Carotid Modeling Update

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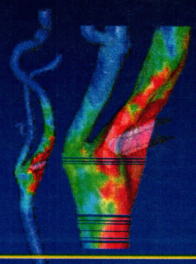
June 5, 2005
Far Side Meeting



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Carotid Anatomy

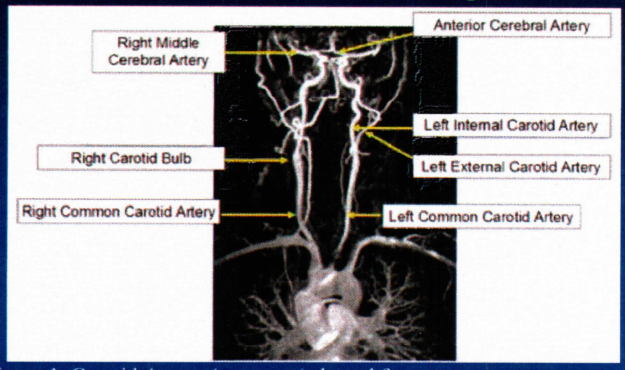
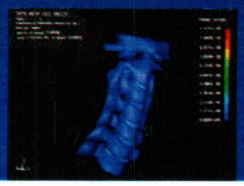


Figure 1. Carotid Artery Anatomy (adapted from http://www.cme.wisc.edu/online/radiology/carotid/anatomy.htm)

Component Neck Models

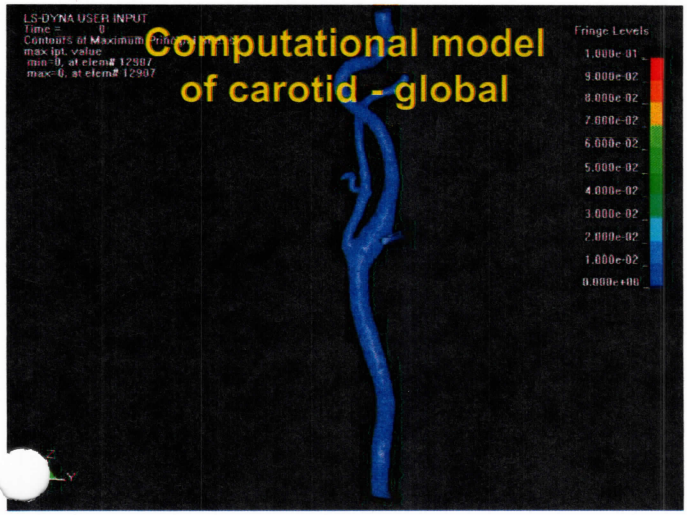
- Detailed design of local neck geometry and interactions
- Computationally more efficient then full body models
- Boundary condition concerns for response due to restraint systems



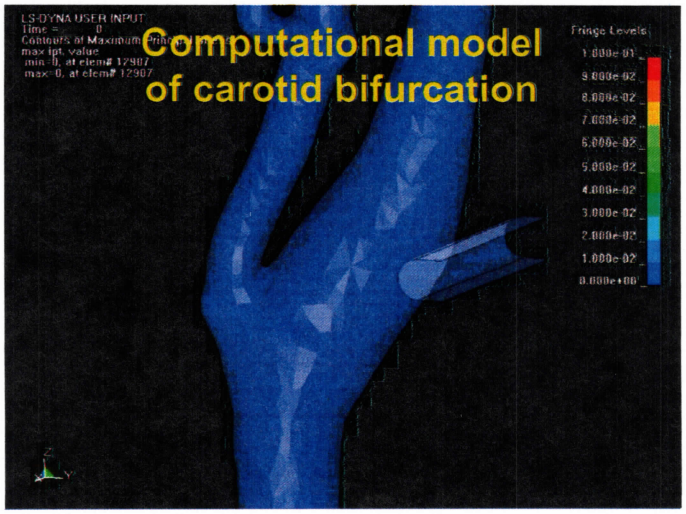
Carotid Model

- Triangular element mesh
- Single layer material
  - Intima, media, adventitia combined
- Isotropic material properties
- Contact algorithms and model stability verified
  - R1.5 mm impactor test

Computational model of carotid - global



Computational model of carotid bifurcation



Development of specimen model for validating material properties

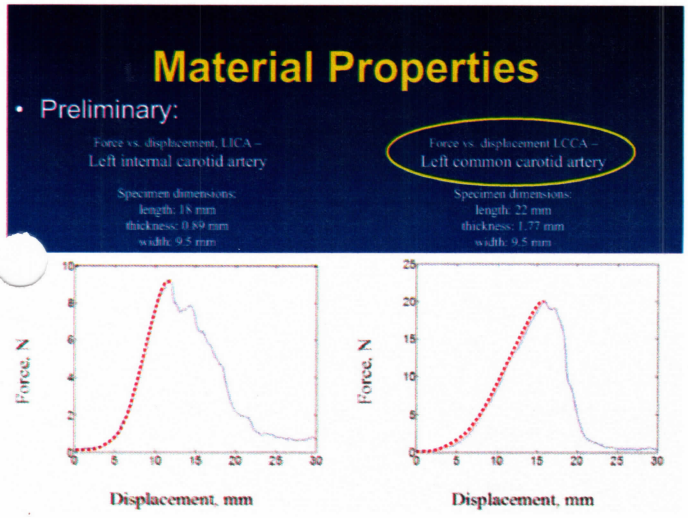
- Data and specimen dimensions obtained from Medical College of Wisconsin for
  - Left Common Carotid Artery (LCCA)
  - Left Internal Carotid Artery (LICA)
- Axial testing
- Left common carotid artery modeled – matching force-displacement response with assumed stress-strain response

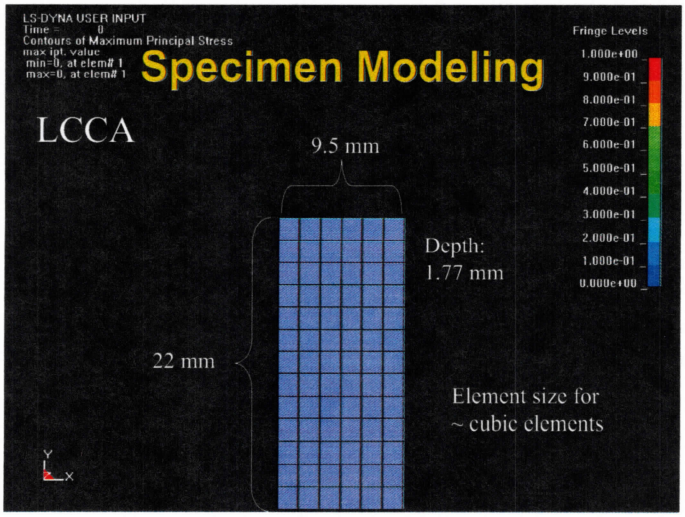
Material Properties

- Preliminary:
  - ~~Mooney-Rivlin (Strain stiffening)~~
  - Is anisotropic behavior significant, requiring more complex meshing?
    - Experimental tests?
  - Other rubber or soft tissue model may provide better fit
    - Need data for poisson's ratio (rubber models work best when close to 0.5)
    - Hyperelastic, 5 constants in Strain Energy Functional

Material Properties

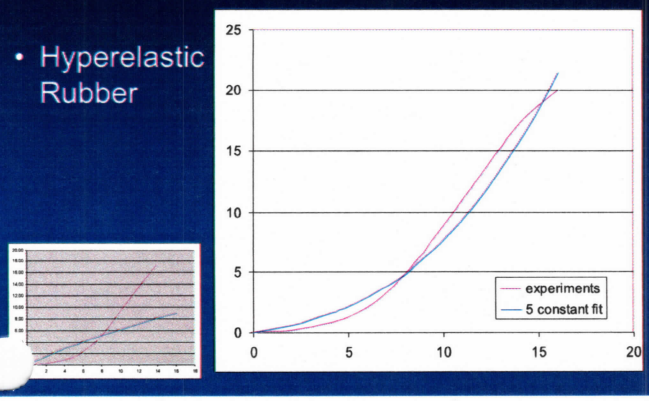
- Preliminary:





Curve Fitting

- Hyperelastic Rubber



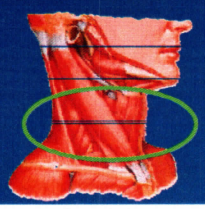
Neck Tissue Representation

Detailed bony anatomy:

- Kinematics extracted from validated global models
- Motion prescribed to local model

Soft tissues as lumped mass:

- Homogenous
- Isotropic
- Intrusion defined/ modeled



Modeling Plan

- SIMon approach for injury prediction
  - Madymo Detailed Neck model subjected to side impact simulation
    - 3 or 4 point simulations
  - Kinematics taken from vertebral bodies and imposed on LS-Dyna neck with carotid artery
  - Soft tissue deformation evaluated from Madymo output or simulated in LS-Dyna with other contacts
  - Resulting stress response of carotid observed
    - Risk assessed at prioritized modes of failure

Previous Conclusions

- Geometry implemented in LS-Dyna
- Preliminary validation begun
- Data fit from MCW near completion
- Require experimental test to verify adequate material representation
- SIMon approach to evaluating soft tissue interaction
- Definition of injury prediction capabilities

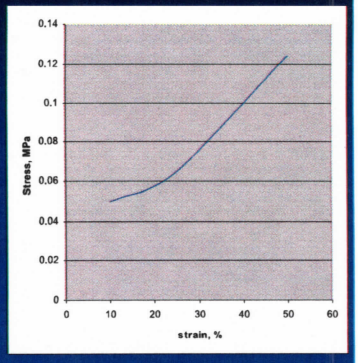
Guillotine Video

Sausage Investigation

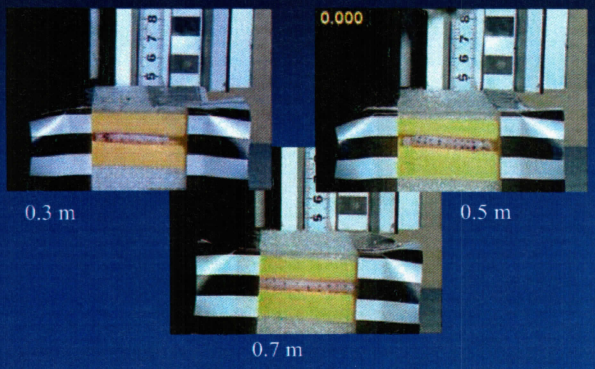
- If you still are interested in the "sausage" investigation, here is the material data to begin with Ethafoam 220
- 36 kg/m3 (2.3 pcf)
- Compressive deflection @10% 50 kPa
- Compressive deflection @25% 65 kPa
- Compressive deflection @50% 124 kPa
- Tensile strength @ peak 220 kPa

Foam Material Data

- Foam Material Data (Ola)



5 mm round shape giljotin, three heights



Results

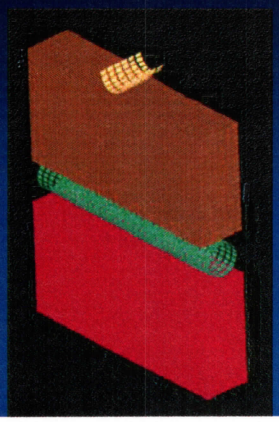
Results

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%	

*same intrusion as 0.7m tests

Model Development

- Foam Layering
- Lagrangian components

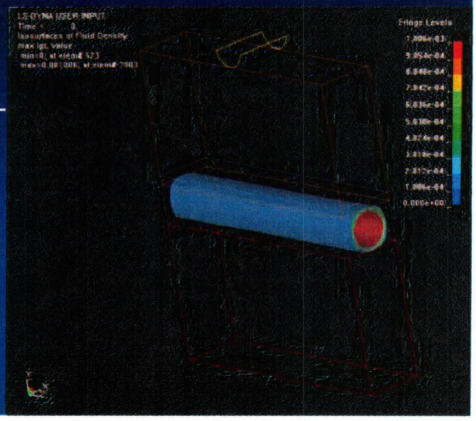


Eulerian flow field

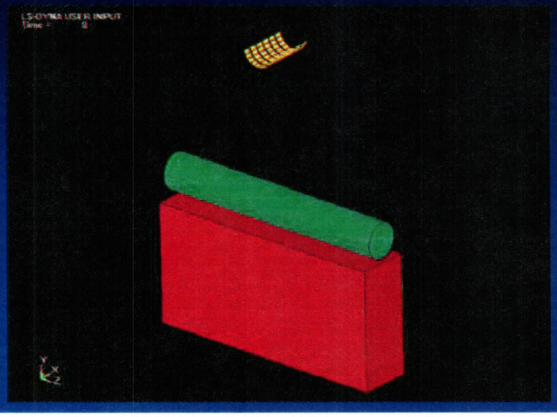
- Eulerian flow field
- Filled and unfilled spaces

Sausage Model

- Lagrangian-Eulerian
- Isolines of Density



Lagrangian Video

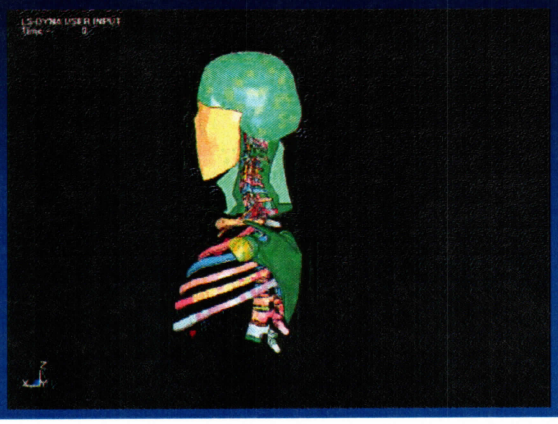


Eulerian Video

Conclusions

- 60% Intima starts to disrupt (Ola)
  - Pig carotid
- 65-85% Mechanical failure (Brian S)
  - Human carotid (Icca, Iica)
- 100% Mechanical failure (Ola)
  - Pig carotid
- 25% Frequency of intimal tearing on modeled tests
- Preliminary Strain of 10-15% from models
- Suggests that intimal damage mechanism is not purely tensile
  - Impact between internal walls important

Begun work with THUMS



Acknowledgements

Medical College of Wisconsin
Autoliv (Ola)

Thank you!
Questions?

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