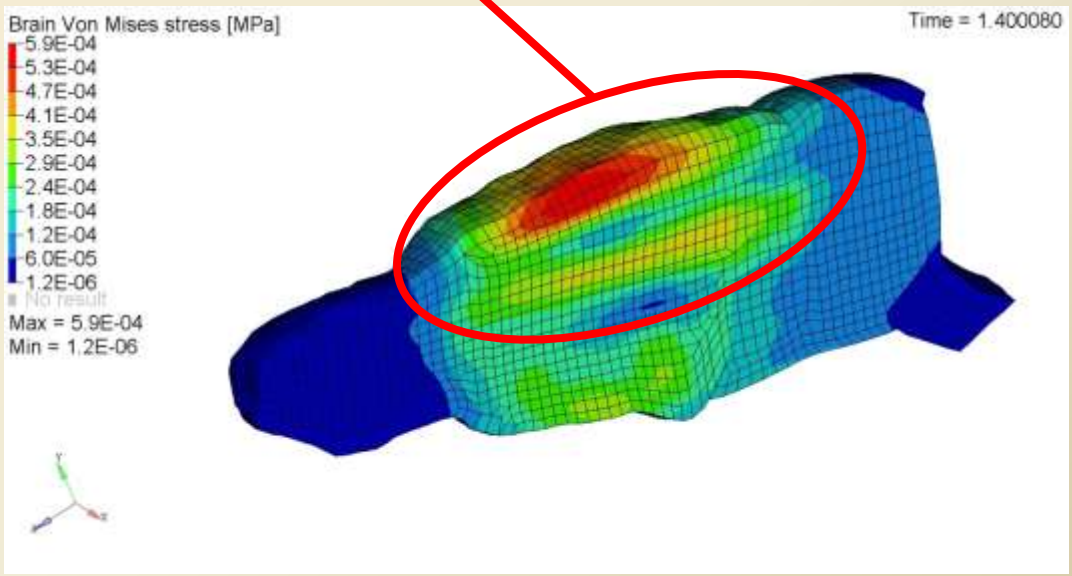
- Vicinity of the corpus callosum



Brain Von Mises stress

> 39 kPa

(Marjoux et al. 2008)



Conclusions, limits and perspectives

Conclusions

FEM of the rat's head developed

- Geometry inferred from MRI and Micro CT
- Mechanical behaviour inferred from litterature

Parametric study achieved on the FEM of the rat's head

- Brain pressure constant with several parameters
- Brain Von Mises stress sensitive to brain short term shear modulus, brain Bulk modulus and brain/skull interface Young modulus

Simulation of a set of experimental impacts on rats' heads from Davidsson et al. 2009

- Angular rotation of the rat's head in the sagittal plane

Comparison between observed and predicted injuries

- Good brain haemorrhages prediction thanks to brain pressure
- Good diffuse brain injuries prediction thanks to brain Von Mises stress

Limits and perspectives

Improvement of the mechanical behaviour of the anatomical components of the rat's head

- Density and stiffness variations of the brain
- Brain/skull interface mechanical behaviour

Improvement of the simulation data set

- New experimental impacts on rats' head
- Improved knowledge on the rat's head dynamical response

Validation of the FEM of the rat's head

- Measurement of any mechanical parameter in rat's brain during impact

Improvement of the injuries observation methods

Transfer of these results on the human's head

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