ARC Farside Meeting Update
Task 3: Carotid Artery

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Center for Injury Biomechanics

WAKE FOREST UNIVERSITY SCHOOL of MEDICINE THE BOWMAN GRAY CAMPUS

CIB

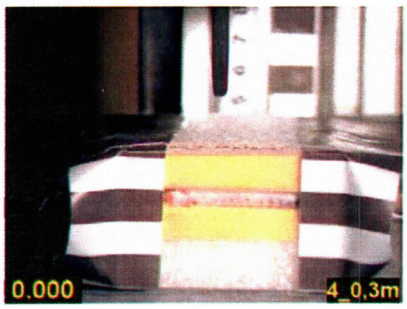
Virginia Tech COLLEGE of ENGINEERING

Review of January Meeting

- Introduced carotid artery material model
  - Direct data fit model
  - 1-D strip test
- Began work of integrating with THUMS
- Group input:
  - Simulation of the "sausage test"
  - Expanded carotid artery stress and strain dataset from MCW

Background on Modeling the "Sausage Test"

- Pressurized porcine carotid arteries
  - Impinged from various heights
- Data from experiment
  - Video of drop
  - Percent injury based on drop height
  - Material information
- Data from previous research
  - Carotid model



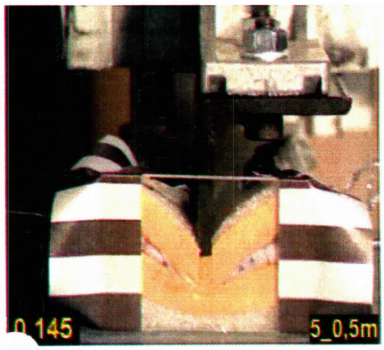
Guillotine Experiment Results

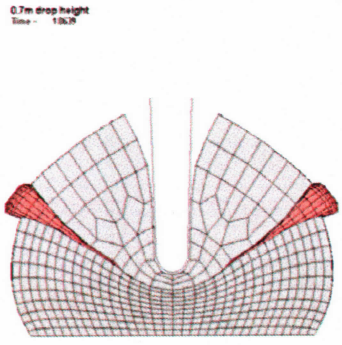
Shape	Height	Number of tests	Injury Frequency	Comment
5 mm	0,3m	2	0%	
5 mm	0,5m	4	25%	
5 mm	0,7m	4	100%	
5 mm	0,7m*	2	0%	Static
19 mm	0,5-1,5m	3	0%	
19 mm	1,7m	4	25%	
35 mm	0,5-1,3m	6	0%	
36 mm	1,7m	4	25%	

Used to develop FE model

*same intrusion as 0.7m tests

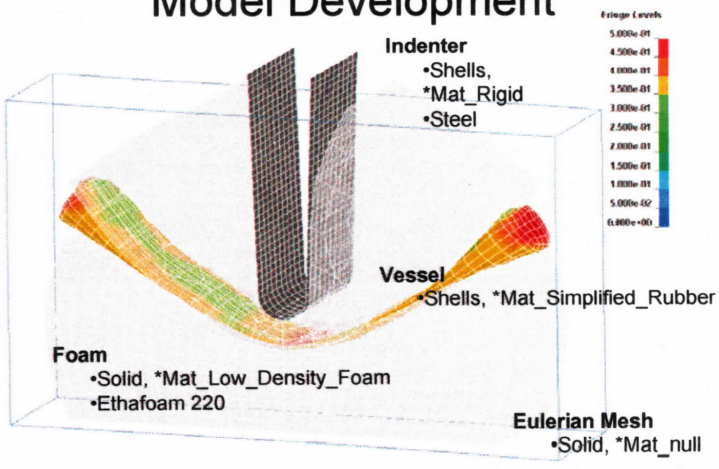
Model Development





- Mesh built from video of impact test

Model Development

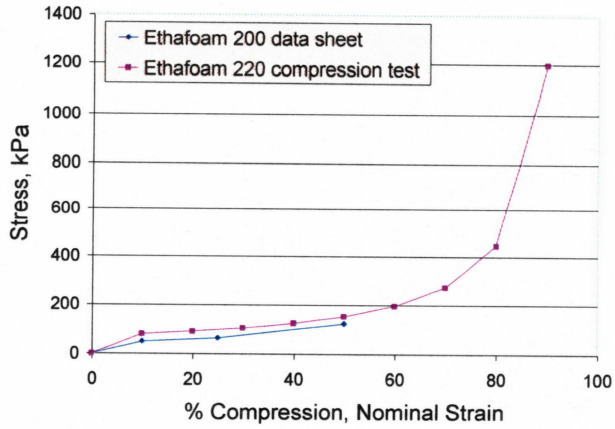


Foam Material Model Summary

- *MAT_low_density_foam
  - Direct curve fit model
- Solid elements
- Use **load curve** to define nominal stress strain curve
- DAMP –Viscous coefficient to model damping

ρ	$36x10^{-6}$	g/mm^3
E	0.236	MPa, $[N/mm^2]$
DAMP	0.5	

Material Model - Foam

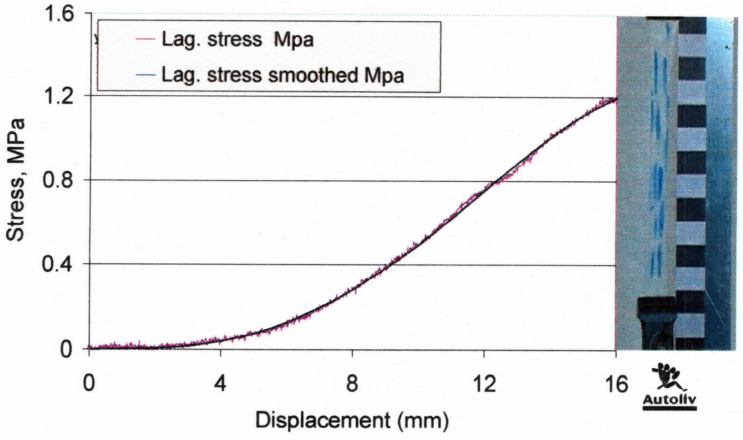


Material model summary

- *MAT_simplified_rubber
  - Direct curve fit model
- Shell elements
- Model is robust
  - Parameter study
  - Mesh density study
- Strain rate effects and damage can be incorporated
  - Enter curves at discrete strain rates
  - Damage function can be implemented

ρ	0.001	g/mm^3
K	2610	MPa, $[N/mm^2]$
G	5.2	MPa, $[N/mm^2]$
SIGF	5.2	kPa, $[N/mm^2]$
HG	Stiffness	

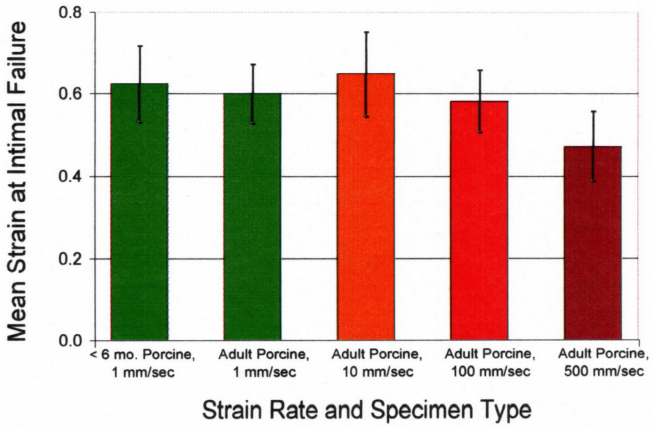
Material Model - Artery



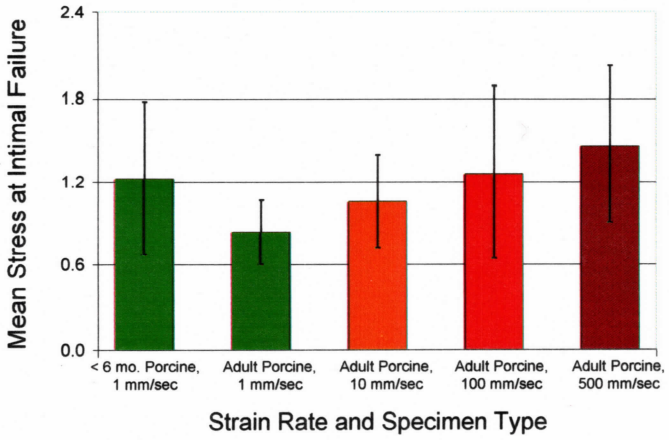
Expanded Carotid Artery Dataset

- Young porcine descending aorta samples
  - Aged < 6mo.
  - 1mm/sec
- Adult porcine descending aorta samples
  - 1mm/sec
  - 10mm/sec
  - 100mm/sec
  - 500mm/sec

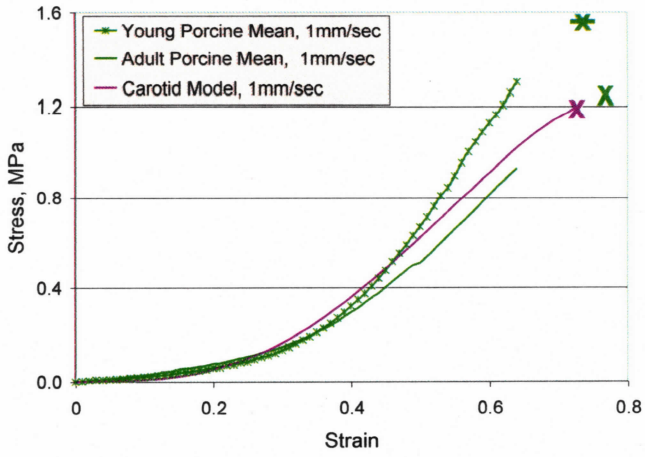
Results – Loading Rate Experiments (MCW)



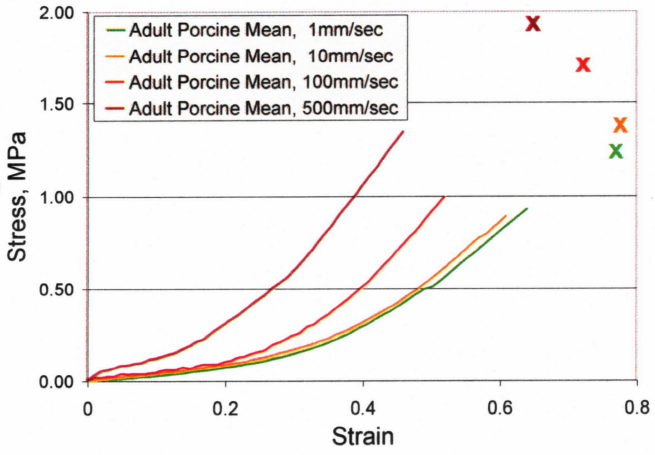
Results – Loading Rate Experiments (MCW)



Effect of Age on Quasi-Static Stress v. Strain

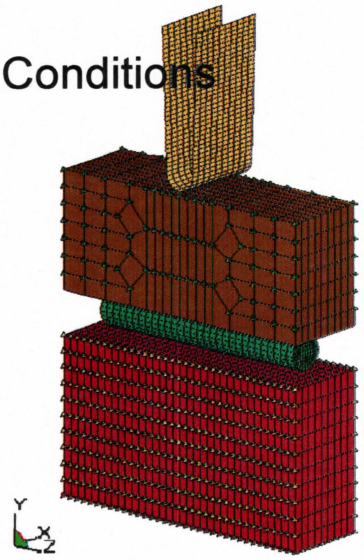


Rate Dependence of Stress v. Strain, Adult Specimens

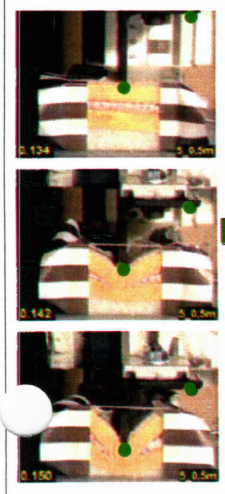


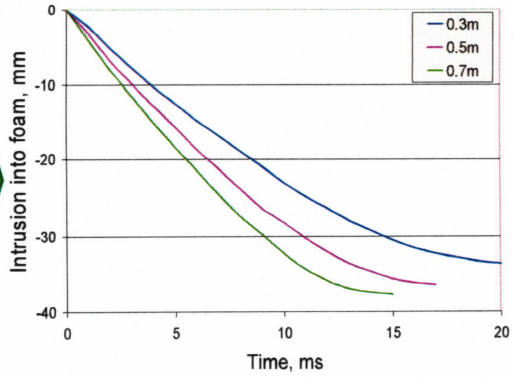
Boundary Conditions

- Bottom-most nodes
  - locked in x,y,z
- Midline foam nodes
  - locked in x-y plane
- Outer foam nodes
  - locked in y-z plane
- Indenter
  - One DOF, y



Indenter Motion Profile Test Matrix

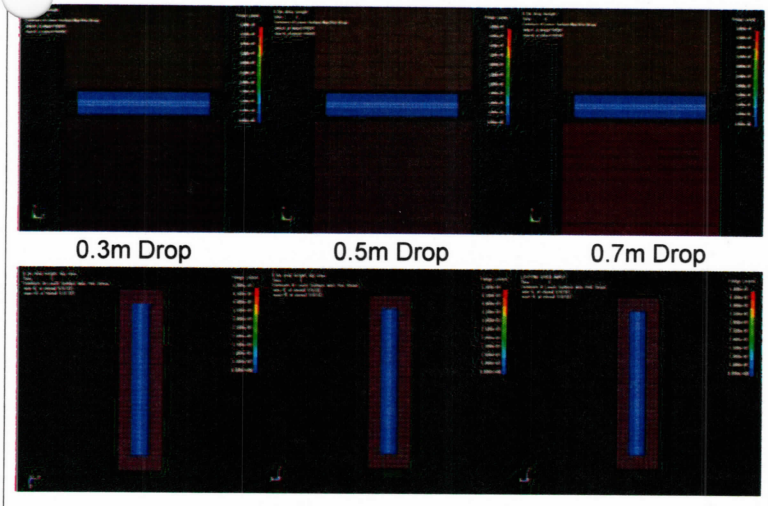




Questions to Answer with Sausage FE Model

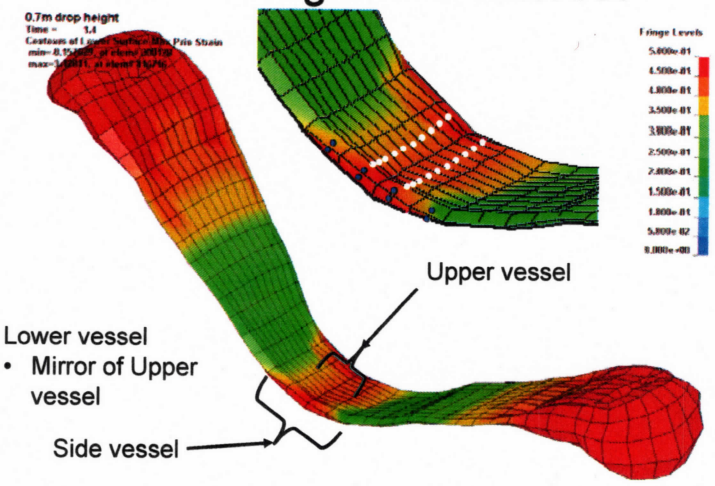
- Where do the greatest stresses occur?
- Is the strain rate different in each case?
- Based on the intimal tearing data: **Does predicted outcome agree with experimental outcome?**

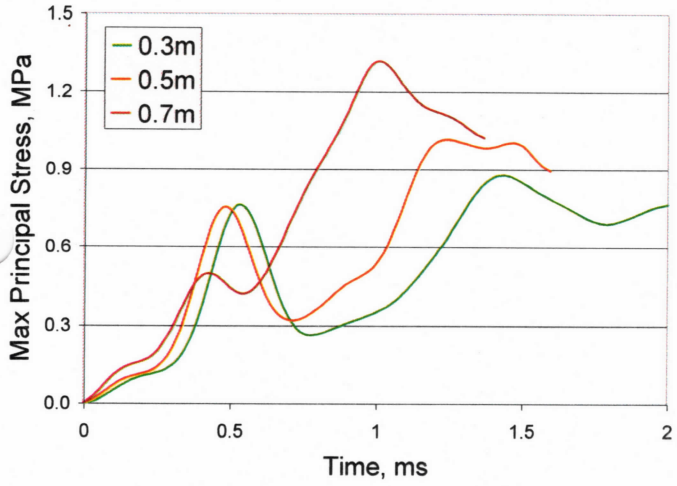
Simulation results

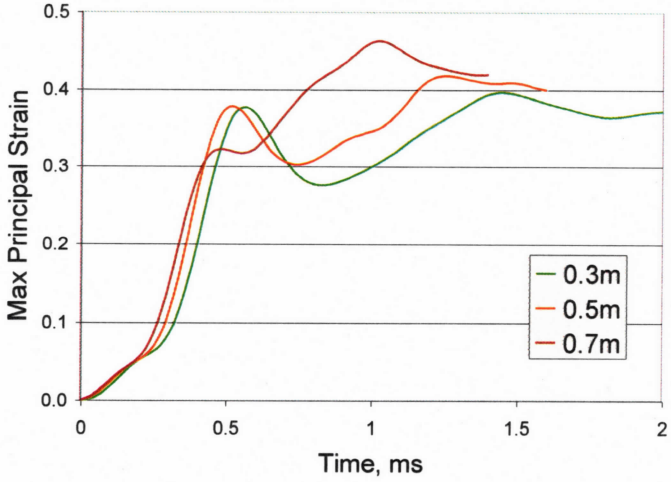


0.3m Drop 0.5m Drop 0.7m Drop

Three Regions of Interest

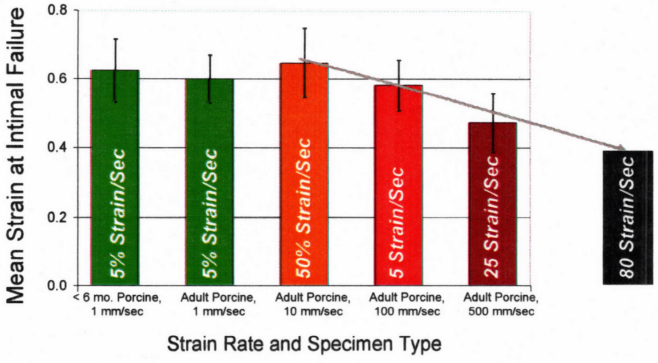






Extrapolate Loading Rate Experiments

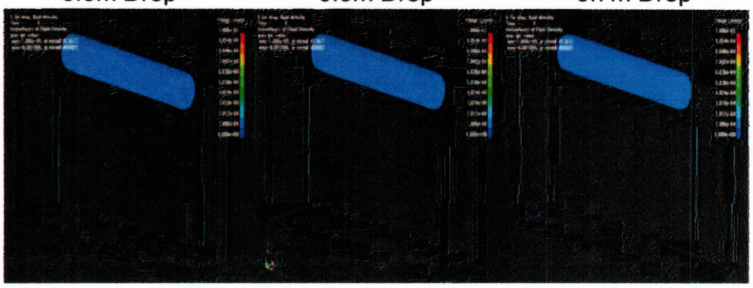
- What is the failure strain at 80strain/sec?
  - Assuming specimen size of 20mm



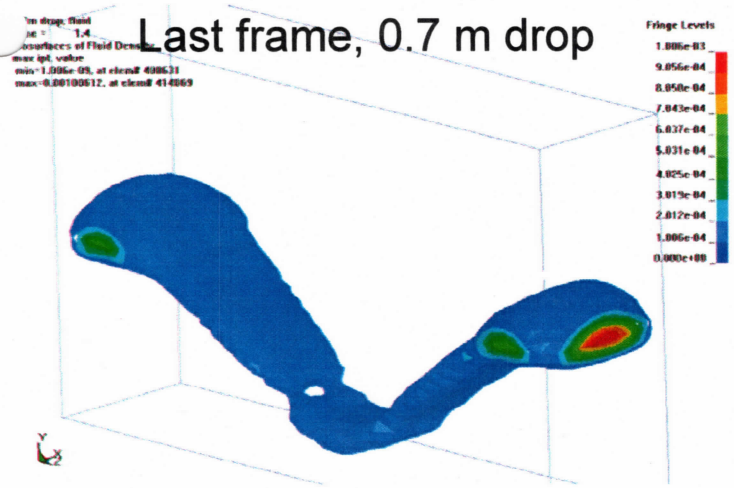
Possible Injury Mechanism

- Is intima to intima contact a candidate for the injury mechanism in guillotine test?

0.3m Drop 0.5m Drop 0.7m Drop



Last frame, 0.7 m drop



Model Summary by the Numbers

	MCW Data		Simulation		Guillotine
Height (m)	Mean Strain	Mean Stress (MPa)	Peak Strain	Peak Stress (MPa)	Injury probability
0.3	0.6	1.2	0.40	0.88	0%
0.5			0.42	1.00	25%
0.7			0.46	1.30	100%

**Mean strain and stress values are for quasi-static (1mm/sec) loading*

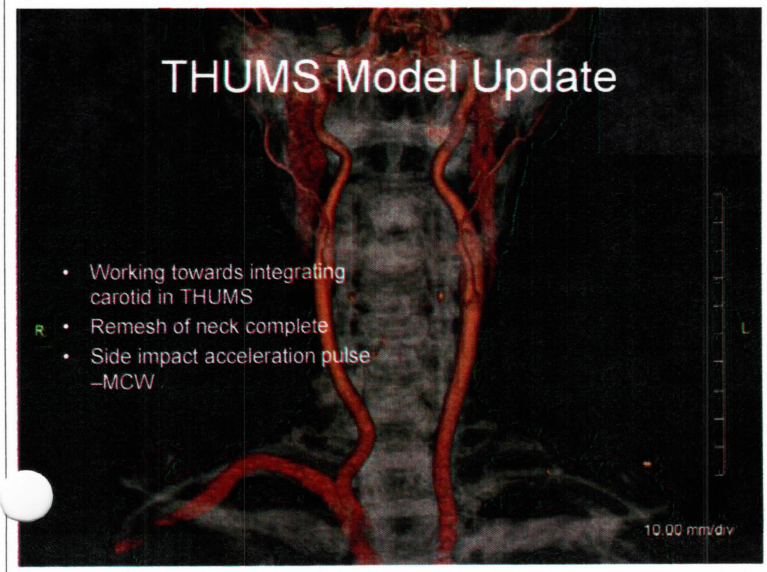
Sausage Test Preliminary Indications

- Strain rates are comparable between drop heights
  - Large strain rates (80strain/sec) at onset of event
- Intrusion increases 12% (33mm to 37mm)
- Predicted strain falls short of mean strain to intimal failure for quasistatic
- Clearly a dynamic event, however – need to test at 1.5 m/s (1500 mm/sec, 75 strains/sec – comparable to simulation with 3.7 m/s impact to side of carotid)
  - 35 mph delta V, 15 m/s
- Possible injury mechanism is intima to intima contact

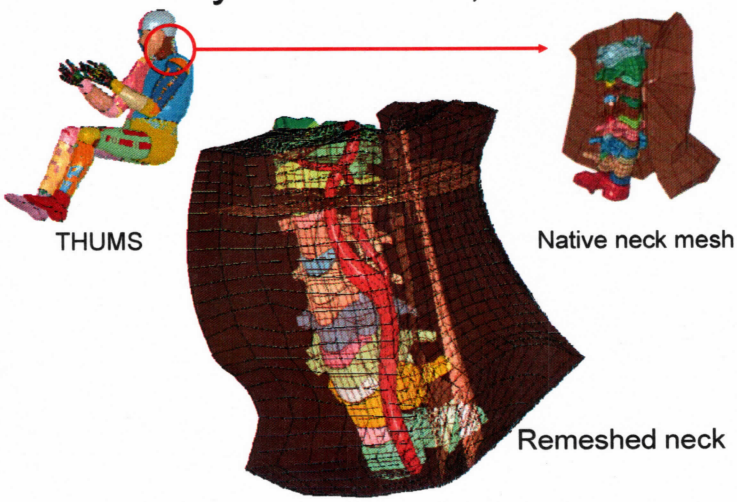
Current limitations

- Time-scaled simulations used (10x)
  - Long run times, and instability errors encountered when run at actual speed
    - "*** Warning negative vol in advection redo cycle"
    - "Node # X has out-of-range velocities"

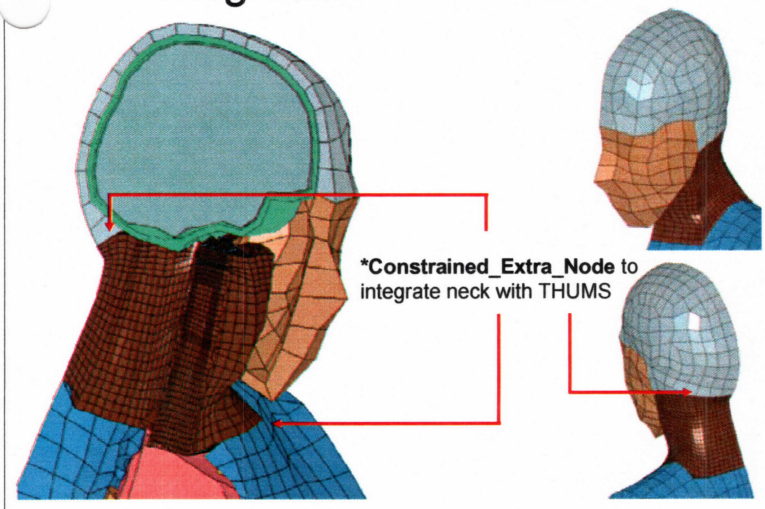
THUMS Model Update



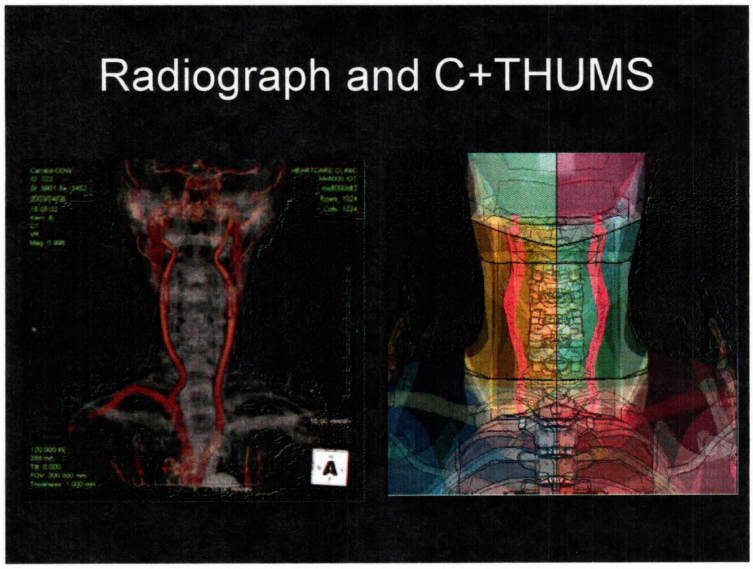
Anatomy of the neck, remeshed



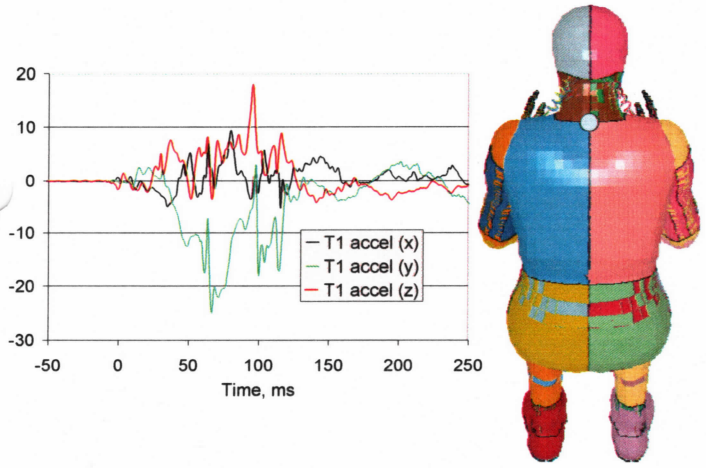
Integration with THUMS



Radiograph and C+THUMS



Simulation plan for C+THUMS



Acknowledgements

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