Some ideas to evaluate safety of robot – human collision

NOTE: All opinions expressed are personal and do not represent the position of NINDS / NIH

Why am I here?

- To share some ideas about a dummy that could be designed to test safety of robot – human interaction
- To request help and collaboration with various aspects of the project.
- To use all data created to-date in design

What I am going to discuss

- Quick intro to my background
- Some dummies I have designed
- How some ideas from them can be used to design robot testing dummy
- Data available in addition to ISO TS 15066 Appendix A

My Background

- Started and ran GESAC, Inc a biomedical R&D company
- Company is a vertically integrated design, manufacture, test, sales and service company with worldwide customer base.
- Currently working as a Program Officer at National Institute of Neurological Diseases and Stroke.
- Also at NIST part time till they figure out that I am bogus!

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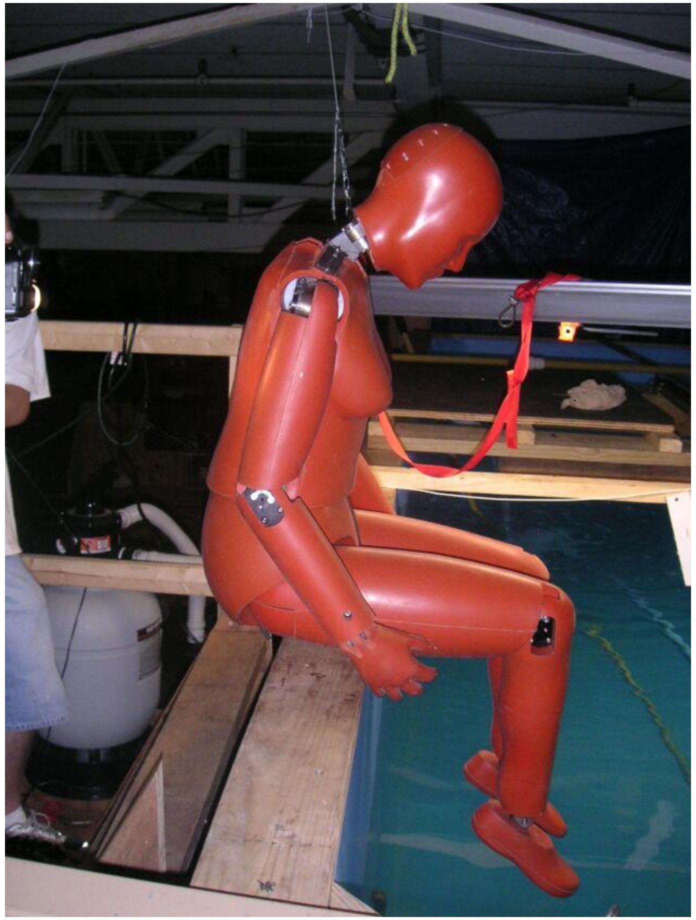
Some dummies my company designed

- Thor advanced frontal crash dummy – male and female
- Polar pedestrian crash test dummy
- Flotation dummies to test flotation devices – big male, small female, child
- Instrumented child dummies – 2.5 kg and 3.4 kg
- A series of seat testing dummies – 9-month, 3-yr small, 3-yr big, 12-year [same as a 5^{th} percentile female dummy]
- Dummy abdomen to test high-speed pre-tensioners

5% female flotation dummy about to take a dive!



3.3 kg designed with 32 sensors

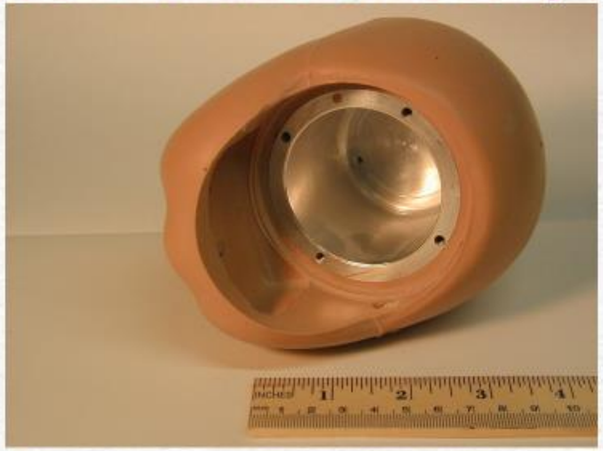
List of Sensors - 1

- 3-axis head angular velocity sensor
- 3-axis accelerometer at head CG
- 3-axis accelerometer at top of neck
- 3-axis accelerometer at neck bottom
- 1-axis Fz load cell at neck bottom
- 3-axis accelerometer at chest CG

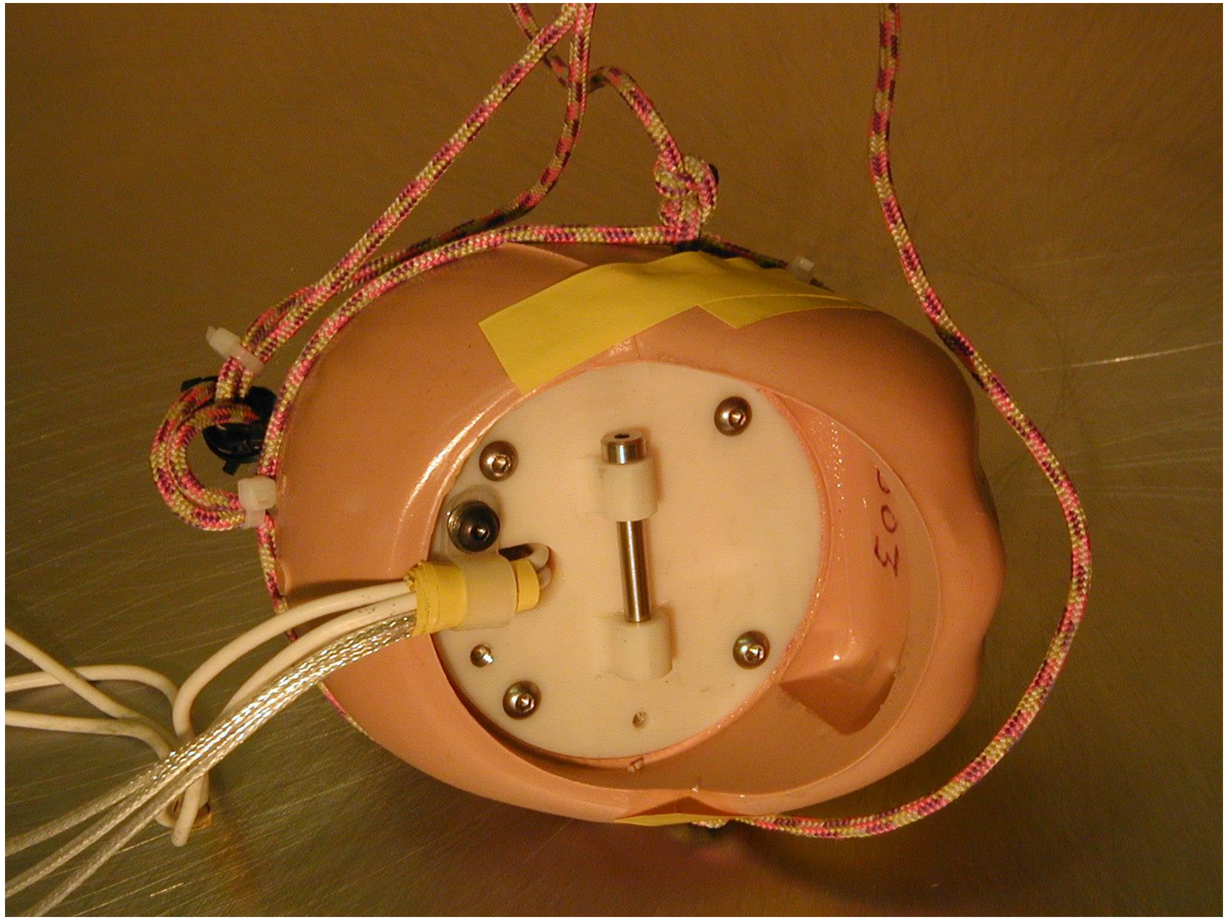
List of Sensors - 2

- 3-axis accelerometer at pelvis.
- 1-axis Fz load cell at lumbar/pelvis.
- String potentiometer on rib to measure rib deflection.
- Pressure mat on abdomen to measure abdominal loads at 5 locations.
- Total of 26 channels.

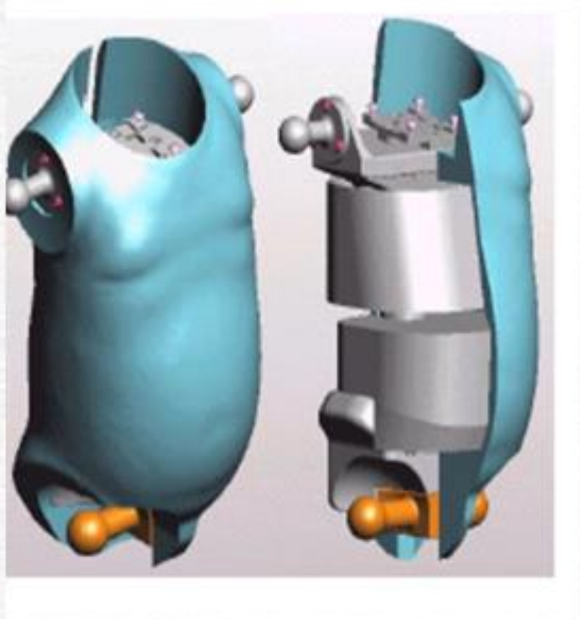
Head Showing Instrumentation Cavity



Head with 3 linear and 3 ang accels



Dummy Torso



Rib Construction

- Dummy has a single rib made of Polycarbonate.
- Damping is provided by damping material used in adult dummies.

Baby dummy head impact test results

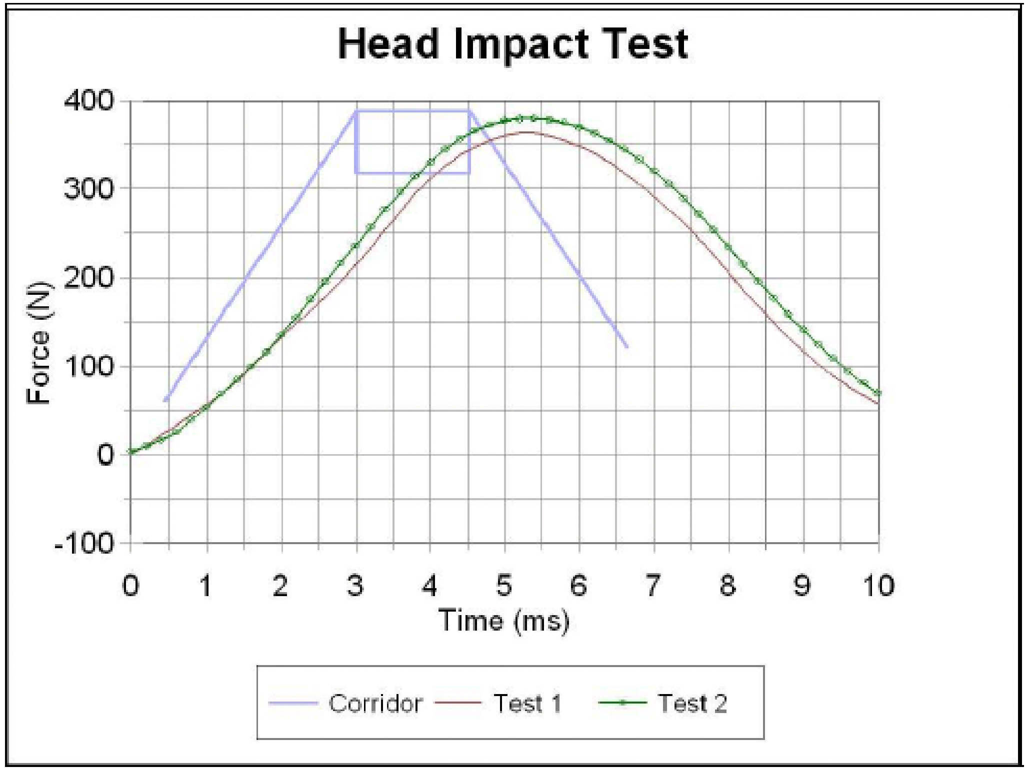


Figure 5. Head impactor force time-history and comparison with corridor.

Baby chest impact test

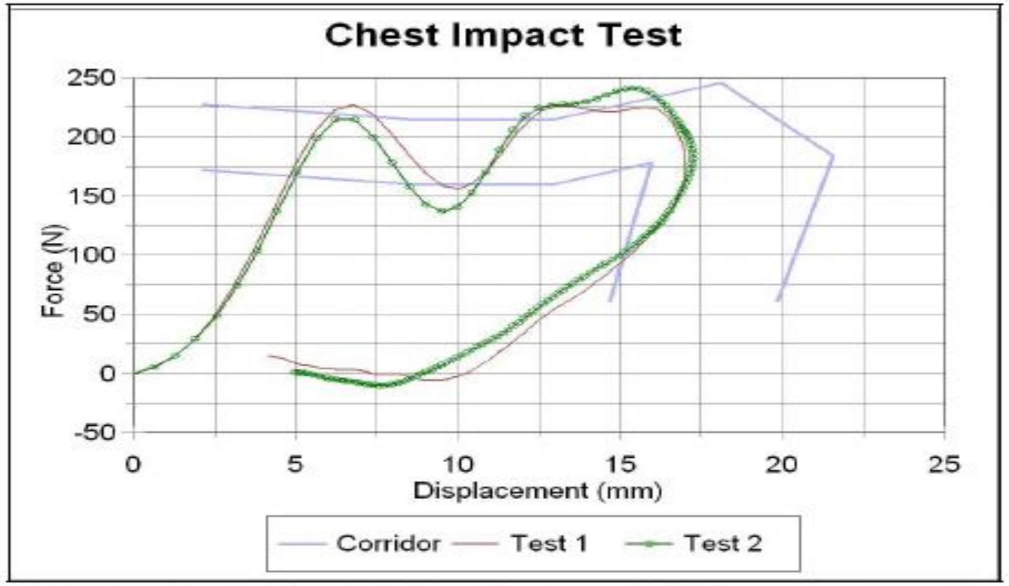
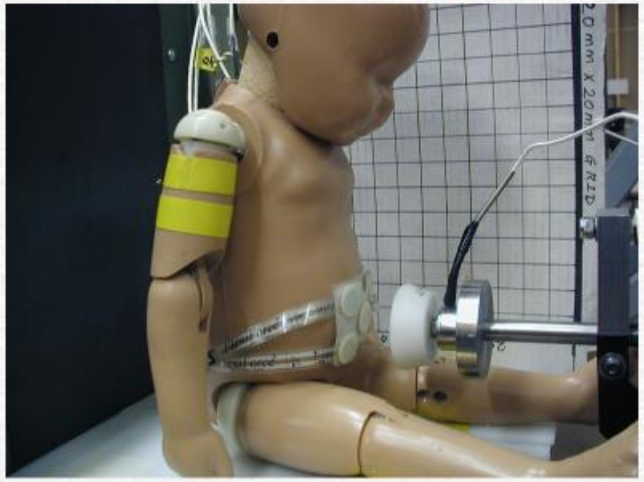


Figure 32. Chest impact test results compared to scaled corridor

FlexForce on Dummy Abdomen



Flexiforce evaluation

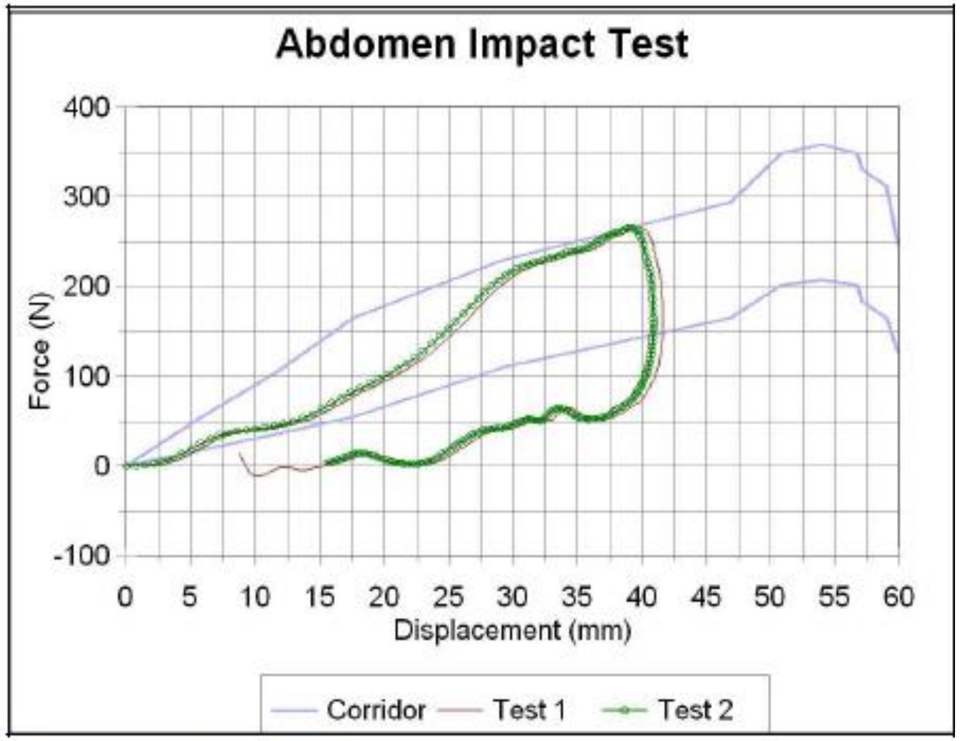
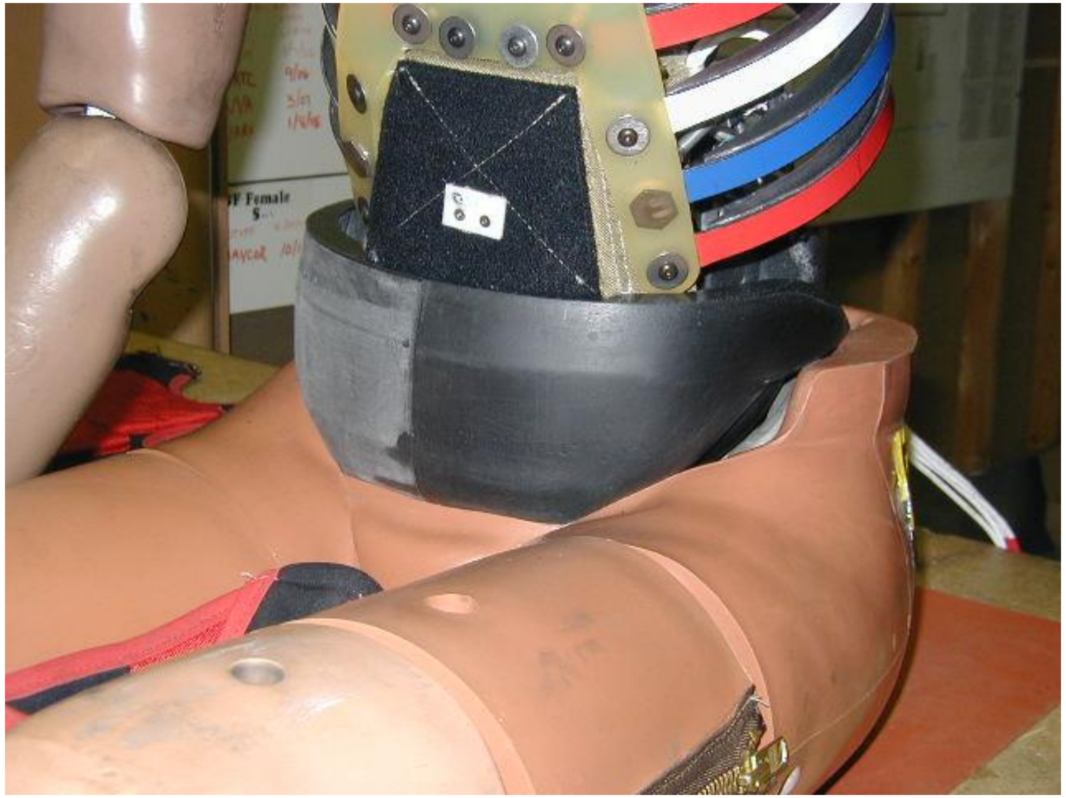
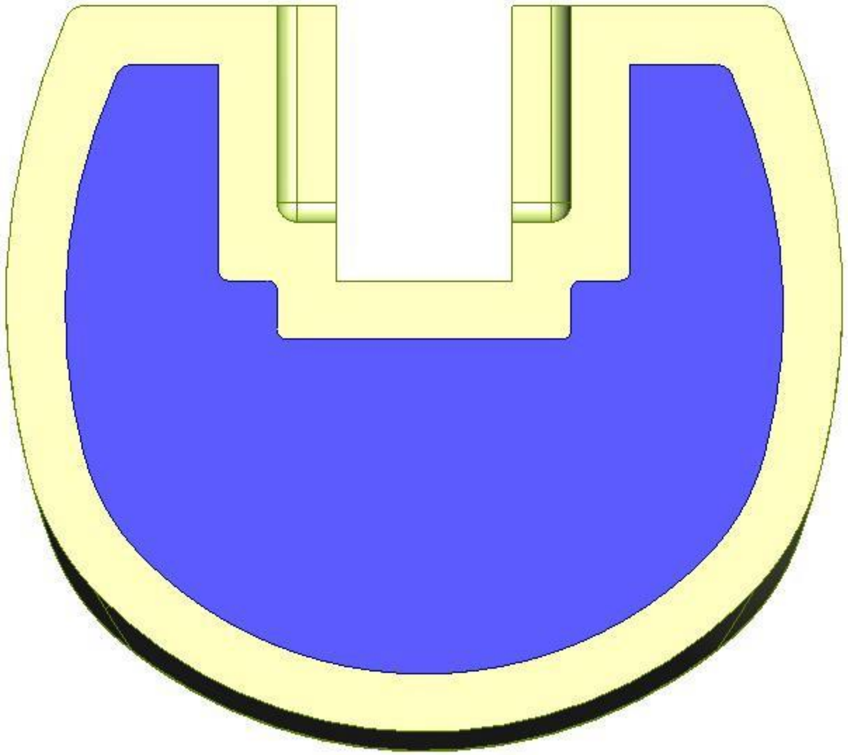


Figure 37. Abdomen impact test results compared to scaled corridor

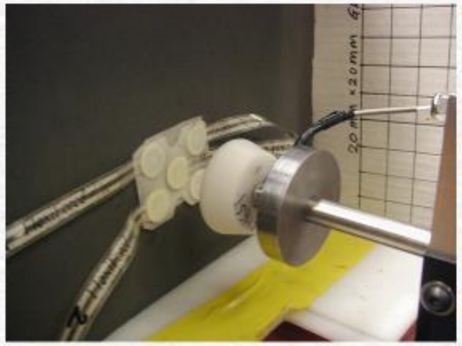
Adult dummy foamed abdomen – Urethane with Silicon insert – biofidelic respons



50% male dummy abdomen with Outer Urethane layer and inner silicone insert



Flexiforce Evaluation



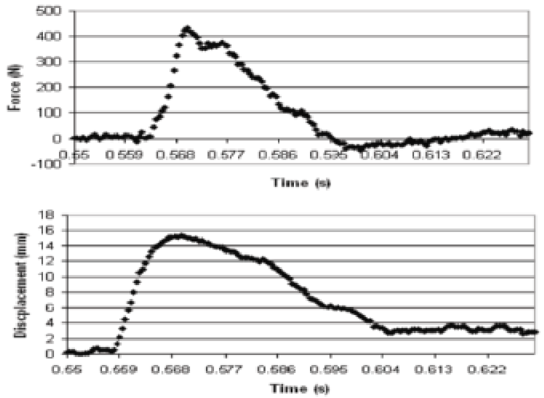
- Preliminary evaluation by 4 m/s impact on 2" thick structural foam
- Foam back supported rigidly
- Compare Flexforce with pendulum load cell

So, What

- Based on some current work, it is possible to use simple math models to simulate contact between dummy and robot – Hertz contact model seems to work well.
- When trying to design anything, it is good to have a math model to exmine design alternatives – lumped mass, finite element, finite difference models can be use.
- Here is a quick look at one application

Desmoulin Calf impact tests

Drop Test on Calf - Desmoulin



1.9 kg wooden impactor against lower leg approximately 2 m/s

Desmoulin Test Simulation – Hertz Contact Model

Variable	Test Value	Simulation Value
Pulse width	36 ms	35.9 ms
Peak Force	430 N	398 N
Peak Accn	25 G	23 G
Peak flesh compression	25 mm	25 mm

Desmoulin calf impact simulation

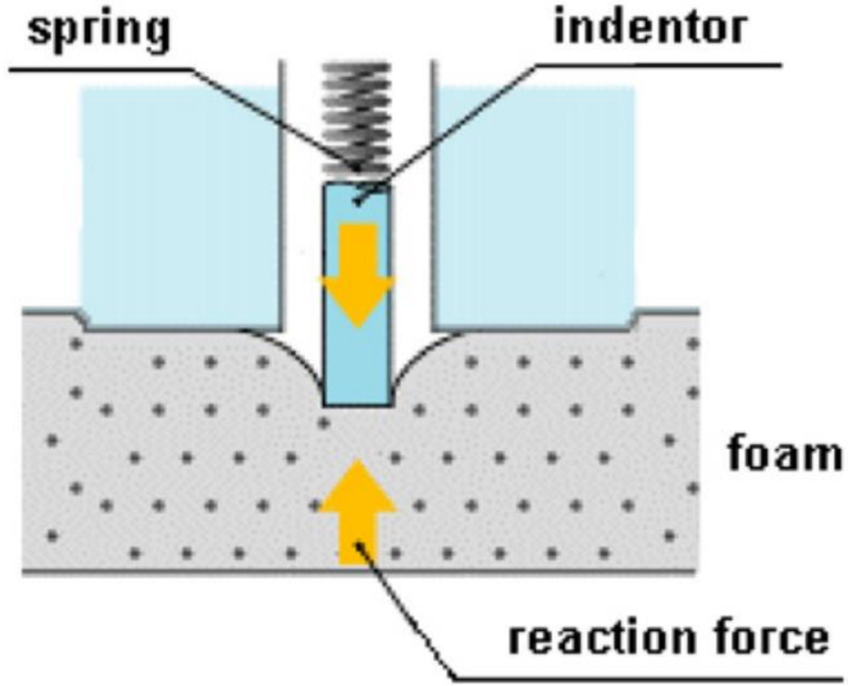
- Based on above simulation, Young's modulus was around 0.35 Mpa
- It is equivalent to about Shore A – 8 foam
- The test device in NIST uses Shore A – 10 foam in the impactor

Overarching idea

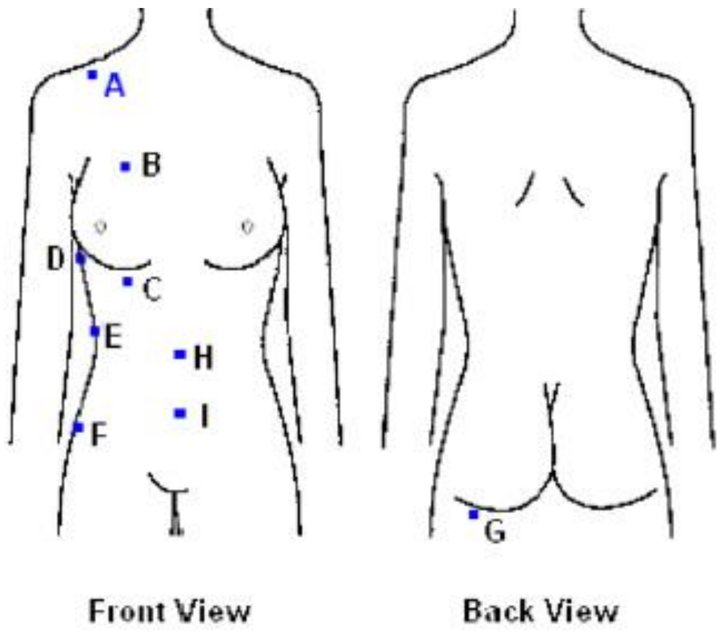
- Design a simple dummy of right anthropometry
- Request cooperation from all stakeholders – academia, manufaturers, test houses, insurance companies, etc.
- Develop instrumentation
- Fabricate
- Develop test matrix
- Relate dummy response to injury criteria
- Test dummy in-house and provide it for use by stakeholders
- Help dummy manufacturers, test houses, robot manufacturers
- Publish drawings, test methodology, injury criteria, etc

Maybe end here!

Softness measurement of open-cell foam and human soft tissue



Softness measurement of open-cell foam and human soft tissue



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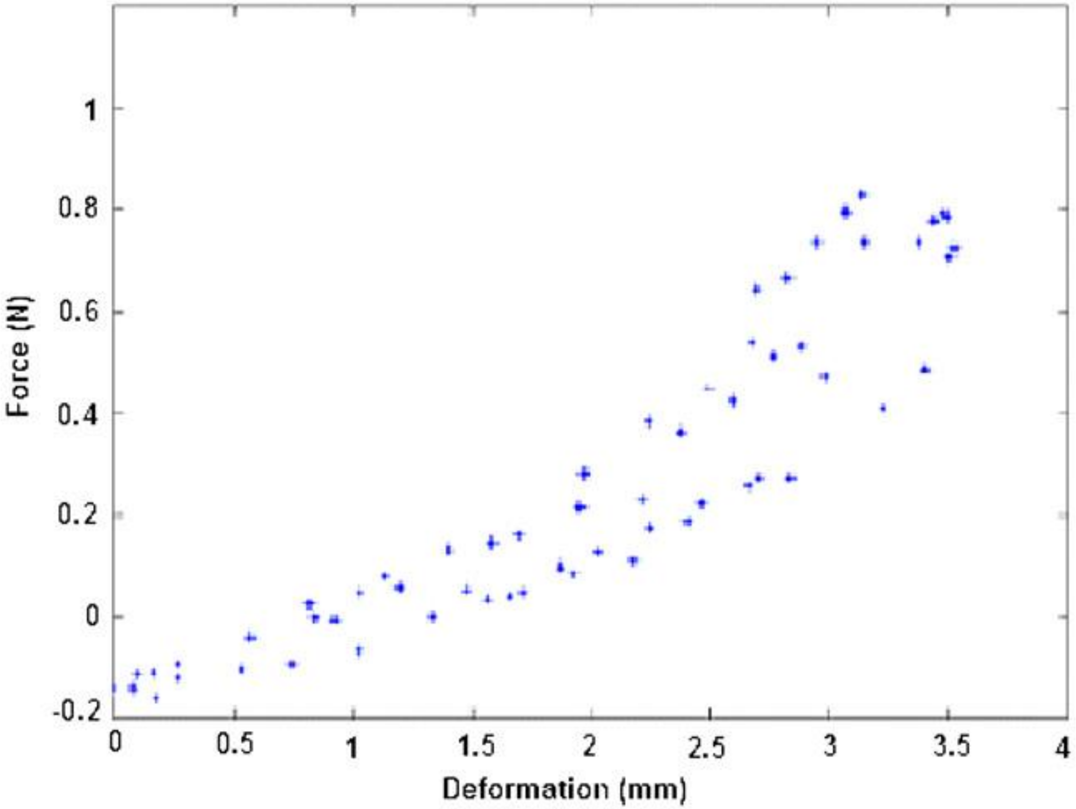
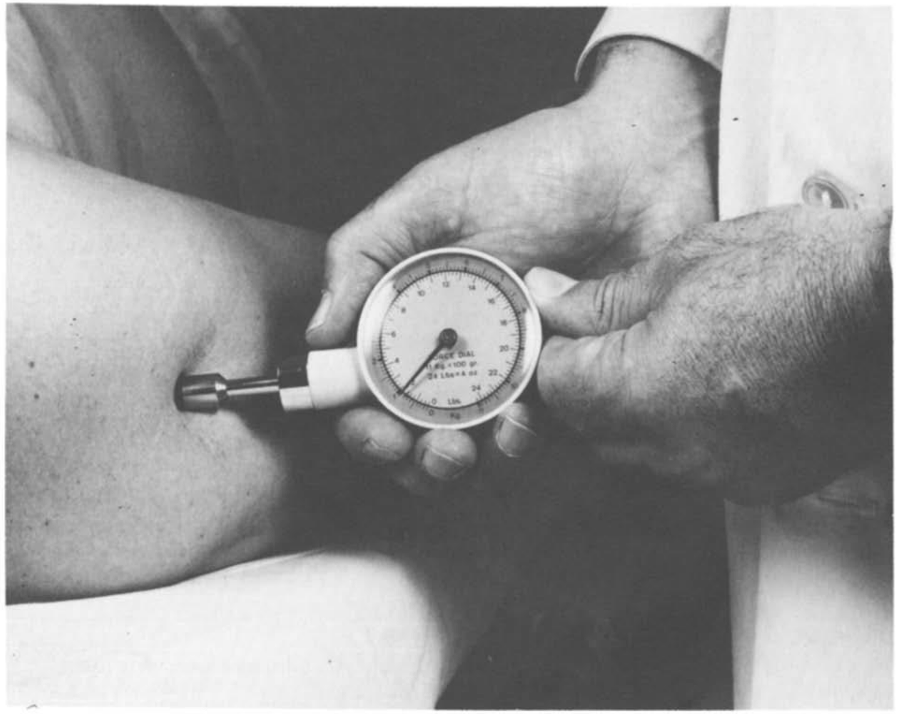


Load / displacement curve for indentation tests on females

Softness measurement of open-cell foam and human soft tissue

- Cylindrical 9 mm dia probe with flat tip
- 20% of tissue thickness
- Each indentation completed within 2 s. Max deformation rate = 3.5/2 mm/s
- Average value of modulus 11.7 kpa. Without shoulder 9.3 kpa. This will help choose foam

Pressure algometry over normal muscles, standard values, validity and reproducibility of pressure thereshold



Pressure algometry over normal muscles, standard values, validity and reproducibility of pressure thereshold

- 24 male, 26 female subjects in 9 sites
- Idential results obtained over muscles of opposite sides proved excellent reproducibility and validity of pressure threshold measurement.

Pressure algometry over normal muscles, standard values, validity and reproducibility of pressure thereshold

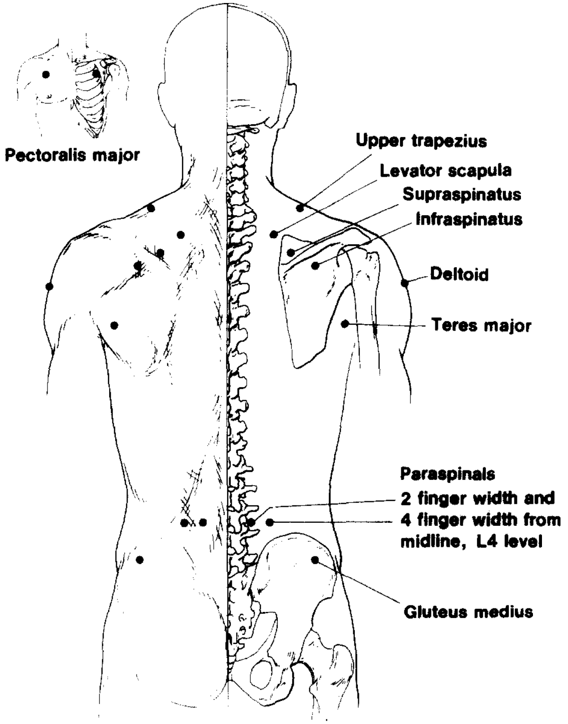
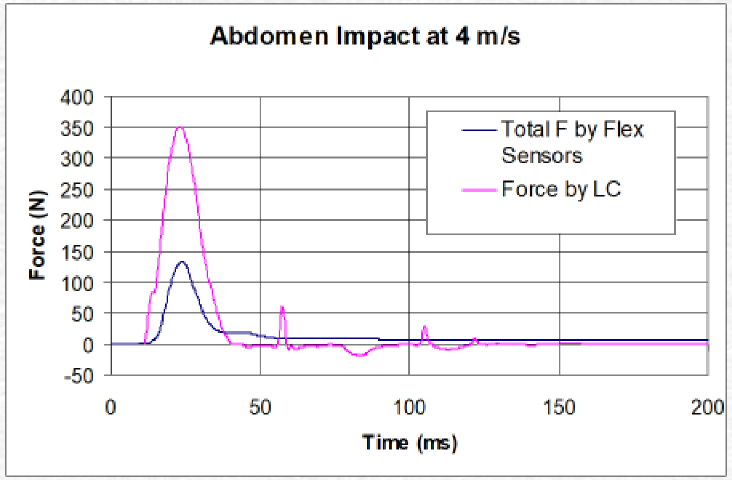


Fig. 2. Sites of pressure threshold measurement in normal control subjects.

Since all subjects were right-handed, there was no need to distinguish according to dexterity.

Combined Sensor Response



Scalability of design – 12 yr and 3-yr old dummies

Scalability – H3 female with Urethane dummy

How did I come up with this overarching idea

- Started with proposals to NIST in 2011 to apply principles of impact biomechanics to understand robot – human collision
- Have been playing around with use of Hertz contact model in human – half space impacts.
- Published several papers on paediatric head impact relating model response to test data including cadaver test data. Note that overall Young's modulus for paediatric head is pretty low, almost as low as some of the muscle groups in extremities.
- Model seems to provide good estimates for force, compression, force duration, etc for impact against hard and soft surfaces
- Recently, used model to estimate Force, duration, compression, etc. in impacts of ball against thigh muscles. Model seems to provide good estimates when compared to experimental data.
- Experimental data indicates that it is possible to draw a probabilistic relationship between Abbreviated Injury Scale [AIS] and limb response [input energy]
- It might be possible to relate pain some level of AIS