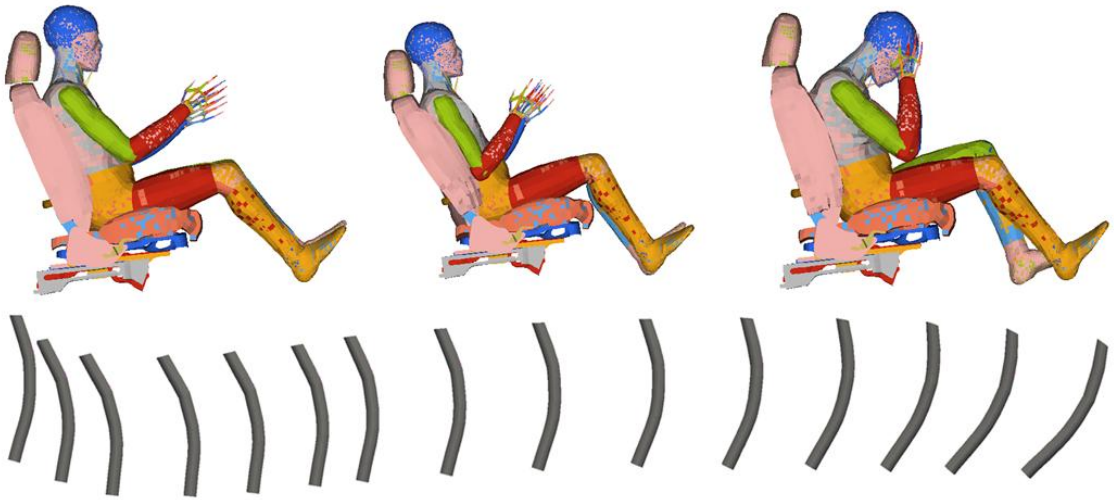
Modelling of Whiplash Trauma

Parametric study of rear-end impacts using FEM and CFD



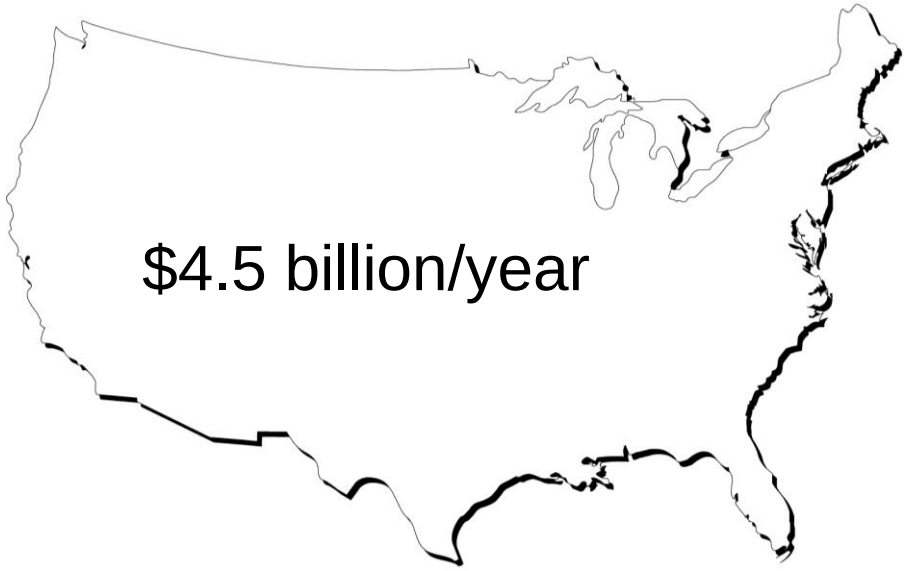
Andreu Oliver González
Mourya Vanama

Outline

- Introduction
- Objective
- Methodology
- Results
- Conclusions
- Future Scope

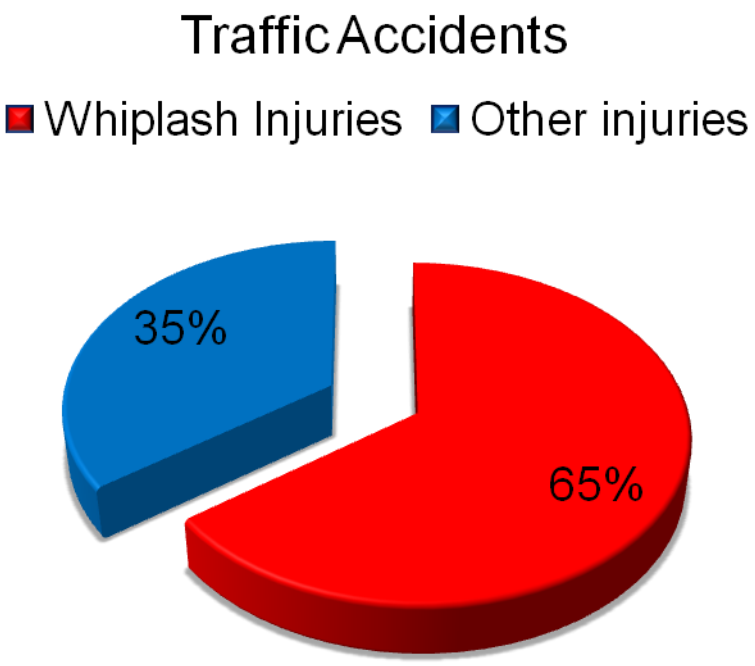
Introduction

Statistics – Whiplash Injuries



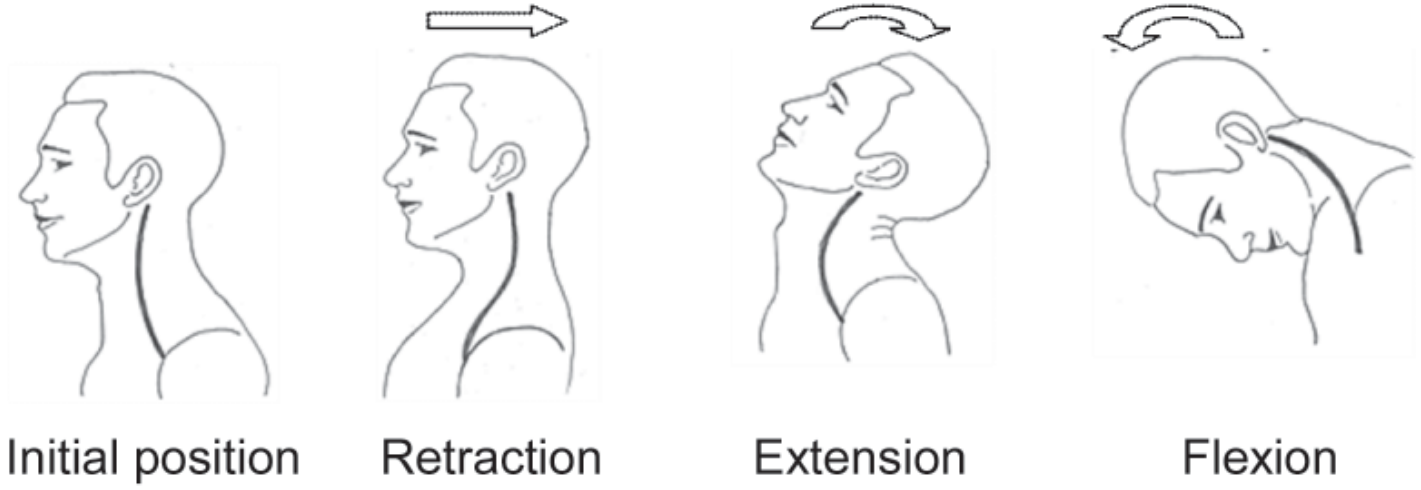
High cost to the society

Statistics – Whiplash Injuries

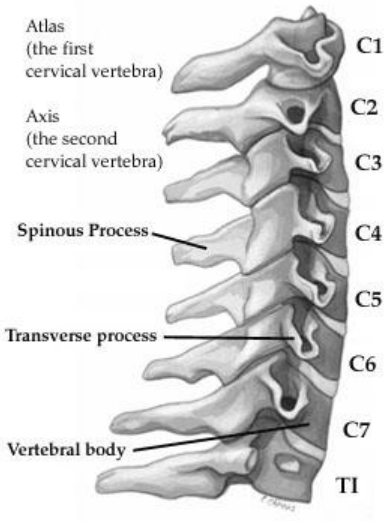


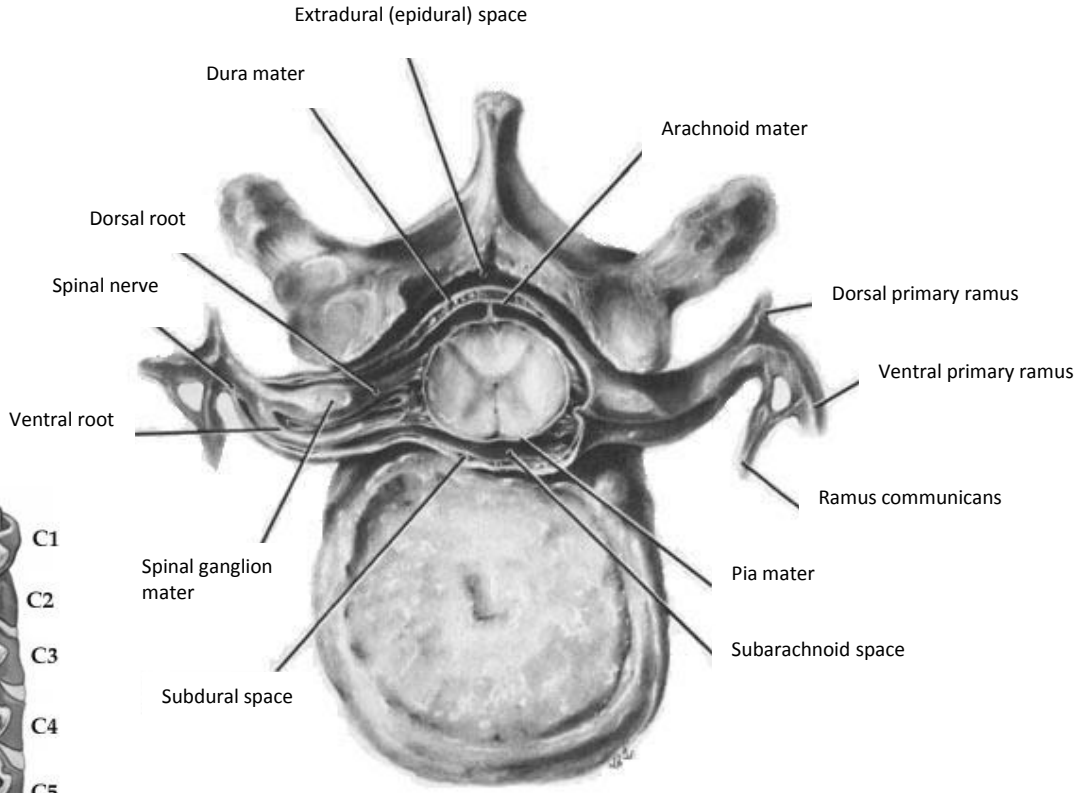
Whiplash Injury

- Hyper extension of the neck
- Low speed rear-end impacts (16-24 km/h)



Anatomy - Human Vertebral Column

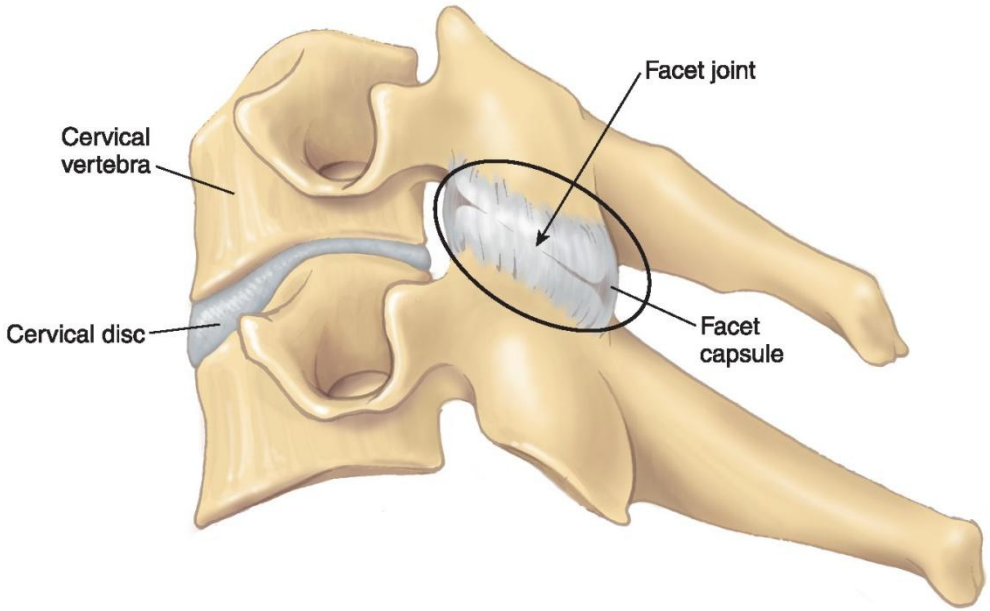


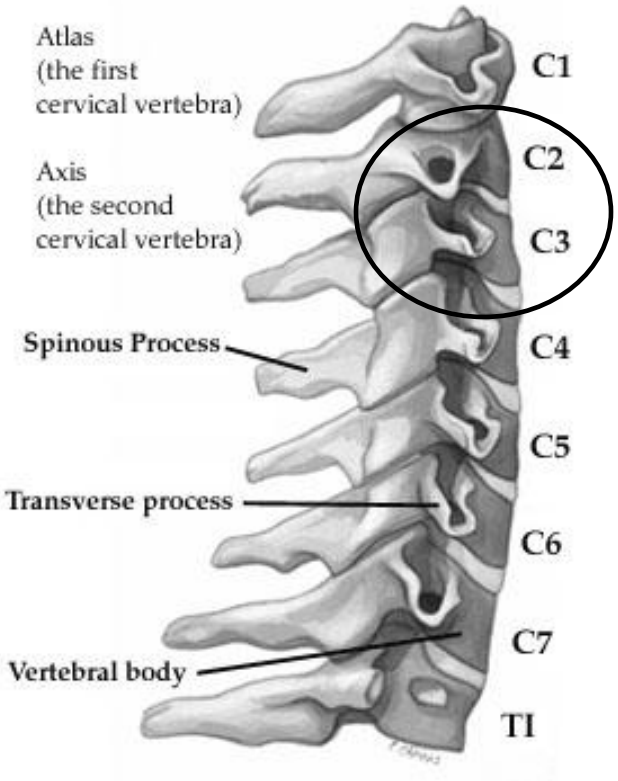


Injury Mechanisms

Facet Joint Capsule Strain

- Impingement of the capsule
- Strain due to deformation

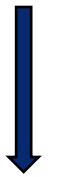




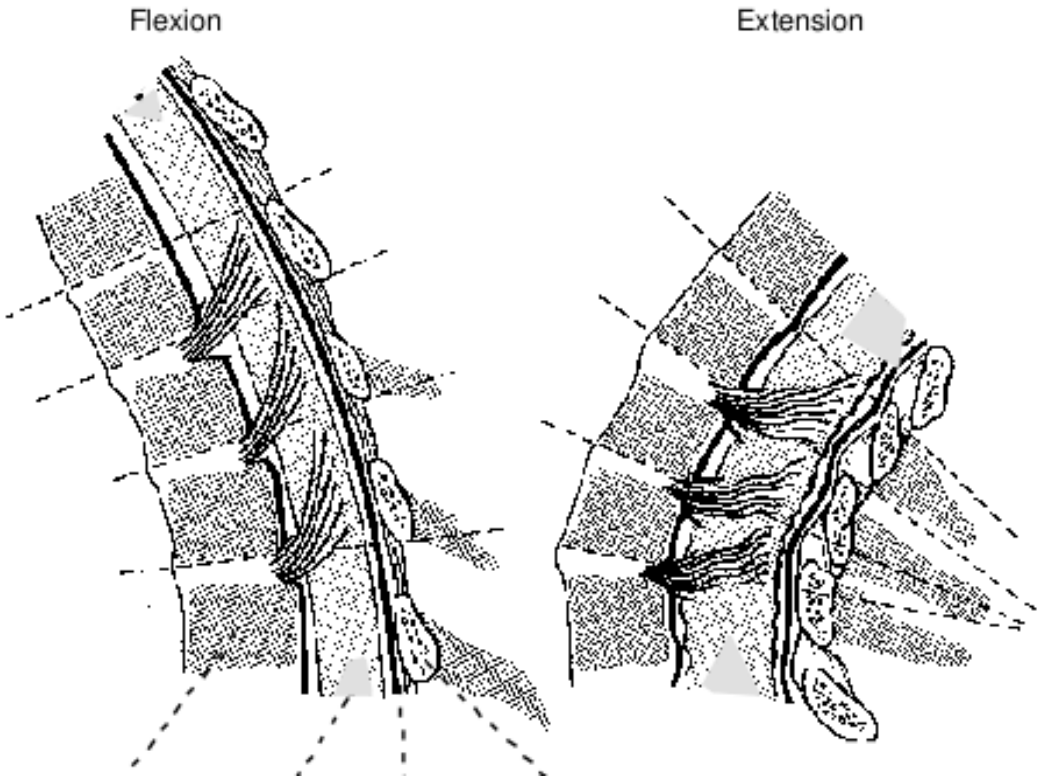
Injury Mechanisms

Pressure Gradients in Spinal Canal

Volume change



Pressure gradient



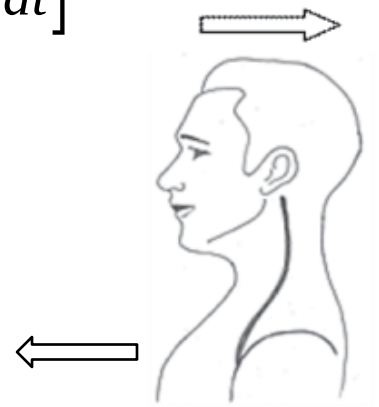
Injury Criterion

Neck Injury Criteria (NIC)

$$NIC = 0.2 \cdot (T_{1Accel} - Head_{CgAccel}) + \left[\int (T_{1Accel} - Head_{CgAccel})dt\right]^2$$

Calculated at maximum retraction phase

Critical limit of 15 m^2/s^2



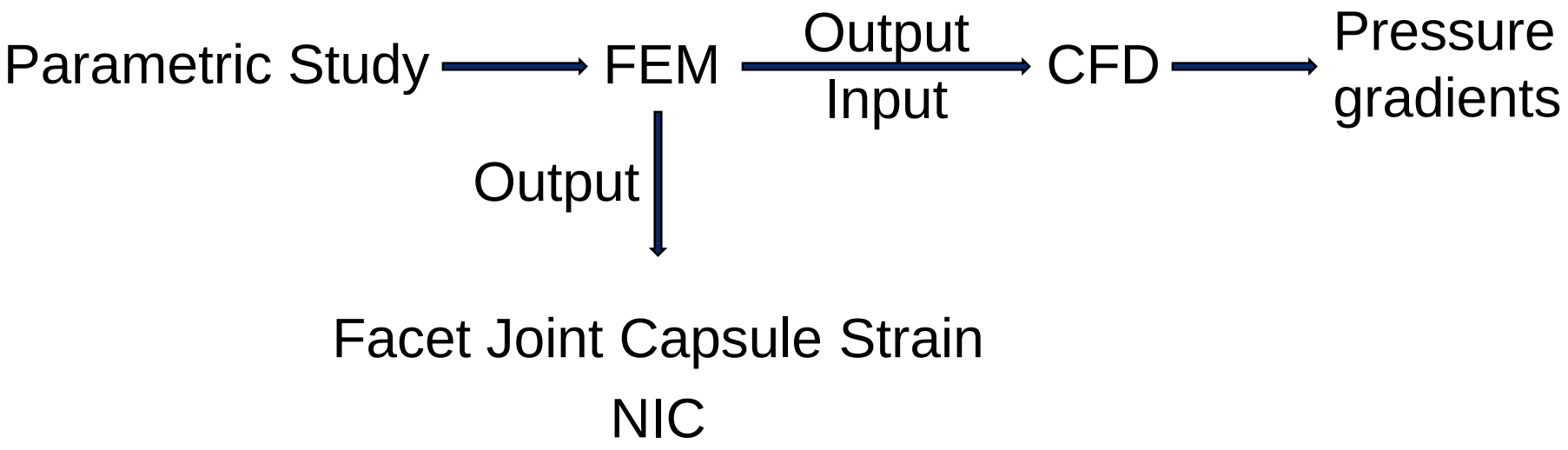
Objective

Investigate the effect of different parameters on:

- Facet joint loadings and NIC → FE simulations (LS-DYNA)
- Pressure gradients → CFD simulations (OpenFOAM)

Methodology

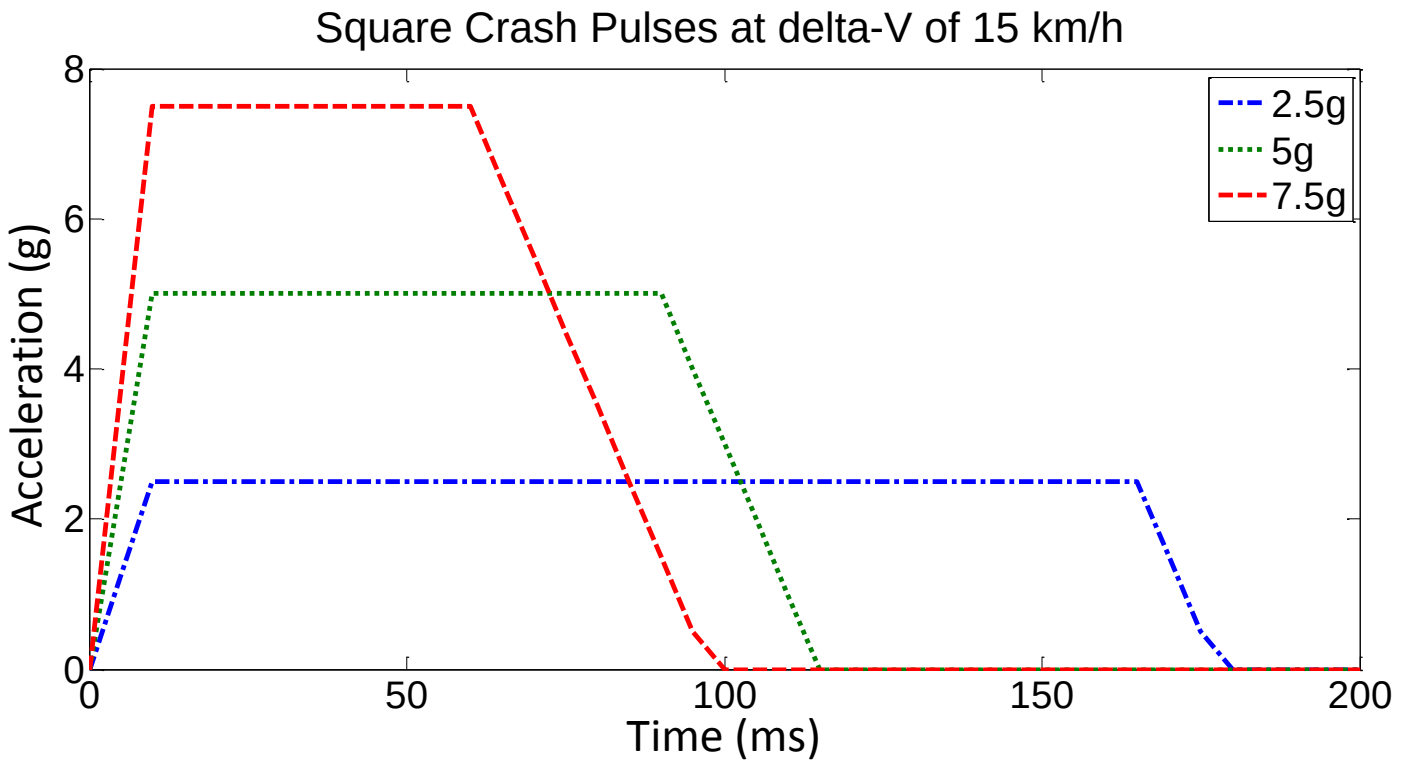
Procedure


Parametric Study
FEM
Output
Input
CFD
Pressure gradients
Output
Facet Joint Capsule Strain
NIC

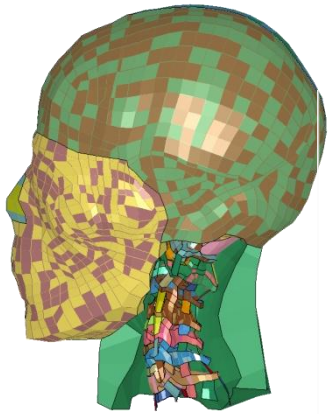
Parametric Study

Parametric Study

Crash pulses



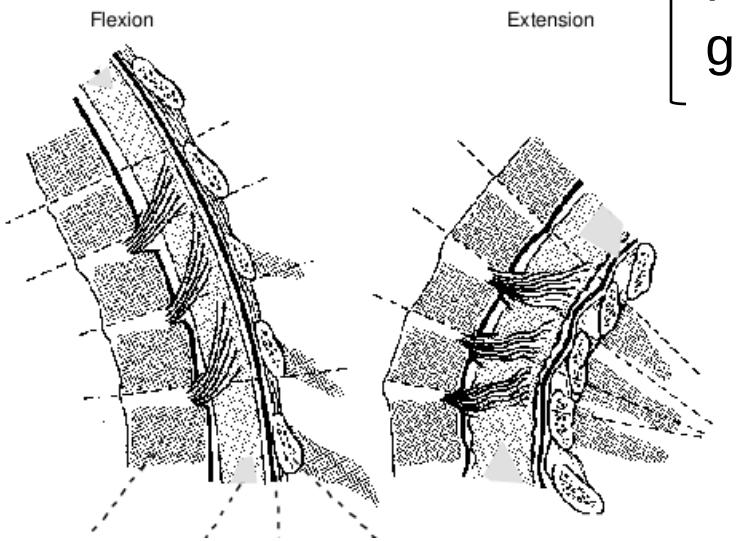
FE modelling



CFD

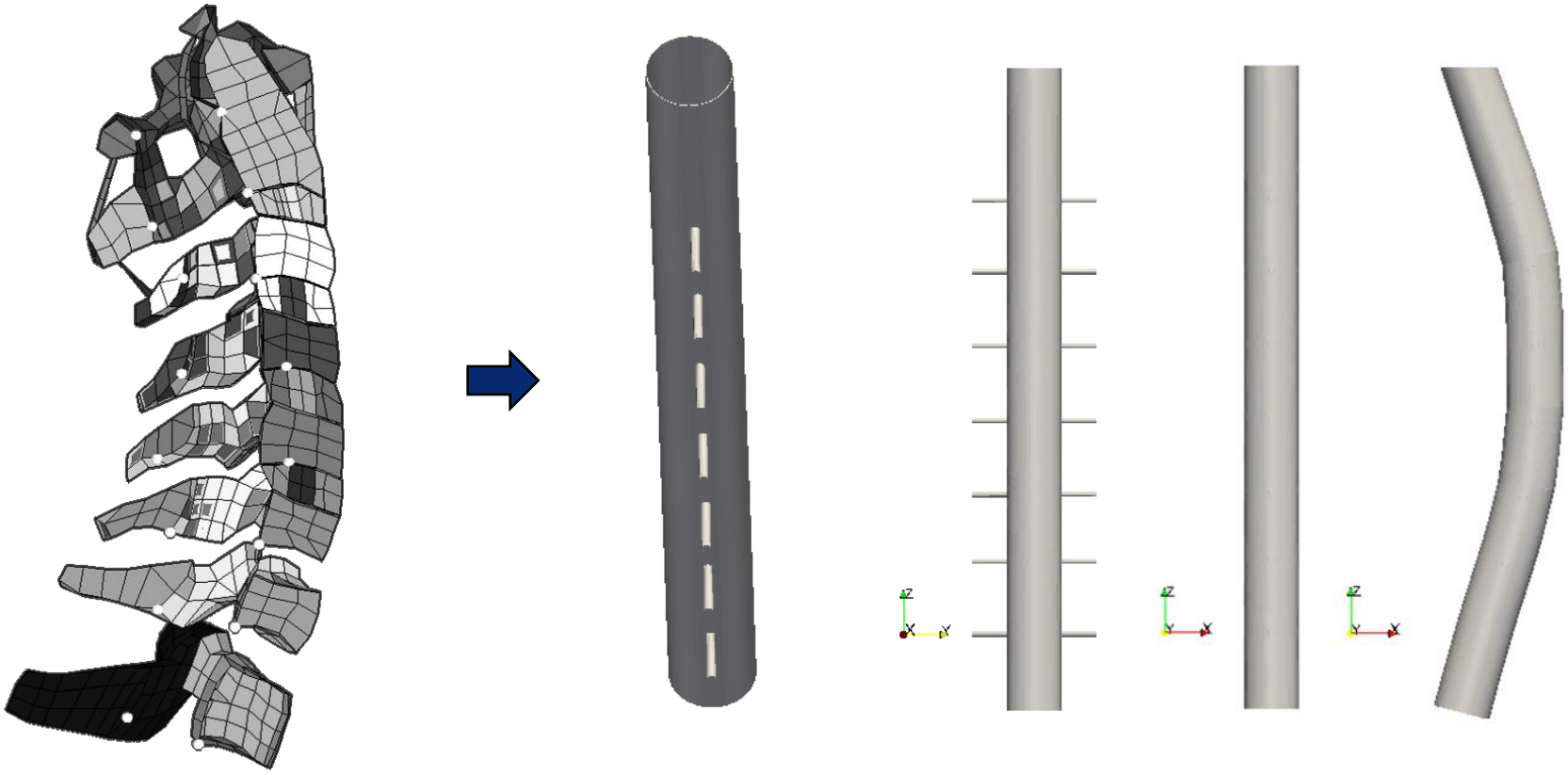
Theoretical model

Whiplash motion → Cervical spinal canal length change → Blood transportation / Pressure gradients → Model of the spinal venous plexus



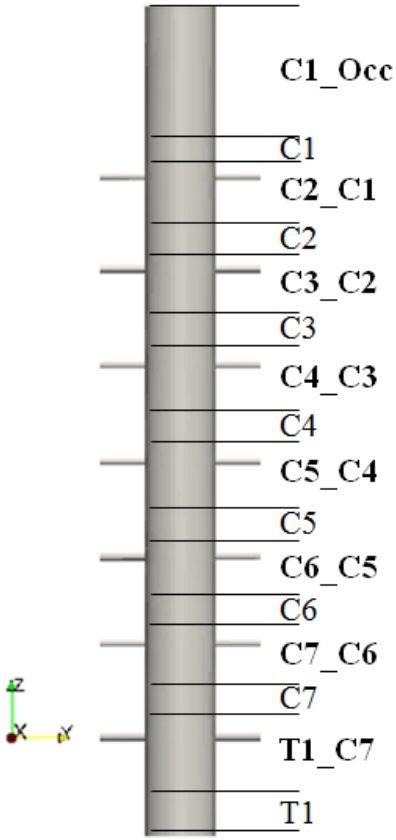
Geometrical model

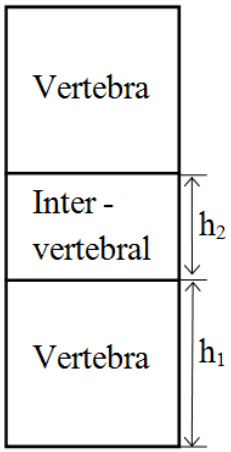
Spinal venous plexus modelled with respect to the THUMS

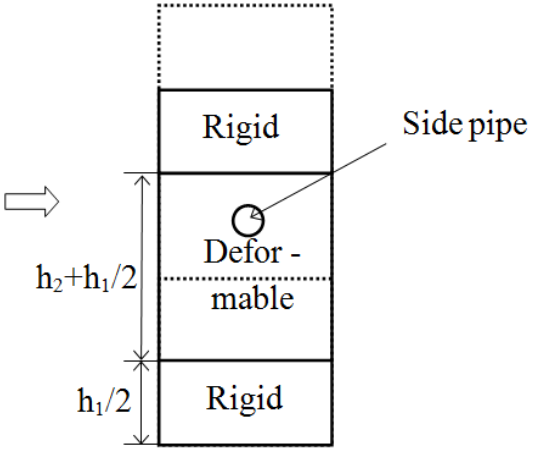


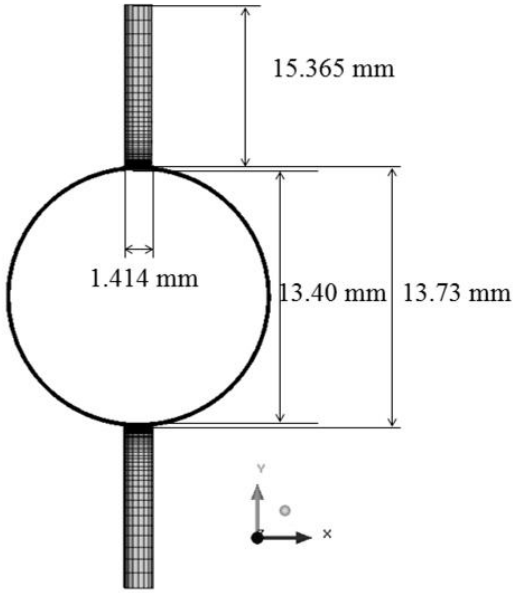
Geometrical model

Different zone heights and top view



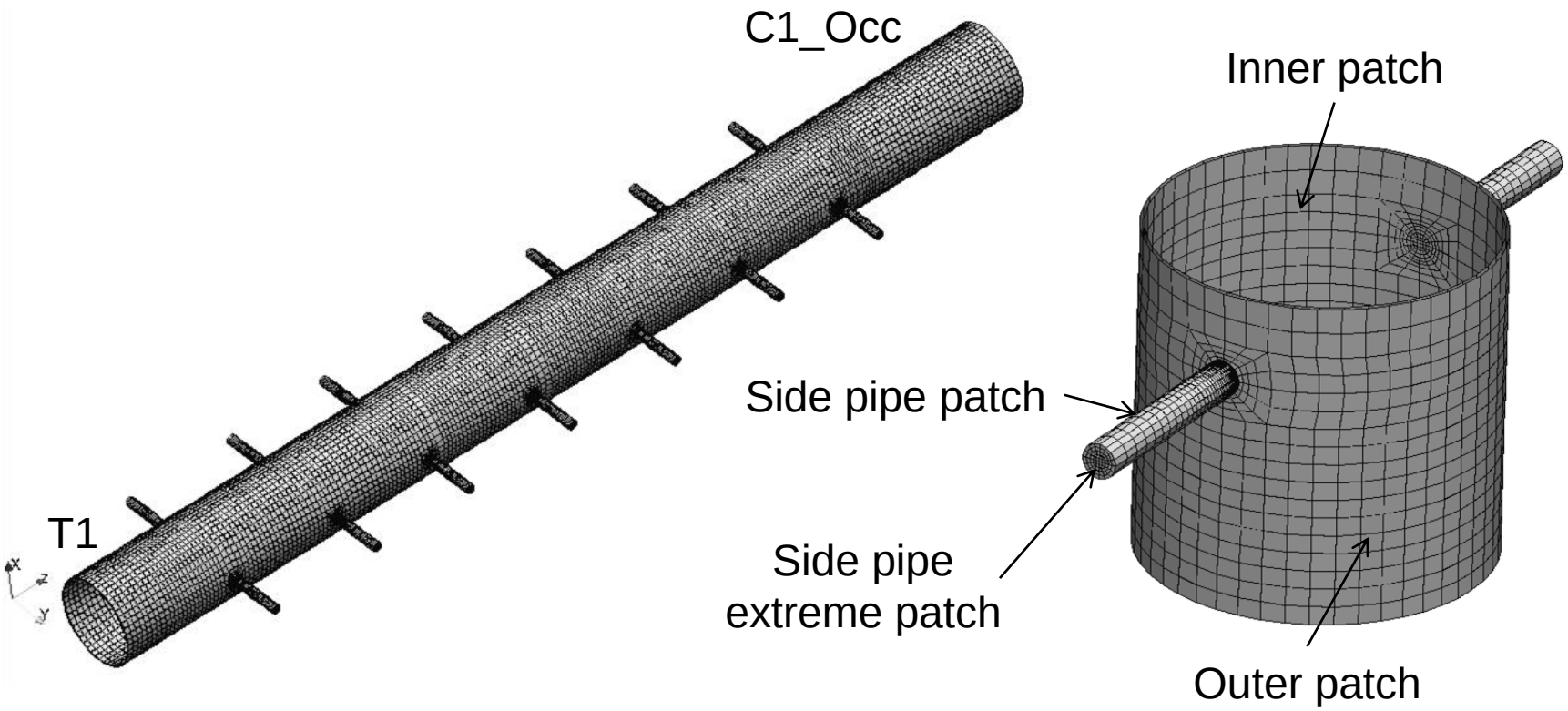




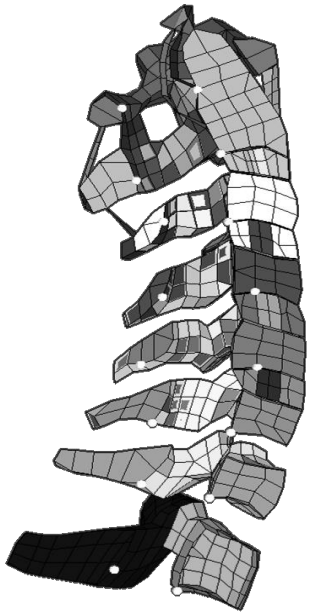


Geometrical model

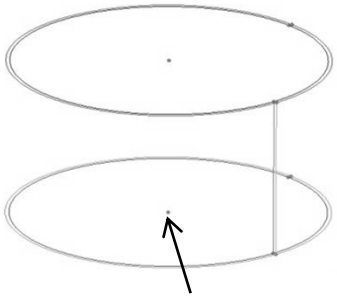
The mesh



Kinematic model



Inter-
polation



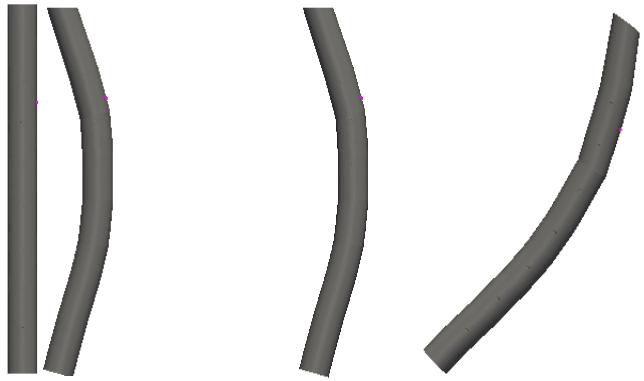
Representative
point

Input
data

- Reading and saving input data
- Cylinder motion
  - Rigid
  - Deformable

a) Rigid cylinders

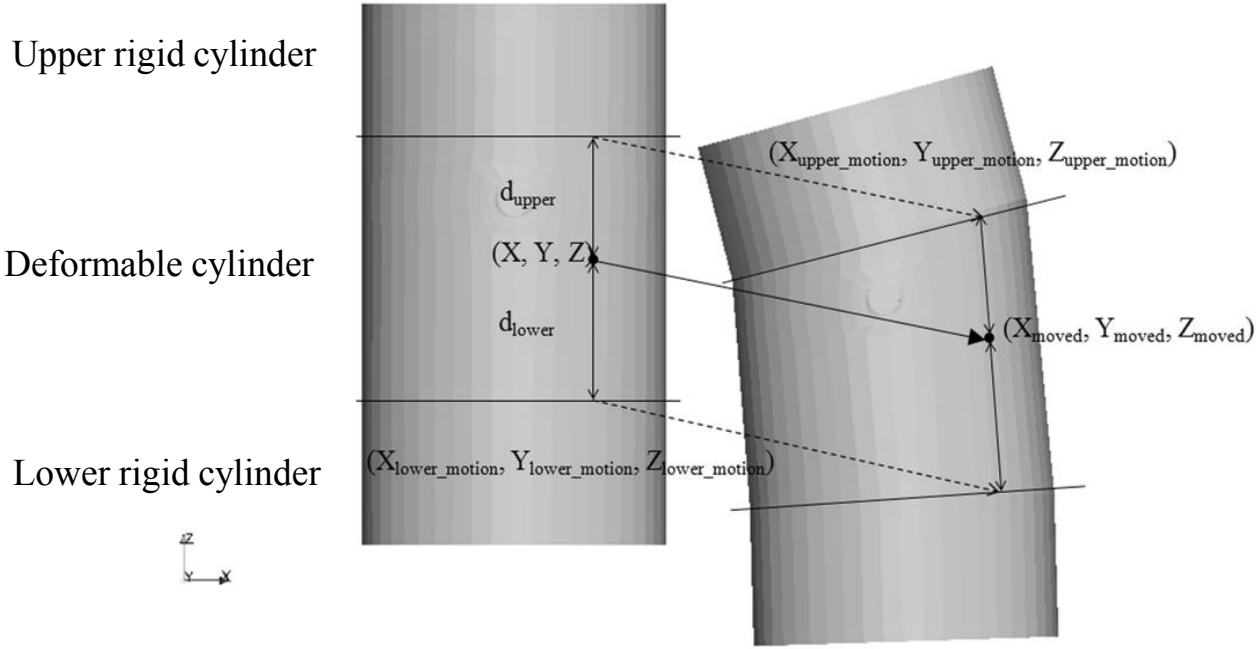
→ Extrapolation of the motion in two steps



Premotion Motion

b) Deformable cylinders

→ Interpolation of the rigid cylinders motion



Fluid dynamic properties

- Blood →
- Newtonian
- Laminar flow

Properties	Value
Density, [kg/m^3]	1050
Dynamic viscosity, [kg/ms]	0.0035
Kinematic viscosity, [m^2/s]	$3.33 \cdot 10^{-6}$

Boundary conditions

- Extremes of side pipes and main pipe → Inlet/Outlet
- The rest of the model → Wall

Solver

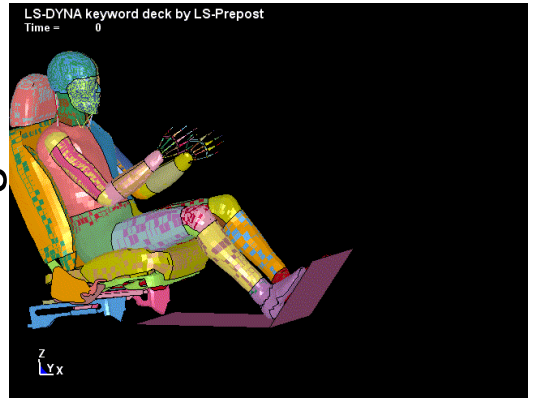
- For incompressible fluid based on PISO and SIMPLE

Results

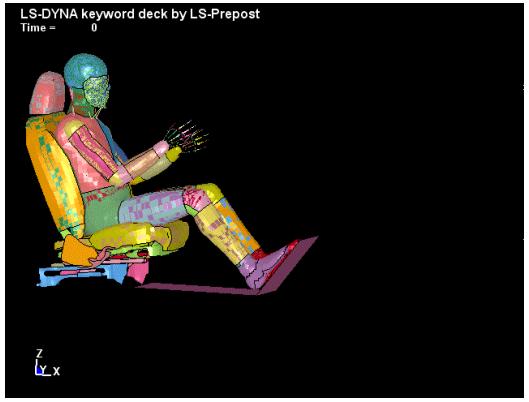
Motion

With head restraint

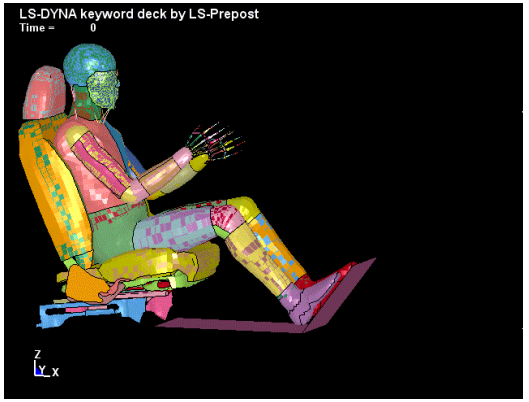
2.5g



5g

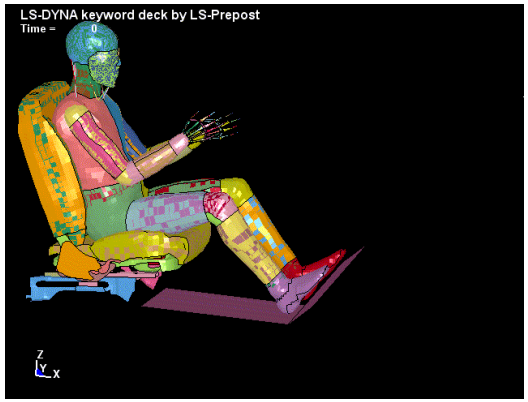


7.5g

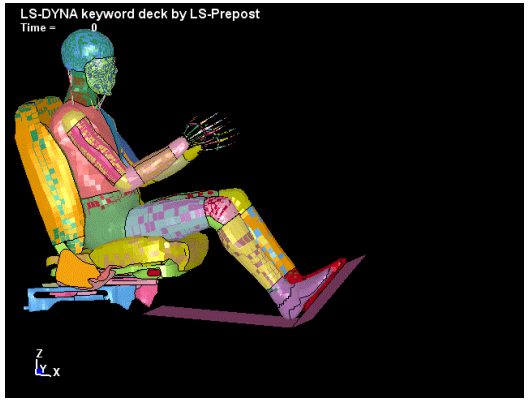


Without head restraint

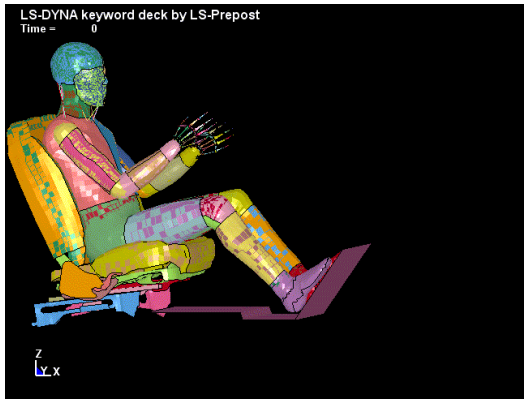
2.5g



5g



7.5g

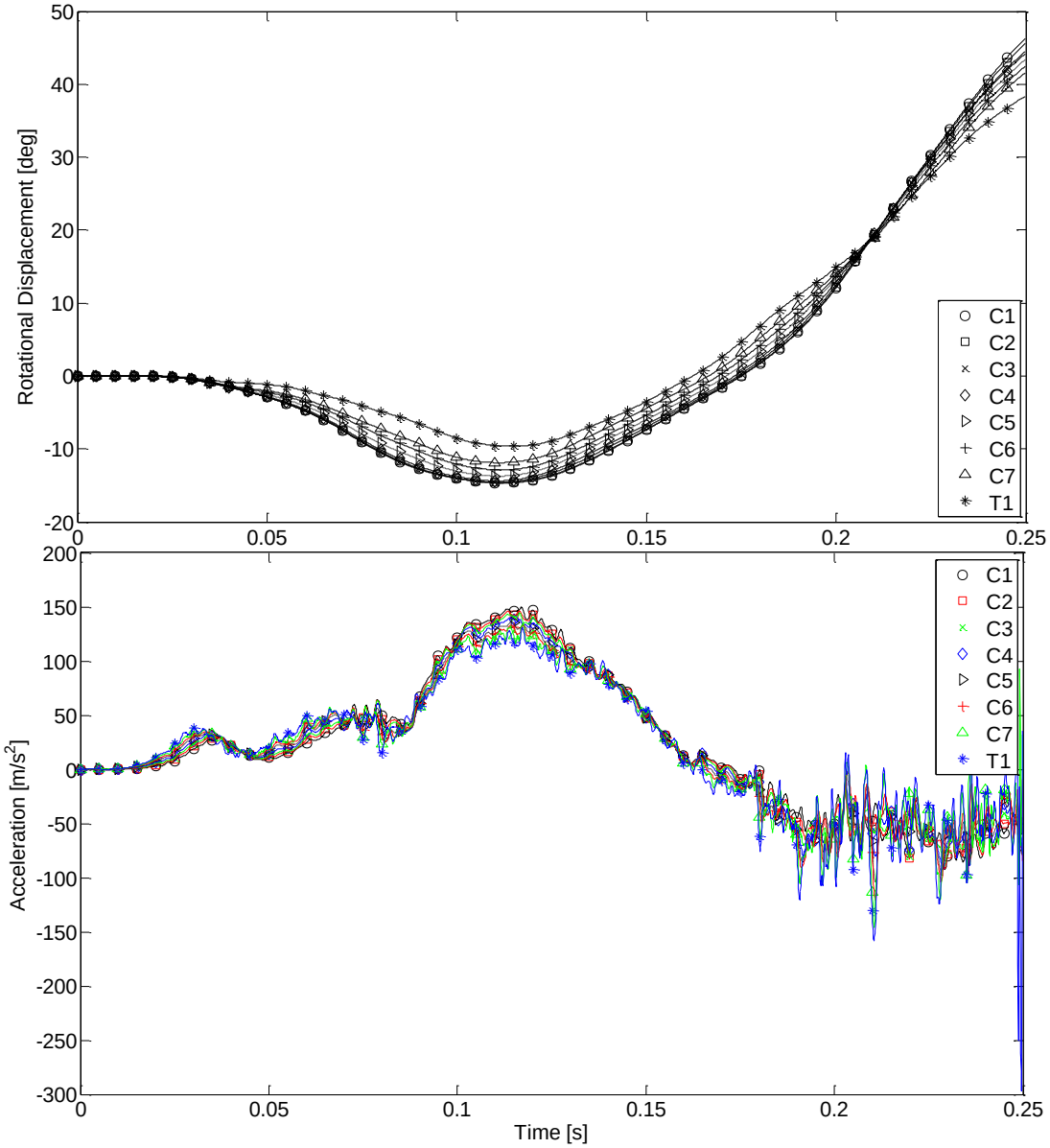


Motion

Rotational displacement around Y axis

Longitudinal acceleration

Max. Extension at 0.115 s



Motion verification

Position and shape of the blood vessels network
Simulation with 5g of acceleration pulse and head restraint

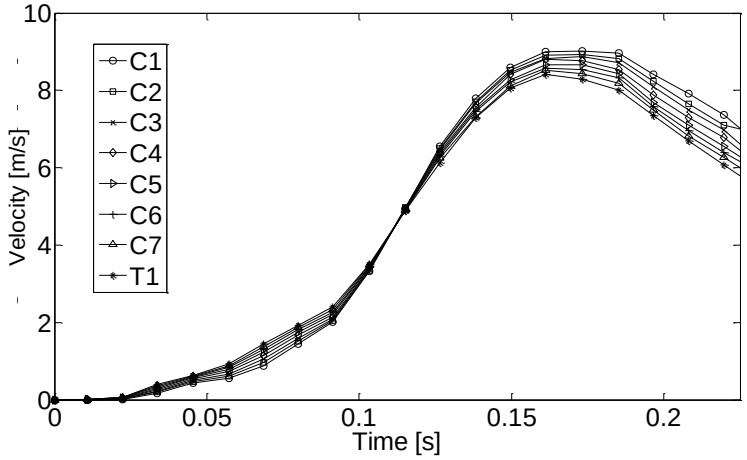
Time: 0.000000 s

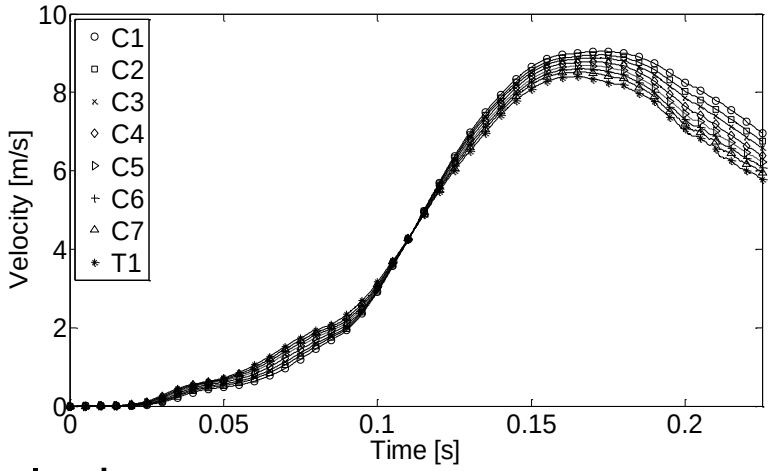
Andreu Oliver Gonzalez
OpenFOAM 1.5-dev

Motion verification

Longitudinal velocity

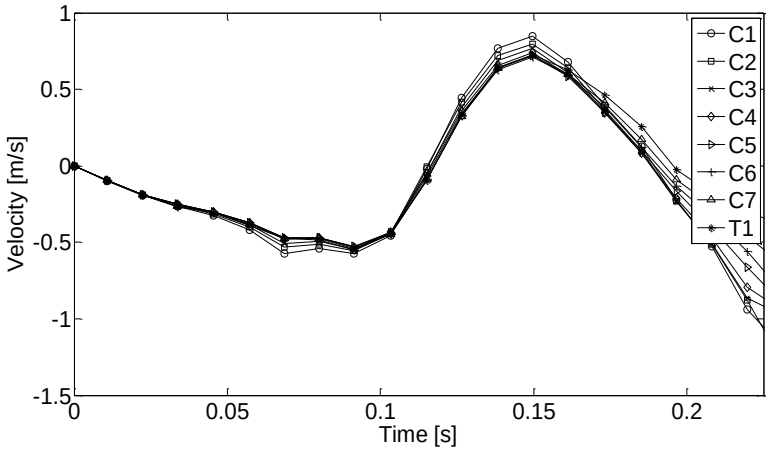
C
F
D

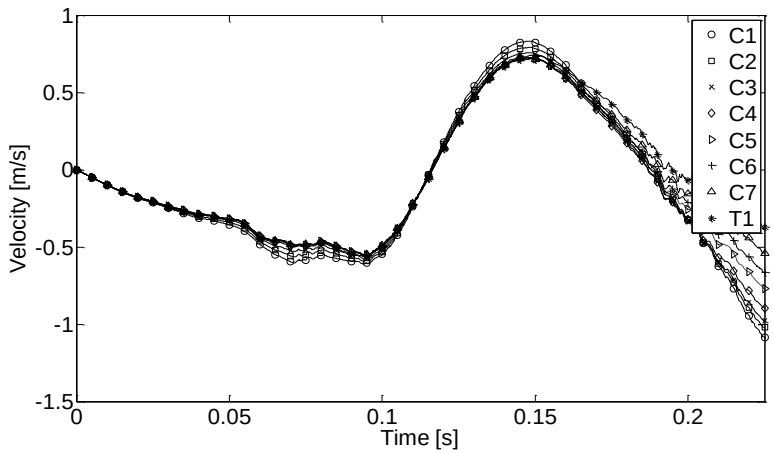




F
E
M

Vertical velocity

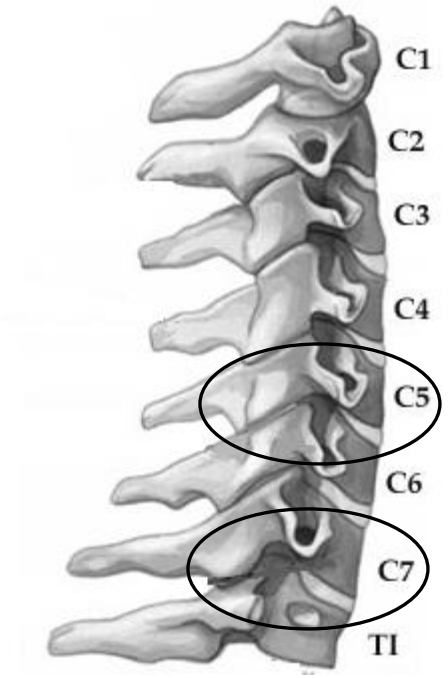




FE simulations

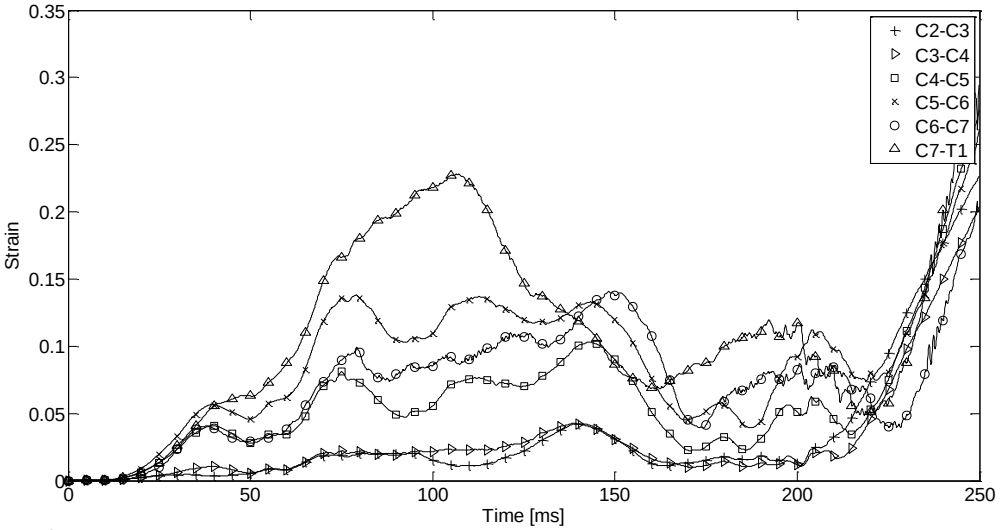
Facet Joint Strains

Acceleration Pulses	Strains (With Head Restraint)					
	C2 - C3	**C3 - C4**	**C4 - C5**	**C5 - C6**	**C6 - C7**	**C7 -T1**
2.5g	0.0342	0.0368	0.1309	0.2062	0.1883	**0.2151**
5g	0.2265	0.2037	0.2759	0.2612	0.2076	**0.2944**
7.5g	0.2893	0.2633	0.3482	0.3290	0.2843	**0.3763**
Strains (Without Head Restraint)						
2.5g	0.1715	0.1712	0.4301	**0.7561**	0.5989	0.5792
5g	0.4814	0.3383	0.5117	**0.9172**	0.6456	0.5791
7.5g	0.4029	0.3088	0.5132	**0.9236**	0.6067	**0.9326**

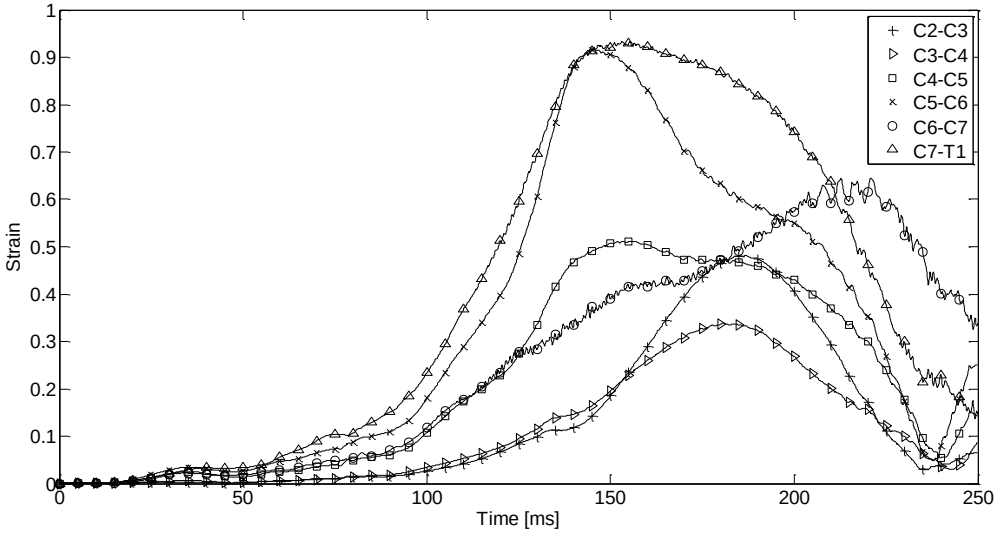


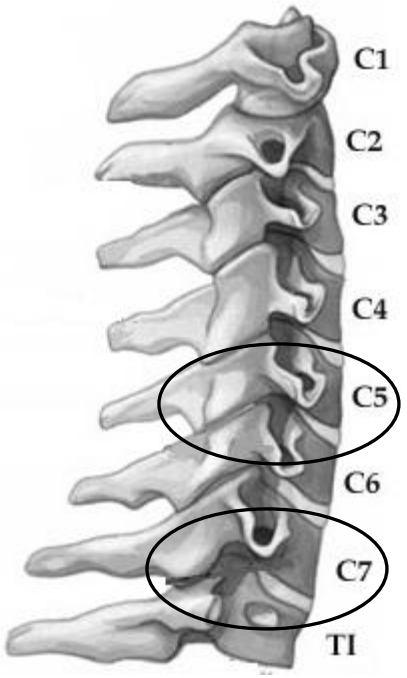
Facet Joint Strains - 5g

With head restraint

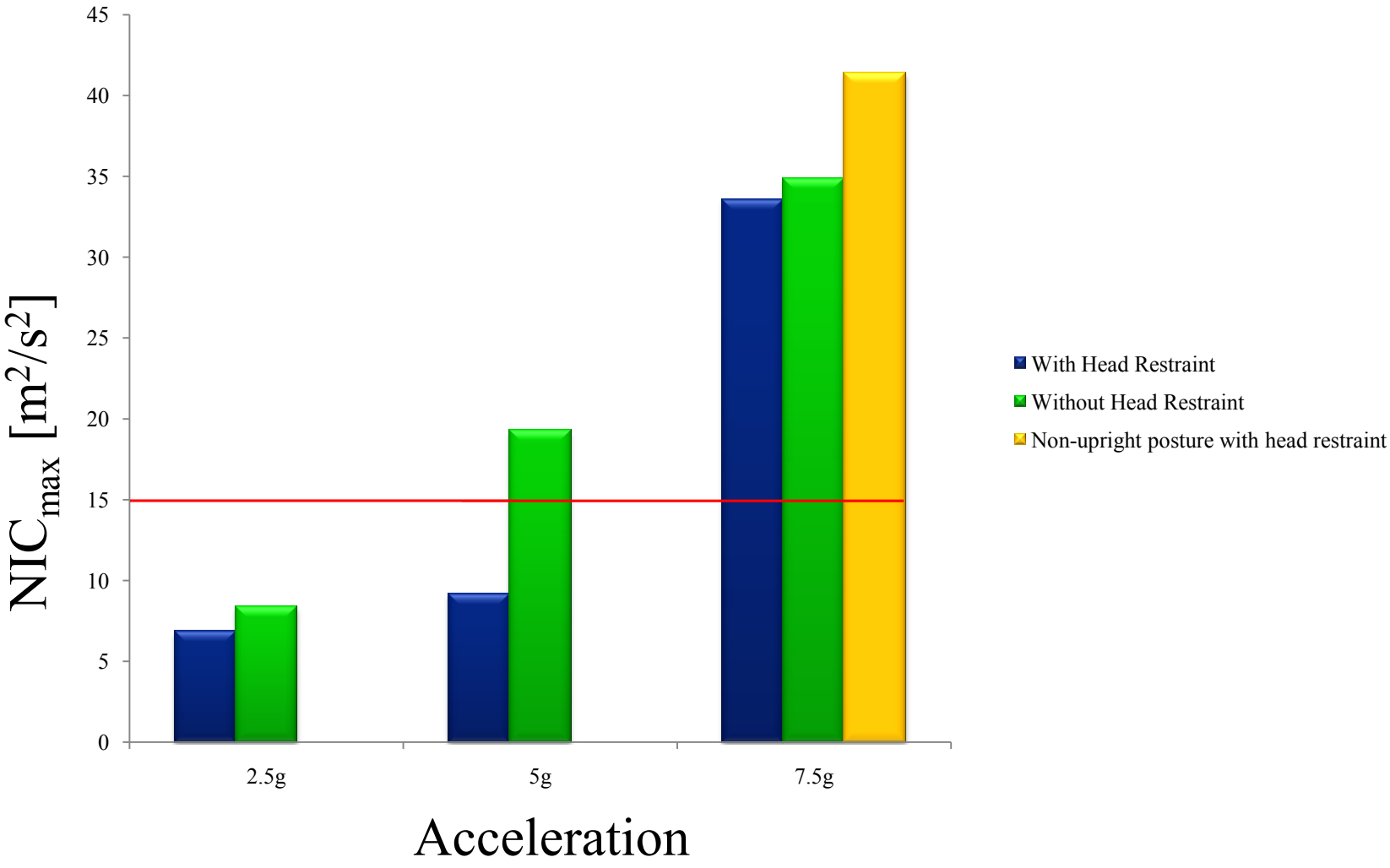


Without head restraint





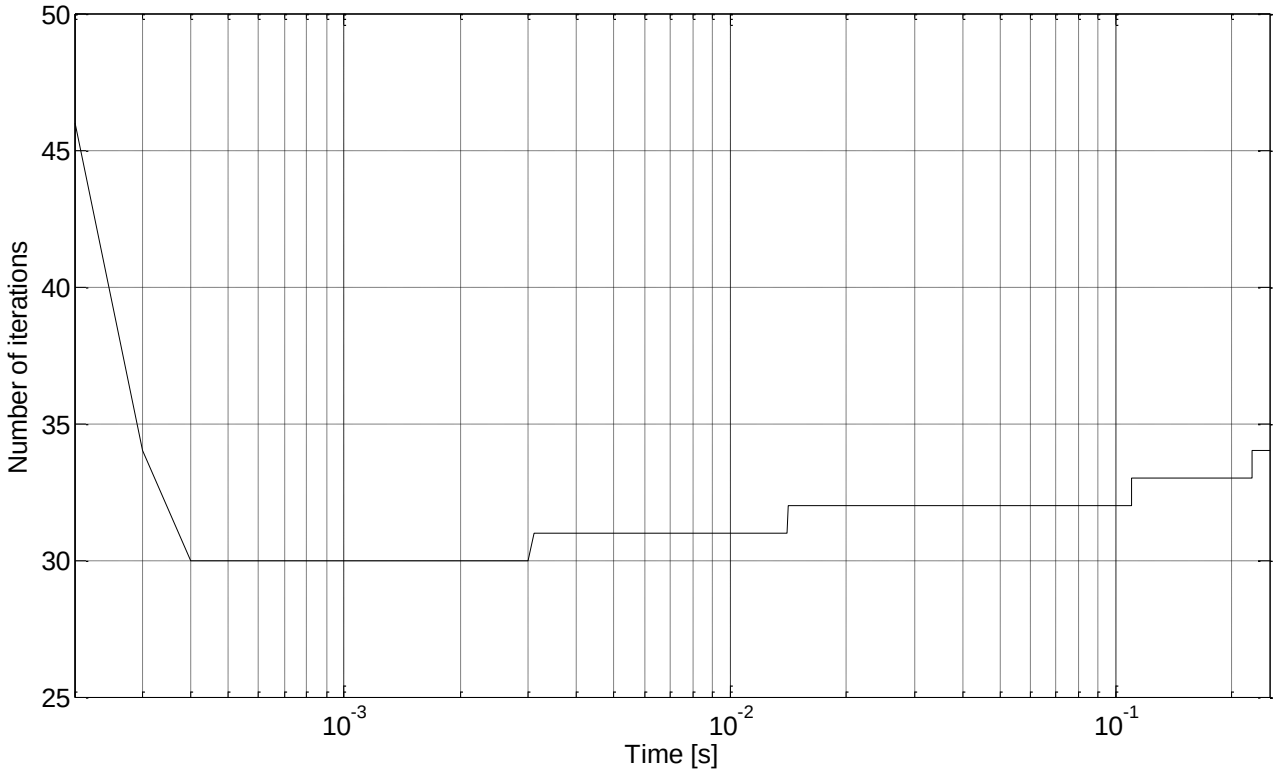
Neck Injury Criterion (NIC)



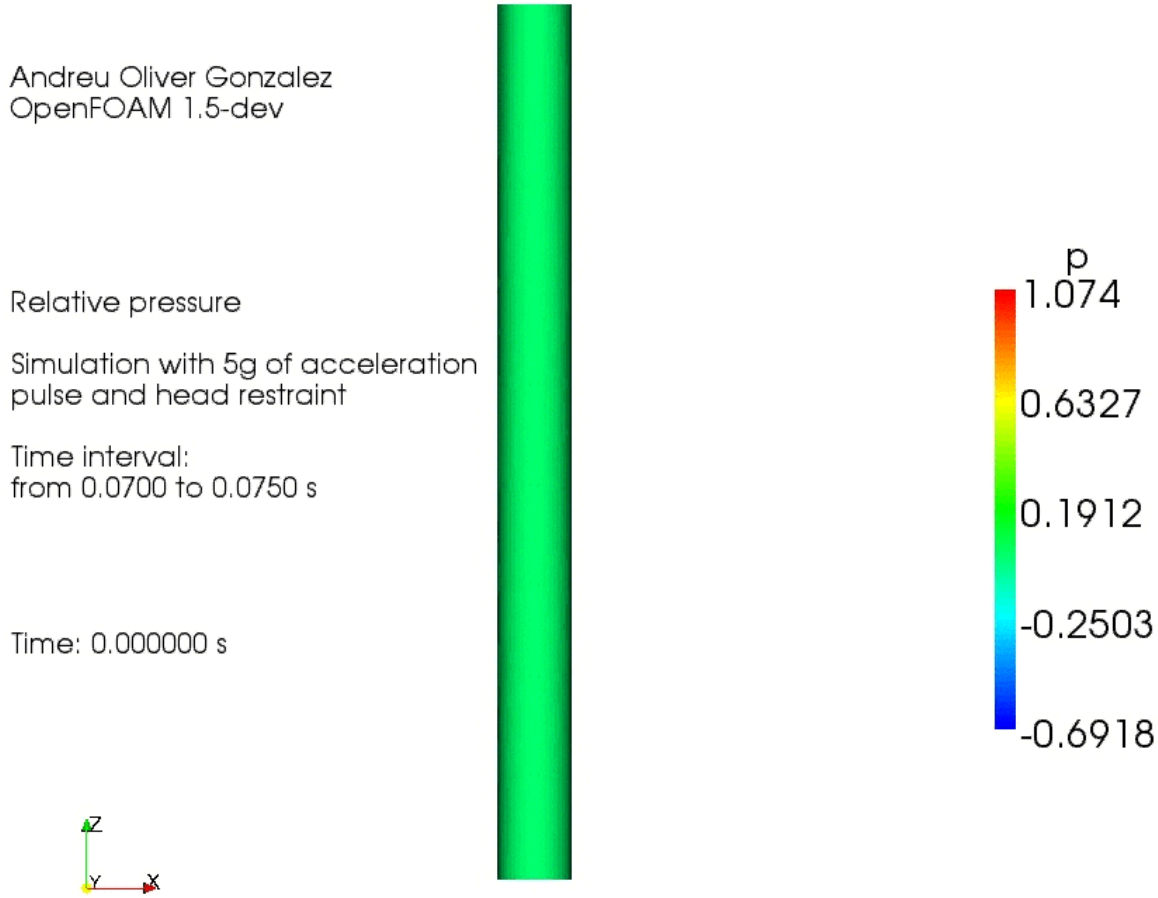
CFD simulations

Convergence

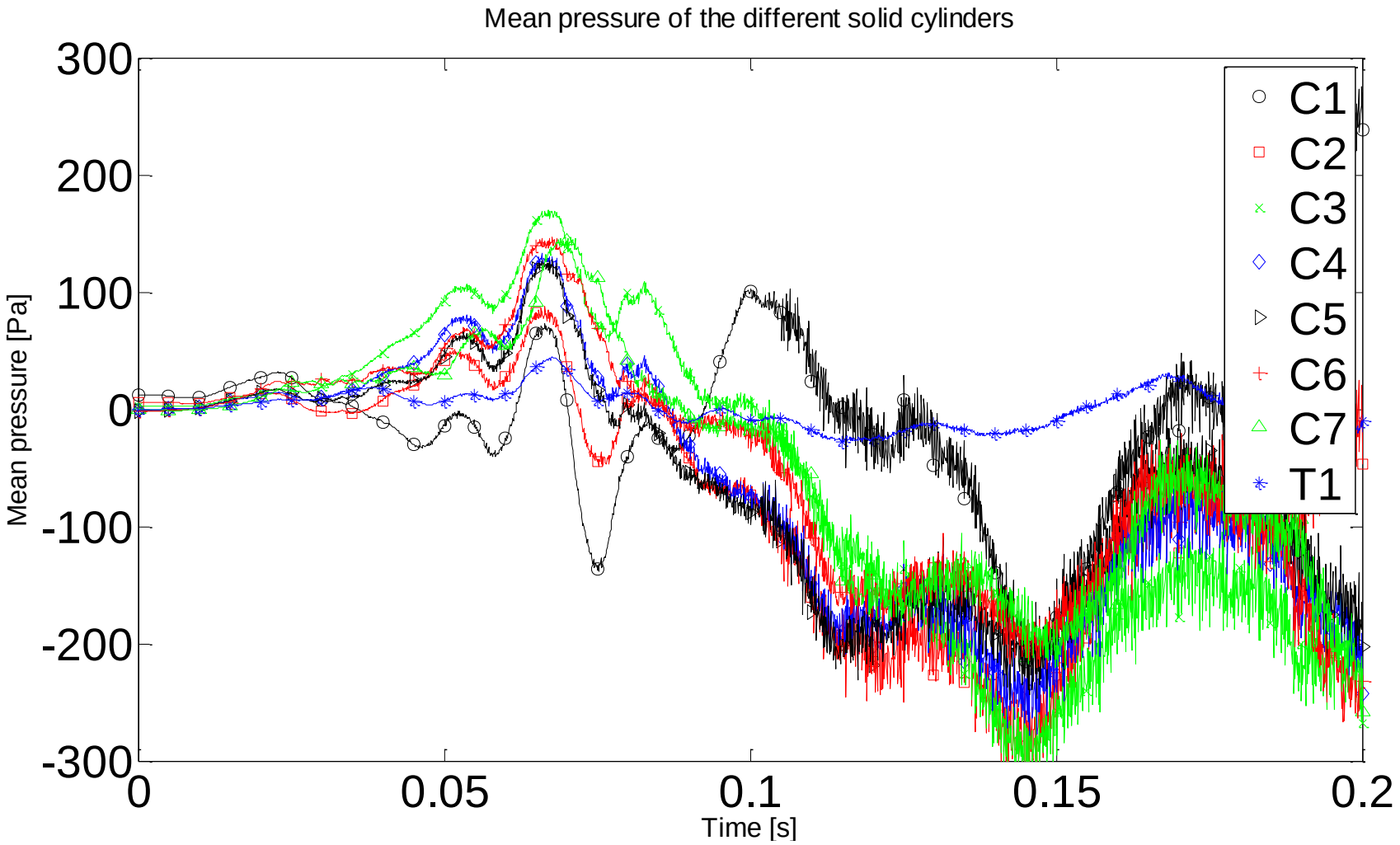
- All time steps should fully converge



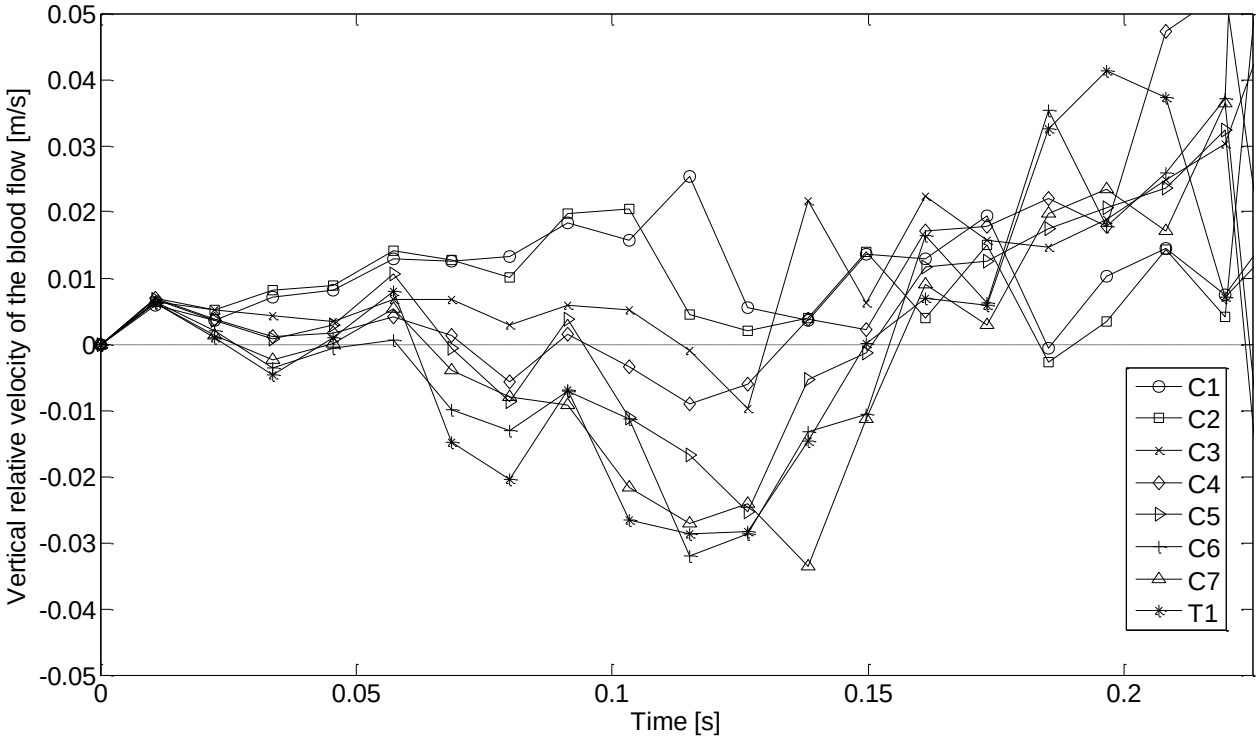
Behaviour of Pressure



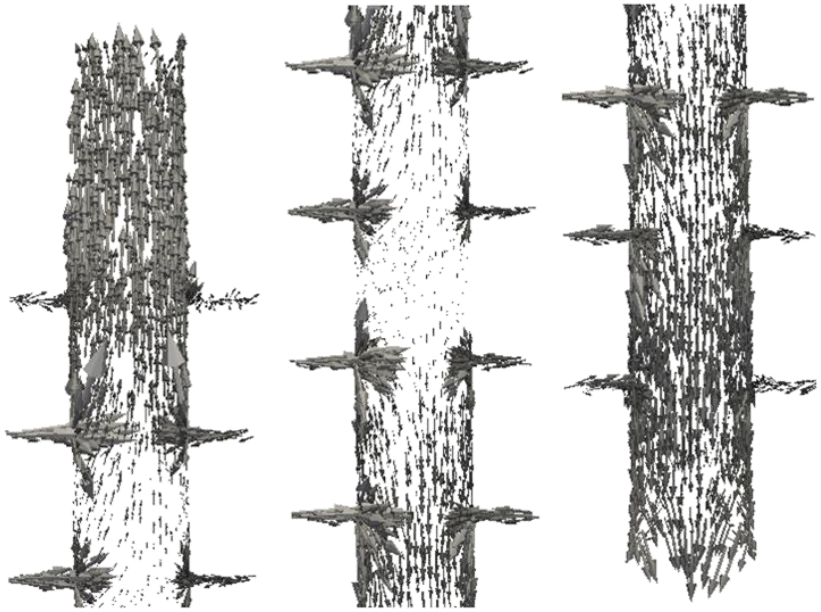
Behaviour of Pressure



Behaviour of Velocity

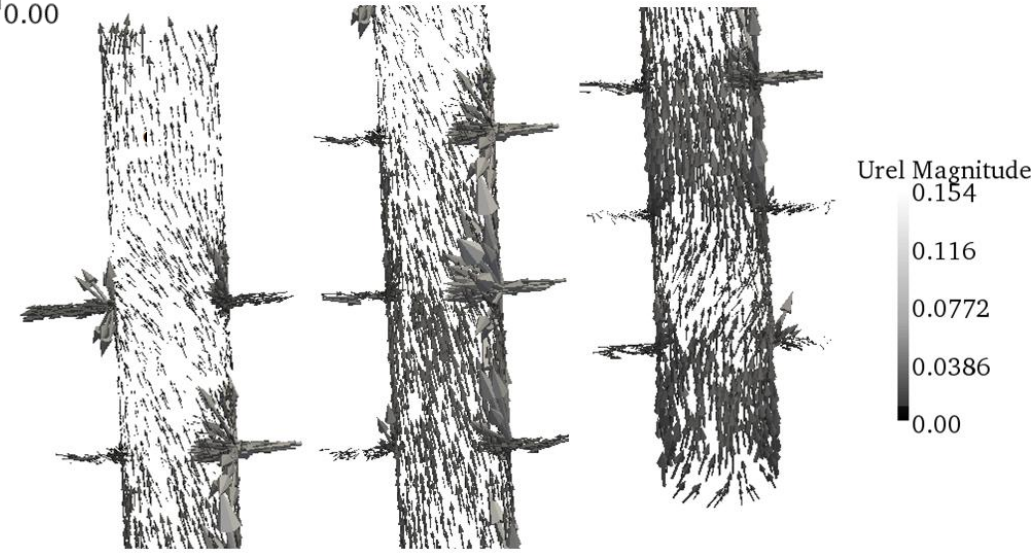


Behaviour of Velocity



t = 0.1209 s

t = 0.1897 s



Conclusions

- Head restraint
  - NIC ↓
  - Facet joint strains ↓
- Ford Taurus Seat – Underperforms for 7.5g
- The CFD solver should be based on SIMPLE algorithm

Future Scope

- FEM simulations
  - Broader parametric study
  - Physiological factors for male and female
  - Analysis of N_{km}
- CFD simulations
  - Consider blood compressibility and vein flexibility
  - Use geometry without hole
  - Include flow resistance when exiting the model
  - Deformation in radial and axial direction

THANK YOU FOR YOUR ATTENTION

Questions?