Comparing Blast Effects on Human Torso Finite Element Model against Existing Lethality Curves

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Abstract

A finite element model of a representative 50th percentile male torso has been created by researchers at the Johns Hopkins University Applied Physics Laboratory. The components of this detailed Human Torso Finite Element Model (HTFEM) include the heart, lungs, liver, stomach, intestinal mass, kidneys as well as the thoracic skeletal structure system. The detailed components of the torso provide relevant internal geometries, material differences and boundary conditions to study the propagation of a blast pressure wave through the thoracic region. Injury due to blast has largely been predicted using the Bowen curves, which are based on experiments of various animal species exposed to air blast that provide a biological response to blast. LS-DYNA, a dynamic finite element modeling tool is used to simulate the complex system response of the HTFEM to an open air blast event. LS-DYNA's enhanced version of the CONWEP blast model will be used to load the HTFEM. Loading conditions representing the overpressure and positive phase duration as defined in existing injury curves adapted from Bowen's lethality model are applied to the HTFEM. These simulations will explore HTFEM response to peak overpressures in the range of 400-800 kPa and positive phase durations in the range of 2.0 to 4.5 ms. The temporal pressure plots show organ response for the various loading conditions. The HTFEM can be used as a tool used to examine the blast effects on the human torso and to aid in the design of personal protective equipment (PPE).

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14. ABSTRACT
A finite element model of a representative 50th percentile male torso has been created by researchers at the Johns Hopkins University Applied Physics Laboratory. The components of this detailed Human Torso Finite Element Model (HTFEM) include the heart, lungs, liver, stomach, intestinal mass, kidneys as well as the thoracic skeletal structure system. The detailed components of the torso provide relevant internal geometries, material differences and boundary conditions to study the propagation of a blast pressure wave through the thoracic region. Injury due to blast has largely been predicted using the Bowen curves, which are based on experiments of various animal species exposed to air blast that provide a biological response to blast. LS-DYNA, a dynamic finite element modeling tool is used to simulate the complex system response of the HTFEM to an open air blast event. LS-DYNAs enhanced version of the CONWEP blast model will be used to load the HTFEM. Loading conditions representing the overpressure and positive phase duration as defined in existing injury curves adapted from Bowens lethality model are applied to the HTFEM. These simulations will explore HTFEM response to peak overpressures in the range of 400-800 kPa and positive phase durations in the range of 2.0 to 4.5 ms. The temporal pressure plots show organ response for the various loading conditions. The HTFEM can be used as a tool used to examine the blast effects on the human torso and to aid in the design of personal protective equipment (PPE).

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Introduction

Blast injury can lead to long term disability and mortality through a number of mechanisms. They include blast overpressure (primary), displacement of the body (secondary), and projectiles caused by the explosion imposed on the body (tertiary). Eardrum rupture, contusions of the gastrointestinal tract, and lung hemorrhage are the main injuries due to direct overpressure from a blast, the latter two frequently lead to mortality (Elsayed 1997). The criteria most often used for predicting injury and lethality in humans are the Bowen curves which are based on experimental tests on animals (Bowen 1968). In 1986, the Bowen curves and criteria were reevaluated to define new terms and conditions that included additional data collected from animal testing as well as human exposure to accidental detonation. The data from these tests were compiled to predict and estimate human injury (Richmond 1986). There are also computer programs that incorporate the analytical injury models as well as calculate blast characteristic for given blast environments including the Blast Effects Computer (BEC), which is a program that includes damage criteria for structures (window breakage) as well as injury criteria for lung damage and eardrum rupture for surface burst explosions (Swisdak 2003). Finite element models of the human form have been established and validated for injury from impacts resulting from long duration impulse events such as auto related impacts or falls as opposed to blast exposure. However, there is still a wide variation, most notably in material property definitions, amongst numerical models in a comprehensive review of computational models for injury for biomechanics research (Yang K.H. 2006). A computational model of the human torso will provide new insight into humans subjected to air blast.

The purpose of this research is to aid the development of the anatomically accurate 50th percentile male Human Torso Finite Element model (HTFEM) by exercising it in a blast environment. The blast environment will consist of loading conditions that have statistical probability of mortality based upon the Bowen curves. The software used to exercise the model is LS-DYNA® (Hallquist 2003). This finite element model (FEM), when fully developed, will show general observations between the internal organ responses relative to position inside thoracic cavity, incident over-pressure and probability of lethality affected by open air blast overpressure as well as provides direction for future model development.

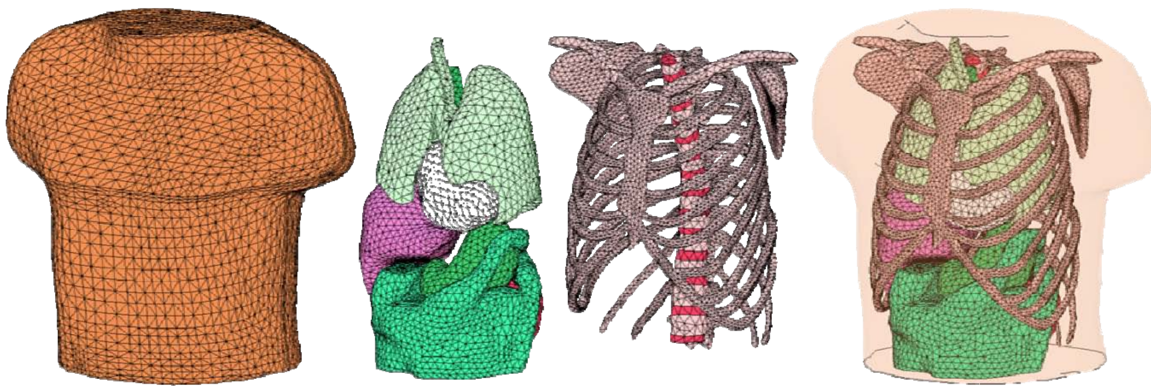
Methods

Human Torso FEM Development

Geometry

The anatomical geometry for the finite element model originated from the geometry supplied by the 4D NURBS-based Cardiac-Torso(NCAT) phantom, a model of the human anatomy, developed for medical imaging research (Segars May 2001). This model has the flexibility to morph to pre-determined size and shape. The rest of the geometry was then transformed to meet the requirements of a 50th percentile male described by the WORLDSID project (Moss 2000).

The geometry was imported as NURBS surfaces and manipulated to contain distinct organs and bones. The Human Torso FEM (HTFEM) consists of the components of the skeletal structure and internal organs. The skeleton was separated to include the individual vertebrae, intervertebral discs, ribs, cartilage, sternum, scapula, and clavicle. The internal organs include the heart and aorta, lungs and trachea, stomach and esophagus, liver, kidneys and an intestinal mass. The remaining space not occupied by the internal organs or skeletal structure is modeled as a homogeneous continuum to represent the space of the mediastinum, viscera, muscle, fat and other soft tissues not discretely modeled. The complete model showing the components can be seen in Figure 1. The skeletal structure, organs, and mediastinum are modeled with 10 noded tetrahedral solid elements, while the outer skin is modeled with triangular shell elements.



(a) (b) (c) (d)

Figure 1 Human Torso Finite Element Model Components (a) HTFEM (b) Internal Organs (c) Skeletal structure (d) Transparent skin exposing the mediastinum and viscera.

Material Properties

The material properties for this HTFEM were adapted from the 5th percentile human torso FEM previously developed by Roberts et al based on an equivalent surrogate model (Roberts 2007). A summary of the material properties are listed in Table 1. The internal organ components are defined to use the general viscoelastic material model as implemented in LS-DYNA. The parameters used in the material model for these components are based upon the silicone gel simulants designed to represent soft tissue and the parameters were measured internally from modified split-Hopkinson bar experimental tests. The elastic properties for the ribs and sternum were obtained from Caruso et al (2006). The properties for the intervertebral discs came also from the open literature (Duck 1990); (Wang 1995). The material properties deviate from the earlier published work to define the vertebra as similar to that of the ribs and sternum since the previous model (Roberts 2007) did not incorporate the individual discs and vertebra modeled. The material model used for the mediastinum/viscera is modified to an elastic equivalent of the viscoelastic properties as previously used in Roberts et al (2007). A summary of the HTFEM is shown in Table 1 including number of elements, material properties: density - ρ, elastic material parameters: Young's modulus - E, Poisson's ratio - ν, and viscoelastic material parameters: bulk modulus – K, short term shear modulus - G_0, long term shear modulus - G_∞, and decay constant - β.

Table 1 Summary of the HTFEM

	Solid Elements	Shell Elements	$\rho^{a,b}$ (kg/mm^3) e-6	$E^{a,b,c}$ (GPa)	$\nu^{a,b}$	K^d (Gpa)	G_0 ^{d} (kPa)	G_∞ (kPa)	β
Skin	-	8192	1.2	.0005	.3	-	-	-	-
Ribs **Sternum** **Vertebrae**	34901	-	1.08	9.5	.2	-	-	-	-
Intervertebral discs	626	-	1.33	.355	.26	-	-	-	-
cartilage	4884	-	1.08	9.5	.2	-	-	-	-
Heart	3262	-	1.0	-	-	.744	6.7e-5	6.5e-5	.1
Aorta	267	-	1.0	-	-	.744	6.7e-5	6.5e-5	.1
Lung	6206	-	0.6	-	-	.744	6.7e-5	6.5e-5	.1
Liver	6326	-	1.06	-	-	.744	6.7e-5	6.5e-5	.1
Kidney	2565	-	1.06	-	-	.744	6.7e-5	6.5e-5	.1
Stomach	2740	-	1.05	-	-	.744	6.7e-5	6.5e-5	.1
Intestinal mass	14698	-	0.6	-	-	.744	6.7e-5	6.5e-5	.1
Mediastinum/viscera	173871	-	2.07	1.02	.4	-	-	-	-

Boundary conditions

The HTFEM is exercised in the dynamic blast environment using the spherical blast condition of the general blast model available in LS-DYNA (Hallquist 2003). The simulation does not include air as a medium to transmit the pressure wave generated from detonation since the *LOAD_BLAST card used to load the finite element model is based on the empirical air-blast equations. The model defines a detonation location at the height position of mid sternum and is applied to the outer surface of the model. The abdominal region of the HTFEM is geometrically closer to the detonation than the mid sternum and therefore experiences the loading first. A progression of the of the blast pressure wave as it acts upon the outer surface of the torso can be seen in Figure 2.

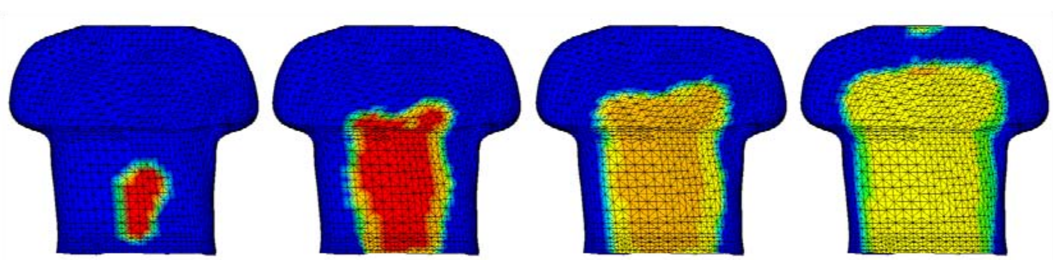


Figure 2 Blast loading time progression: 0.10 ms, 0.12 ms, 0.140ms, 0.18ms, respectively.

The orientation of the HTFEM with respect to the blast exposure is based upon the lethality curves described by Bowen for a standing orientation defined as the long axis of the body is perpendicular to the propagating pressure wave (Bowen 1968). The Blast Effect Computer

(Swisdak 2003) and ConWep (Hyde 2004) were consulted to determine the charge weights and detonation distance to achieve the incident overpressure and duration that lie on the Bowen lethality curves. The use of the spherical air blast option does not take into account the ground reflections and is therefore a less severe environment than the hemispherical or surface burst of the same charge weight and distance. The blast levels chosen lie on the 1% lethality curve and two are from the 50 % lethality curve as seen in Figure 3. These conditions are well above the threshold for lung damage. The simulation characteristics shown in Figure 3 are also identified in Table 2.

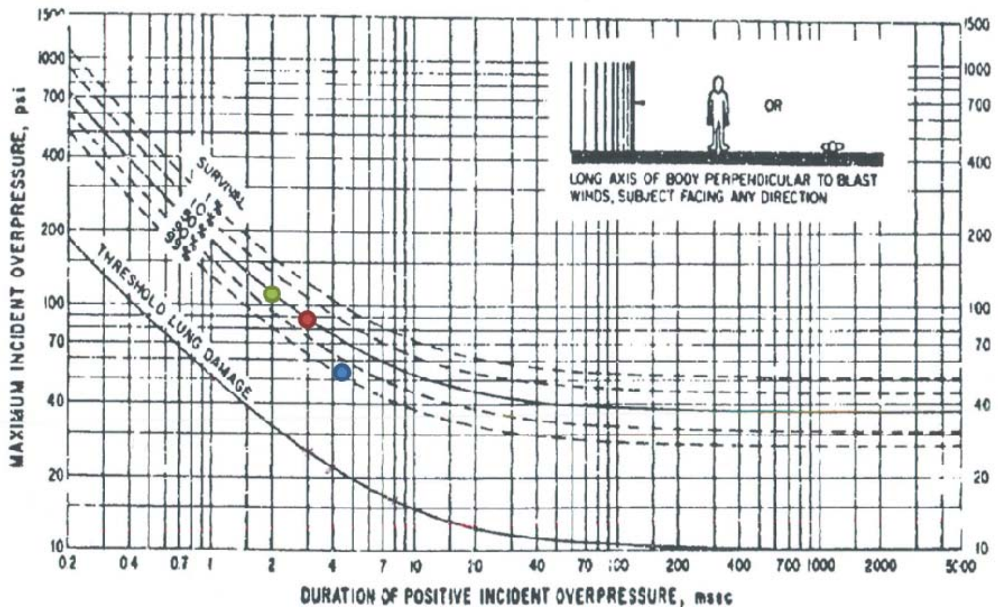


Figure 3 Survival curves predicted for 70-kg man applicable to free-stream situations where the long axis of the body is perpendicular to the direction of propagation of the shock blast wave. Caption and Figure Extracted from Figure 6 of *Estimate of Man's Tolerance to the Direct Effects of Air Blast* **(Bowen 1968)**. Case 1, Case 2 and Case 3 (blue, red and green respectively) are superimposed.

Table 2 Simulation parameters

Case	Charge weight [kg]	Charge Distance [m]	Peak incident overpressure [kPa (psi)]	Positive phase duration [ms]	Lethality [%]
1	8.1	2.9	400 (58)	4.4	1
2	4.98	2.08	600 (87)	3.04	50
3	1.36	1.19	800 (116)	2.02	50

Results and Discussion

Maximum pressure in the heart, liver and stomach are examined for these three loading cases while the elemental pressure can be seen to show the pressure propagate through the thorax. Figure 4 shows a transverse section through the HTFEM at rib 5. This section shows the heart liver, ribs and lungs. Particular emphasis will be paid to the heart and liver. The high positive pressure appears to not dissipate from the soft tissue region in front of the ribcage while it travels through the internal organs within the ribcage and dissipates. A similar observation can be seen in the 0.30 ms image in Figure 4 where a buildup of pressure is seen in the region anterior to the vertebral column

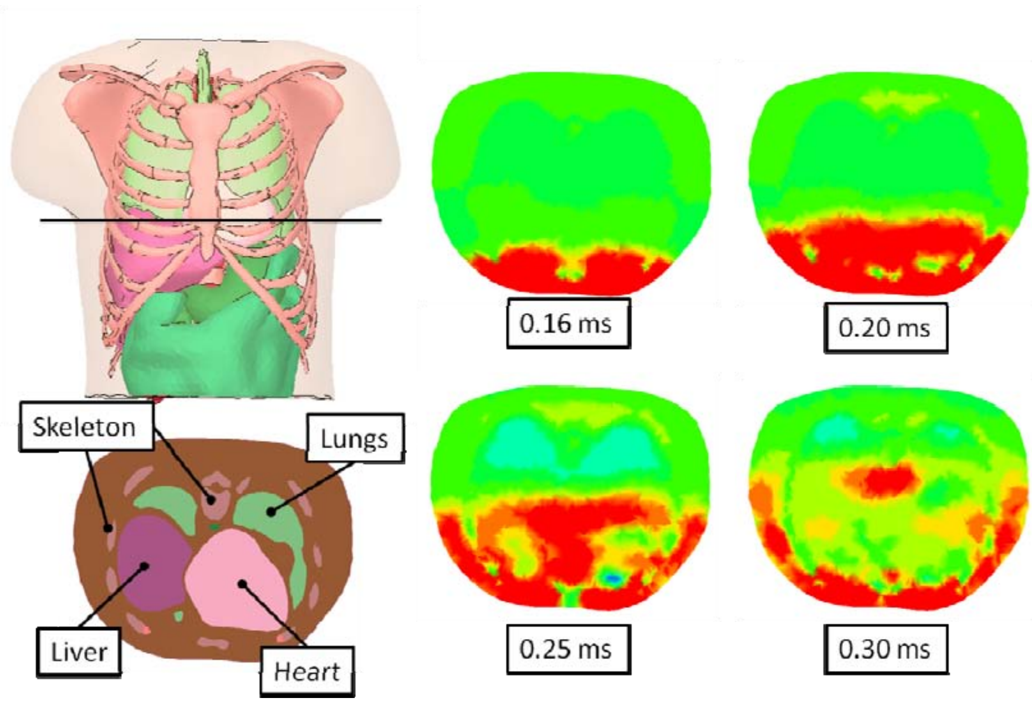


Figure 4 Pressure propagation through mid section of HTFEM for case 1

The maximum pressure in the liver, heart and stomach are compared for the three simulations. Figure 5 shows the pressure time history comparison for the heart, liver and stomach for Case 1. The pressure-time histories shown in Figure 5 are normalized to liver's maximum initial peak. The most protected organ, the heart, sits behind the sternum within the ribcage and shows the lowest peak pressure response. The liver, which is also partially protected by the ribs, has the next highest peak pressure, while the stomach, which is exposed, has the highest peak pressure. The pressure histories show similar characteristics between the three cases.

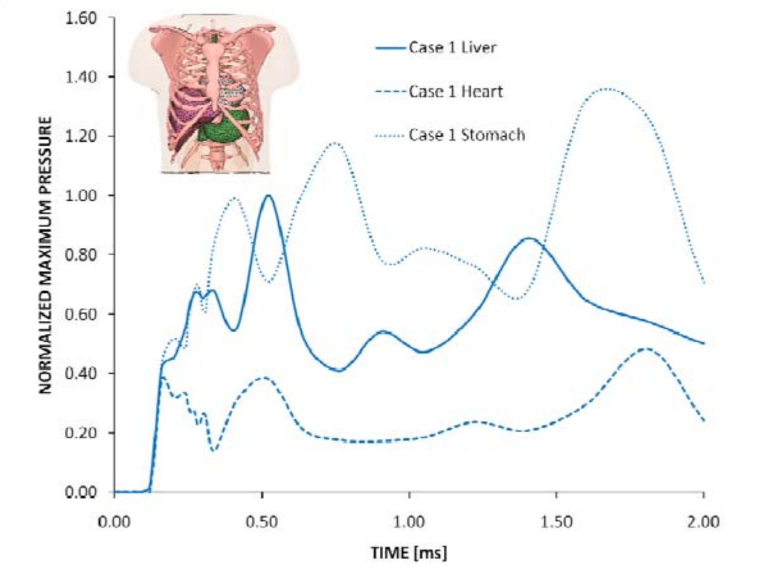


Figure 5 Maximum organ pressure time history response for the heart, liver and stomach for Case 1. Values normalized to Liver maximum initial peak.

The two cases that represent 50th percentile lethality scenarios yield different pressure histories within different organs. Figure 6 and Figure 7 show a comparison from the three loading cases of the normalized maximum pressure response for the heart and liver, respectively. The time histories in these two figures are normalized to Case 1 for the heart and liver, respectively. The magnitude of the heart response increases relative to the incident overpressure as seen in Figure 6. In Figure 7, it appears that there is a better correlation to the lethality percentage, since the pressure histories in the Liver for the two 50th percentile lethality cases (Case 2 and Case 3) are closer in magnitude than either one of these cases is to the pressure history for a 1 percent lethality case (Case 1).

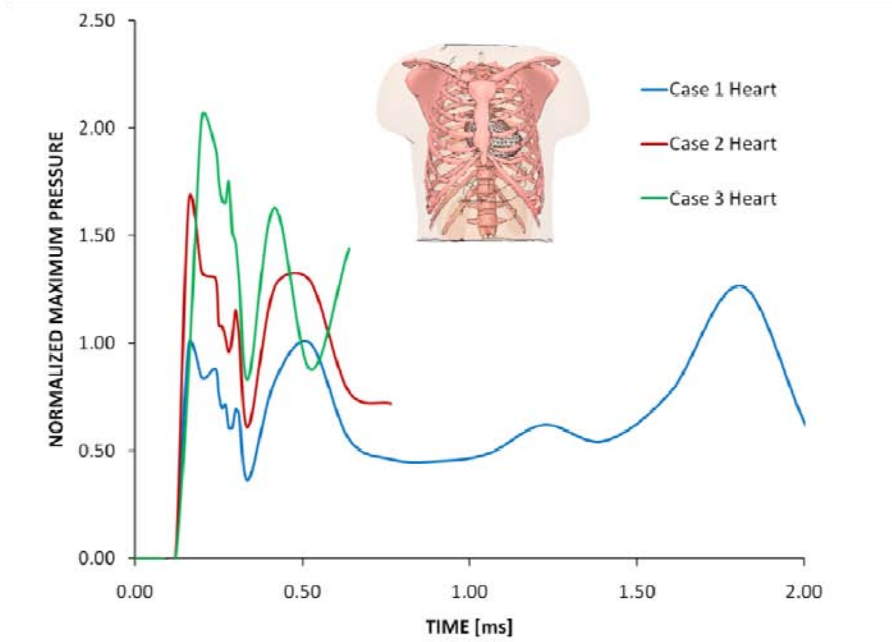


Figure 6 Maximum pressure response comparison for heart. Values normalized to Case 1 maximum initial peak

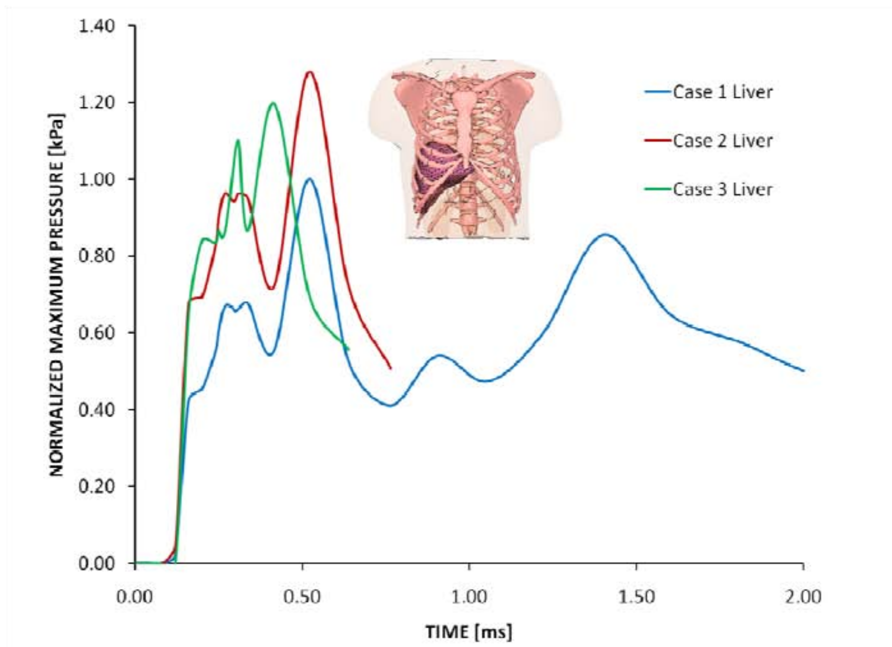


Figure 7 Maximum pressure response for the liver. Values normalized to Case 1 maximum initial peak

Conclusions

These results lead to some preliminary observations on the influence of geometric differences of HTFEM organ position, incident overpressure and percent lethality on the internal organ response. The heart, which is protected by the ribcage and resides partially behind the sternum, has the lowest peak response, while the liver, which is also protected by the ribcage, but is more exposed, exhibits a higher response. For a given load case in this study, the peak pressure in the stomach is the highest among the three organs.

The Bowen lethality curves are well-accepted; however, a computational model with the ability to represent the anatomical uniqueness of the human form will allow the exploration into other aspects of blast injury that cannot be determined through test devices and animal testing data. The HTFEM has been exercised in a severe blast environment for 3 cases that each have a statistical probability of mortality based upon the Bowen curves. The internal organ response of the HTFEM shows there is potential correlation to the geometric position of the organs, applied incident overpressure and the percent lethality.

The HTFEM represents the 50th percentile male geometry though it is not yet validated for the blast environment to predict injury. However, general observations made about the blast loading condition can help guide the further development of the HTFEM to become validated against relevant experiments.

Recommendations and Future Work

As the HTFEM further develops the loading conditions will need to be improved to be more realistic. Using the *LOAD_BLAST card allows the model to be exercised in the blast environment without the computational expense of the more accurate Arbitrary Lagrangian Eulerian (ALE) modeling techniques. A more realistic loading condition can be obtained by mapping a computational fluid dynamics (CFD) generated 3-D temporal pressure profile to the HTFEM or by modeling the actual explosion within an Eulerian air mesh directly in LS-DYNA. These options can be explored using modeling techniques such as Arbitrary Lagangian Eulerian (ALE) methods.

Future HTFEM development will build upon its current status and further examine areas that need more detailed definition. For example, the material models and parameters used for the soft tissue components are based upon silicone gel properties, and not human properties; they are fairly generic and are mostly differentiated from one another by their densities. Material model development and validation is needed to better represent the human and to be able to use the HTFEM to predict blast injury and/or lethality.

Under blast loading, the air-filled cavities in the body are particularly susceptible to damage which can lead to injury and mortality. The current model simulates lung tissue with a low-density compressible material that simulates these air filled cavities but does not address gas flow within the lungs or the effects of gas in the intestinal cavity. Improvements to the HTFEM could include more detailed consideration of air filled cavities, as modeled by ALE to address the effect of gas within the soft tissue structures.

The HTFEM can be used to make general observations about pressure propagation and compare relative response from different loading conditions. When it has matured to a validated state it can be used as a tool used to examine the blast effects, blast injury and lethality, on the human torso and aid in the design of personal protective equipment (PPE).

Works Cited

Bowen, I.G., Fletcher, E.R., Richmond, D.R. *Estimate of Man's Tolerance to the Direct Effects of Air Blast.* Technical Progress Report, DASA-2113, Washington, DC: Defense Atomic Support Agency, Department of Defense,, 1968.

Caruso, K. S. Hijuelos, J. C. Peck, G. E. Biermann, P. J. Roberts, J. C. "Development of Synthetic Cortical Bone for Ballistic and Blast Testing." *Journal of Advanced Materials*, 2006: VOL 38; NUMB 3, pages 27-36.

Duck, F. A. *Physical properties of tissue:A comprehensive reference book.* Academic Press, Harcourt Brace Jovanovich, Publishers, 1990.

Elsayed, N. M. "Toxicology of Blast Overpressure." *Toxicology* vol. 121 (1997): 1—15.

Hallquist, J.L. "LS-DYNA Keyword User's Manual, Nonlinear Dynamic Analysis of Structures." Livermore, CA: Livermore Software Technology Corporation, 2003.

Hyde, D. W. " ConWep 2.1.0.8 [Computer software]. ." Vicksburg, MS: US Army Engineer Research & Development Center, 2004.

Moss, S., Wang, Z., Salloum, M., Reed, M., van Ratingen, Cesari, D., Scherer, R., Uchimura, T. and Beusenberg, M. *Anthropometry for World SID A World –Harmonized Midsize Male Side Impact Crash Dummy.* SAE 2000-01-2202, Washington, D.C.: SAE, 2000.

Richmond, D. R., Yelverton, J. T., Fletcher, E. R. "New Air Blast Criteria for Man." *Twenty-Second DoD Explosive Safety Seminar.* Anaheim, CA: DoD Explosive Safety Board, 1986.

Roberts, J.C., Merkle A.C., Biermann P.J., Ward E.E., Carkhuff B.G. "Computational and experimental models of the human torso for." *Journal of Biomechanics*, 2007: Volume 40, Issue 1, 2007, Pages 125-136.

Segars, W.P. *Development of a new dynamic NURBS-based cardiac-torso (NCAT) phantom.* The University of North Carolina, May 2001.

Swisdak, M. M., Ward, J. M. "DDESB Blast Effects Computer Computer Version 5.0, DDESB TP 17,." Alexandria, VA: Department of Defense Explosive Safety Board, May 2003.

Wang, H.C. *Development of a side impact finite element human thoracic model. Ph.D. Thesis.* Detroit, MI.: Wayne State University, 1995.

Yang K.H., Hu J,White N.A. King A.I., Chou C.C., Prasad P. "Development of Numerical Models for Injury Biomechanics Research: A Review of 50 Years of Publications in the Stapp Car Crash Conference." *Stapp Car Crash Journal.* The Stapp Association, 2006. pp. 429-490.

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34th DDESB Seminar Portland, Oregon July 13-15, 2010

APL
The Johns Hopkins University
APPLIED PHYSICS LABORATORY

The Johns Hopkins University Applied Physics Lab

Overview

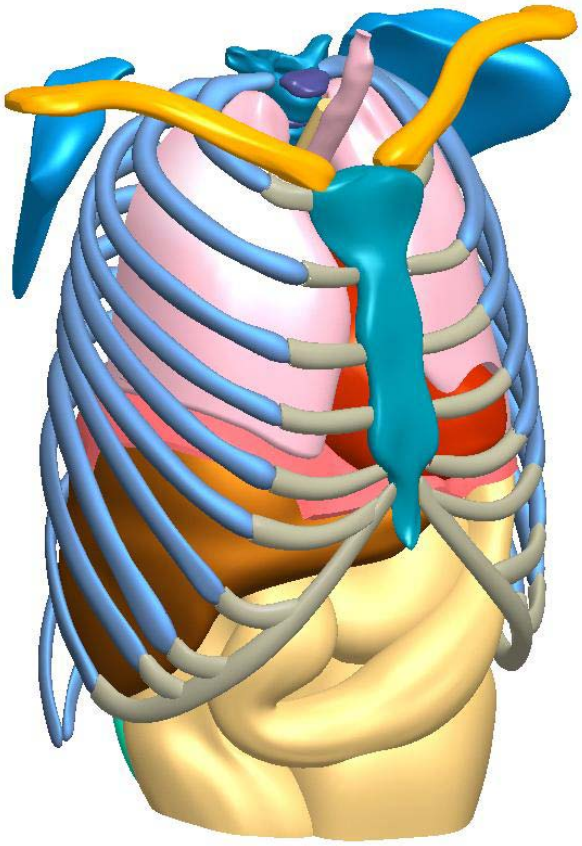
- **Introduction**
- **Finite Element Model (FEM) Development**
  - **Geometry**
  - **Material Properties**
  - **Boundary Conditions**
- **Results**
- **Conclusions**
- **Recommendations**

Purpose

- The purpose of this research is to aid the development of the anatomically accurate 50th percentile male Human Torso Finite Element model (HTFEM) by exercising it in a blast environment
  - Loading conditions with statistical probability of mortality based upon the Bowen curves
  - Internal organ responses relative to
    - Position inside thoracic cavity
    - Applied incident over-pressure
    - Probability of lethality

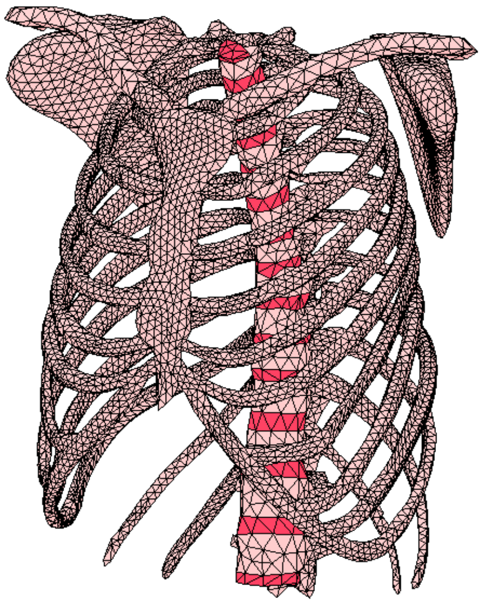
Finite Element Model (FEM) Development: Geometry

- **Male geometry originated from the 4-D NURBS-based Cardiac- Torso (NCAT) phantom that was developed for medical imaging research**
- **The original geometry was resized to a 50th percentile male based from the WORLDSID project**



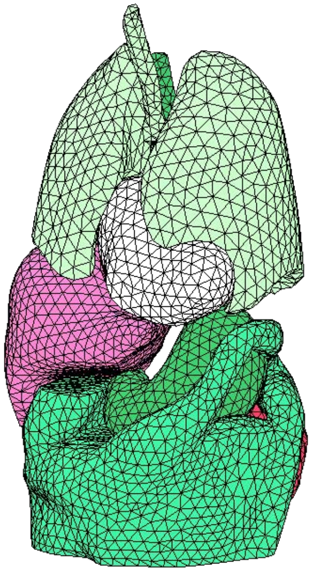
HTFEM Development
Skeletal Structure

- **Ten-noded tetrahedral elements**
- **Components**
  - **Ribs**
  - **Sternum**
  - **Cartilage**
  - **Thoracic Vertebrae**
  - **Intervertebral Disc**
  - **Scapula**
  - **Clavicle**



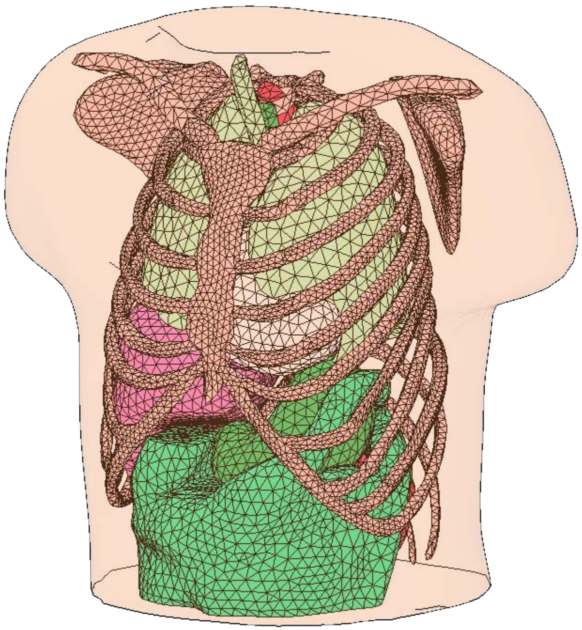
HTFEM Development
Internal Organs

- **Ten-noded tetrahedral elements**
- **Components**
  - **Lungs and trachea**
  - **Heart and aorta**
  - **Liver**
  - **Kidneys**
  - **Stomach and esophagus**
  - **Intestinal mass**



HTFEM Development

- **Components**
  - **Mediastinum/viscera**
    - **Ten-noded tetrahedral elements**
  - **Skin**
    - **Triangular shell elements**



HTFEM Development
Material Properties

	Solid Elements	Shell Elements	P (kg/ mm³) e-6	E (GPa)	v	K (Gpa)	G0 (kPa)	G∞ (kPa)	β
Skin	-	8192	1.2	.0005	.3	-	-	-	-
Ribs Sternum Vertebrae	34901	-	1.08	9.5	.2	-	-	-	-
Intervertebral discs	626	-	1.33	.355	.26	g	gg	g	g
cartilage	4884	-	1.08	9.5	.2	f	f	f	f
Heart	3262	-	1.0	-	-	.744	6.7e-5	6.5e-5	.1
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Kidney	2565	-	1.06	-	-	.744	6.7e-5	6.5e-5	.1
Stomach	2740	-	1.05	-	-	.744	6.7e-5	6.5e-5	.1
Intestinal mass	14698	-	0.6	-	-	.744	6.7e-5	6.5e-5	.1
Mediastinum/viscera	173871	-	2.07	1.02	.4	-	-	-	-

HTFEM Development Boundary Conditions

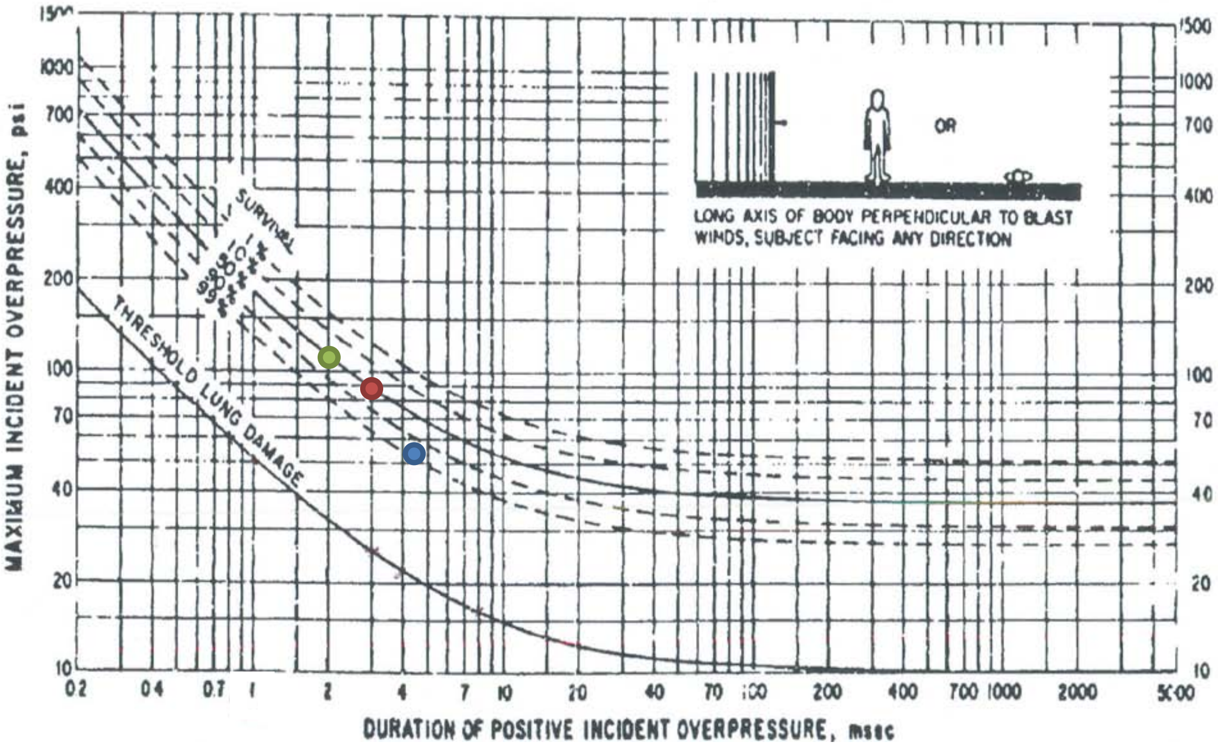
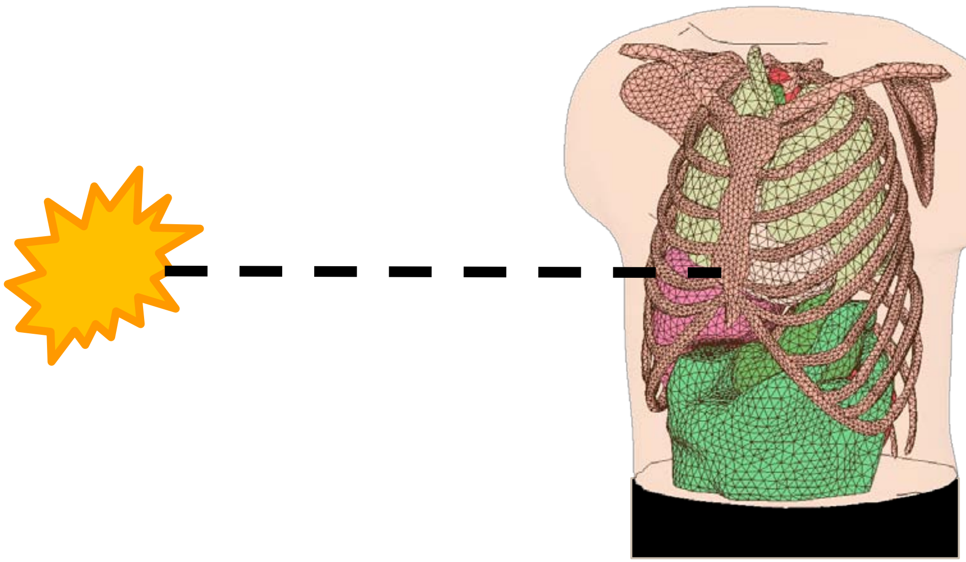
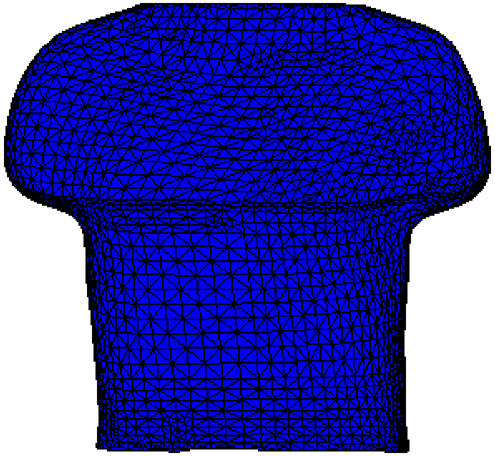


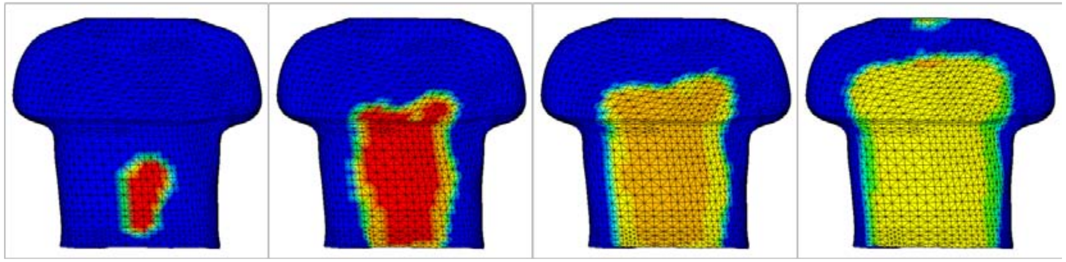
Figure extracted from Figure 6 of *Estimate of Man's Tolerance to the Direct Effects of Air Blast* (Bowen 1968)

Case	Charge Weight [kg]	Charge Distance [m]	Peak Incident Overpressure [kPa(psi)]	Positive Phase Duration [ms]	Lethality [%]
1	8.1	2.9	400 (58)	4.4	1
2	4.98	2.08	600 (87)	3.04	50
3	1.36	1.19	800 (116)	2.02	50

HTFEM Development
Boundary Conditions

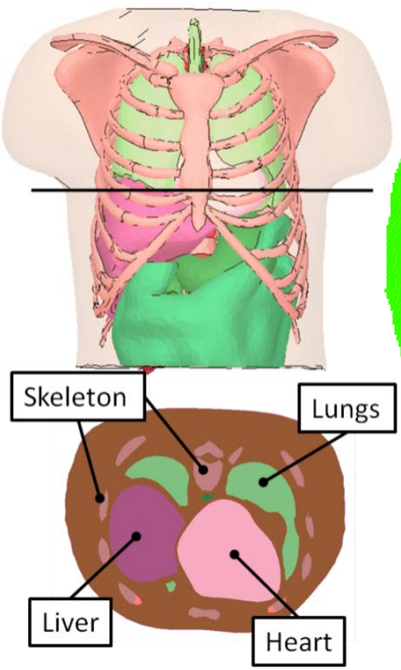


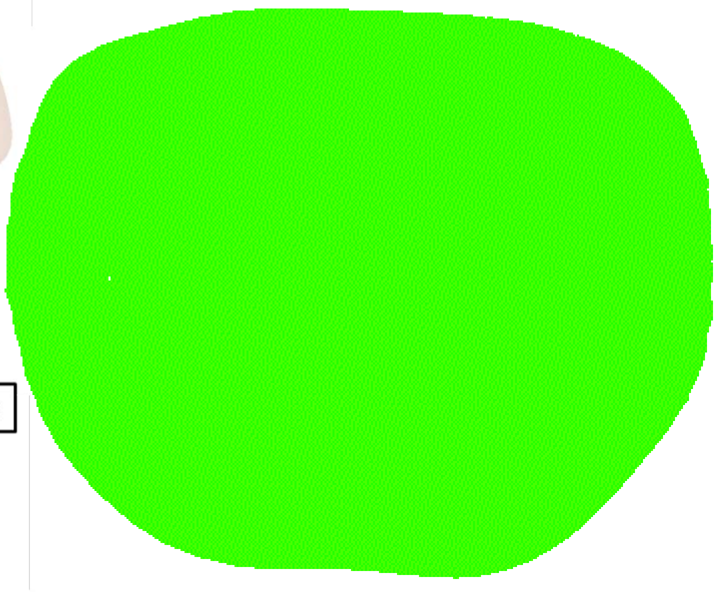


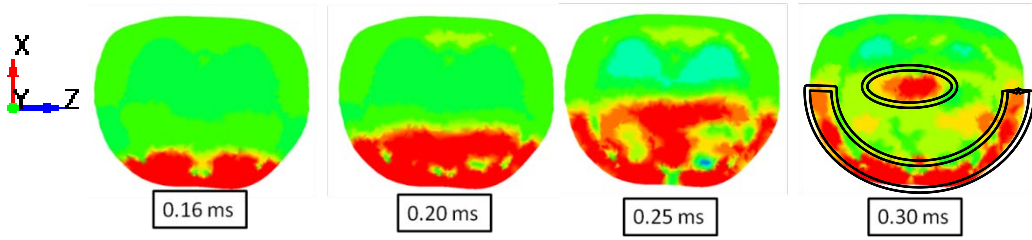


Results

- **Pressure propagation**
- **High pressure stagnates anterior to the skeletal structure**
  - **Ribcage**
  - **Vertebral column**
  - **Same area where element failure occurs**

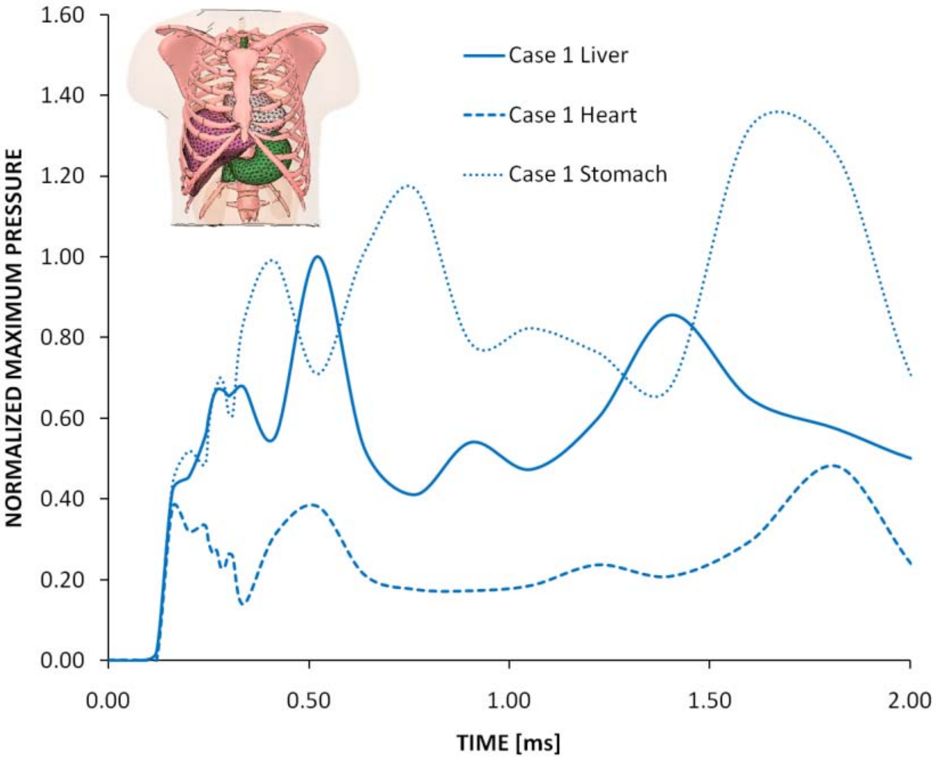






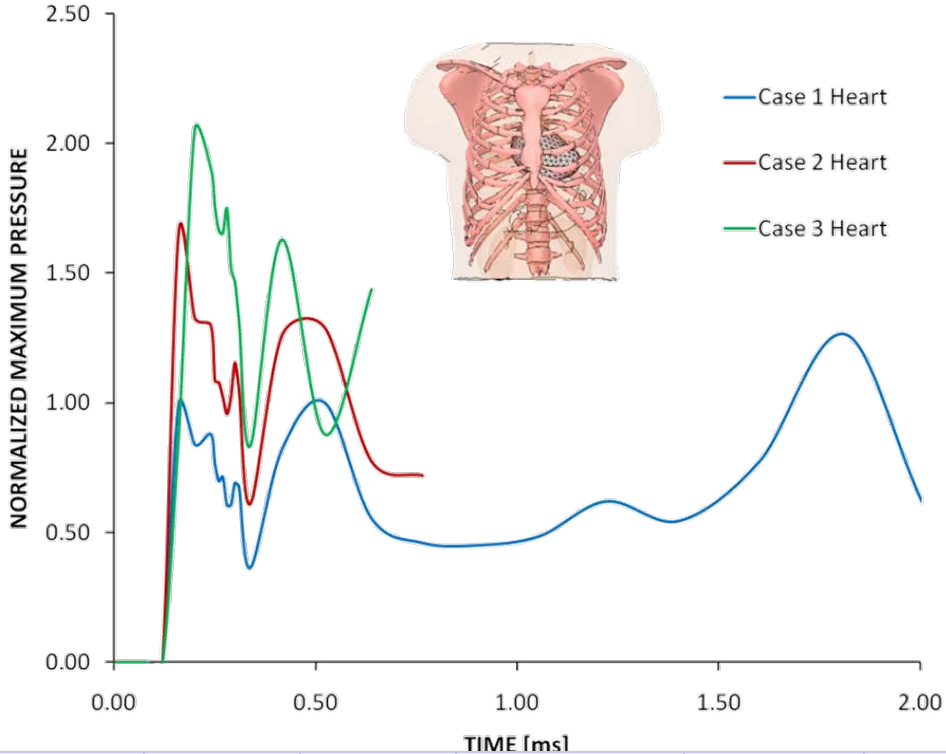
Results

- **Case 1 Organ response comparison**
- **Results normalized to Liver maximum initial peak**
- **Heart response is the lowest**
  - **Most protected by sternum and ribcage**
- **Liver and stomach are similar initially**
  - **Stomach peaks first**
  - **Stomach secondary peak visible**
    - **Stomach is most exposed**
    - **Liver resides mostly behind the ribcage**



Results

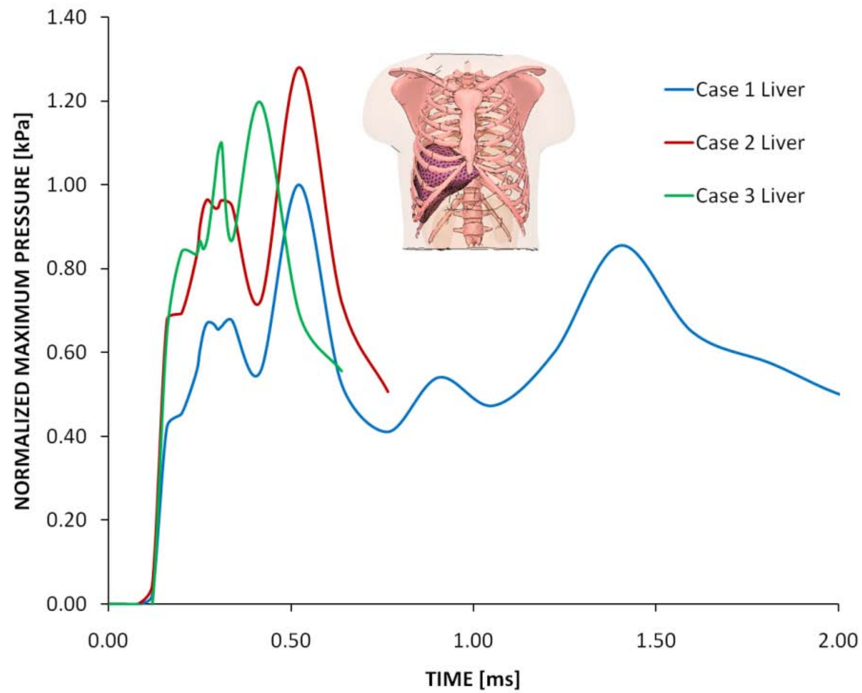
- **Heart response comparison**
- **Results normalized to Case 1 Heart maximum initial peak**
- **Severity of response increases as the peak incident over pressure increases**



Case	Charge Weight [kg]	Charge Distance [m]	Peak Incident Overpressure [kPa(psi)]	Positive Phase Duration [ms]	Lethality [%]
1	8.1	2.9	400 (58)	4.4	1
2	4.98	2.08	600 (87)	3.04	50
3	1.36	1.19	800 (116)	2.02	50

Results

- **Liver response comparison**
- **Results normalized to Case 1 Liver maximum initial peak**
- **Severity of response increases as lethality increase**
  - **Case 2 and 3 not significantly different as the heart response**



	Case	Charge Weight [kg]	Charge Distance [m]	Peak Incident Overpressure [kPa(psi)]	Positive Phase Duration [ms]	Lethality [%]
	1	8.1	2.9	400 (58)	4.4	1
	2	4.98	2.08	600 (87)	3.04	50
	3	1.36	1.19	800 (116)	2.02	50

Conclusions - General Observations

- HTFEM exercised in severe blast environment for statistical probability of mortality based upon the Bowen curves
- HTFEM shows distinction between the internal organ responses relative to position, incident overpressure and %lethality
  - Heart response is lowest among the heart liver and stomach (the stomach is the highest)
    - Response relative to amount of soft tissue exposure to pressure wave
    - Heart is most protected by ribcage and the stomach is the least protected
  - Peak incident overpressure show a relative relation to the Heart response
  - Lethality response shows a relative relation to the liver response

Conclusions

- **Computational models representing anatomical uniqueness of the human form**
  - **Allow the exploration into other aspects of blast injury that cannot be determined through test devices and animal testing data**
- **General observations for these blast loading condition**
  - **Guide the further development of the HTFEM to become validated against relevant experiments**

Recommendations

- Improve the loading conditions to be more realistic
  - Mapping a computational fluid dynamics (CFD) generated 3-D temporal pressure profile to the HTFEM
  - Modeling the actual explosion within an Eulerian air mesh directly in LS-DYNA

Recommendations – Future Work

- Apply validated human properties to the model to predict, computationally, injury and/or lethality due to blast exposure.
- Include the air-filled cavities
  - Lungs
  - Gastrointestinal cavity
- Explore model response with PPE

Final Thought

- **HTFEM can be used to make general observations**
  - **Pressure propagation**
  - **Compare relative response from different loading conditions**
- **In mature and validated state, it can be a tool to examine**
  - **Blast effects (blast injury and lethality)**
  - **Aid in the design of personal protective equipment (PPE)**

Comparing Blast Effects on Human Torso Finite Element Model against Existing Lethality Curves

Emily Ward
Tim Harrigan
Andrew Merkle
Jack Roberts

34th DDESB Seminar Portland, Oregon July 13-15, 2010

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