Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Development and validation of a finite element human torso model under blunt ballistic impact

A. Bouamoul
DRDC Valcartier

H. Lévesque
Research Assistant, Laval University

Defence R&D Canada – Valcartier
Technical Memorandum
DRDC Valcartier TM 2006-560
December 2007

Canada

Development and validation of a finite element human torso model under blunt ballistic impact

A. Bouamoul
DRDC Valcartier

H. Lévesque
Research Assistant, Laval University

Defence R&D Canada – Valcartier

Technical Memorandum

DRDC Valcartier TM 2006-560

December 2007

Author

Amal Bouamoul

Approved by

Dennis Nandlall

Section Head, Weapons Effects and Protection

Approved for release by

Christian Carrier

Chief Scientist

Abstract

A simplified finite element model of a human torso has been developed in order to investigate and predict the biomechanical response of an actual torso to blunt ballistic impacts. The model consists of a simplified three-dimensional human torso. The torso was impacted with a non-compressible polyvinyl chloride cylinder. The projectile is a cylinder 37 mm in diameter and either 28.5 mm or 100 mm long. The purpose of this study was to validate the biomechanical response model with the results of experiments on post mortem human subjects published in the open literature. The chest dynamic deflection, the dynamic force applied to the chest and the force applied to the chest as a function of chest deflection were compared and validated with the experimental data. Substantial agreement between the numerical model and the experiments was achieved.

Résumé

Un model tridimensionnel d'éléments finis a été développé dans l'objectif d'étudier et de prédire les réponses biomécaniques d'un torse humain sous l'impact de projectiles non-pénétrants. Le projectile utilisé est fabriqué en chlorure de polyvinyle non compressible et a un diamètre de 37 mm et 28.5 mm ou 100 mm de long. L'objectif de cette étude est la validation des réponses biomécaniques du modèle numérique avec des résultats expérimentaux publiés en littérature ouverte sur des cadavres humains. La déflection dynamique du torse, la force dynamique appliquée sur le torse et la force appliquée sur le torse en fonction de sa déflection sont les réponses biomécaniques utilisées pour valider le modèle numérique. Basé sur ces critères, le modèle numérique a suffisamment bien reproduit le comportement d'un torse humain sous l'impact de projectiles non-pénétrants.

This page intentionally left blank.

Executive summary

In recent years, the use of non-lethal weapons by military forces has increased. Non-lethal weapons are designed to control rioting crowds or disruptive individuals without causing severe or lethal injuries, although some severe injuries and fatalities have been reported. Blunt ballistic impacts are defined as 20–200 g projectiles impacting at 20–250 m/s.

A simplified finite element three-dimensional torso model was built and impacted by a non-compressible polyvinyl chloride cylinder 37 mm in diameter and either 28.5 mm or 100 mm long. The evaluation and validation of the biomechanical response model were based on the results of experiments on post mortem human subjects published in the open literature. The impact conditions were 140 g at 20 m/s, 140 g at 40 m/s and 30 g at 60 m/s. The chest dynamic deflection, the dynamic force applied to the chest and the force applied to the chest as a function of chest deflection were compared and validated with the experimental data. Substantial agreement between the numerical model and the experiments was achieved.

This study was done at DRDC Valcartier between September and December 2005, under the numerical models development and integration for complex blast injury and protection (virtual man) project 12ra.

Bouamoul, A. and Lévesque, H. 2007. Development and validation of a finite element human torso model under blunt ballistic impact. DRDC Valcartier, TM 2006-560. Defence Research and Development Canada.

Sommaire

Depuis les dernières années, l'utilisation des armes non-pénétrants a augmentée. Ces armes sont conçues pour contrôler les foules ou des individus hostiles sans leurs causer des blessures graves. Cependant, quelques accidents et blessures sévères ayant causés la mort ont été reportés. Les impactes non-pénétrants sont causés pas des projectiles ayant une masse entre 20 g et 200 g et une vitesse entre 20 m/s et 250 m/s.

Le model numérique d'éléments finis utilisé dans cette étude représente une géométrie tridimensionnelle simplifiée d'un torse humain impacté pas des projectiles cylindriques. Les projectiles sont faits de chlorure de polyvinyle non compressible ayant un diamètre de 37 mm et 28.5 mm ou 100 mm de long. L'évaluation et la validation des réponses biomécaniques du model ont été faits avec des résultats expérimentaux provenant de cadavres humains et publiés en la littérature ouverte. Les conditions d'impact étaient 140 g à 20 m/s, 140 g à 40 m/s et 30 g à 60 m/s. La déflection dynamique du torse, la force dynamique appliquée par le projectile sur le torse et la déflection en fonction de la force sont les données utilisées pour valider le modèle numérique. Une bonne concordance entre les résultats provenant du model numérique et ceux des tests expérimentaux a été obtenus.

Ce travail a été réalisé à RDDC Valcartier entre septembre et décembre 2005 dans le cadre du projet 12ra '*Numerical models development and integration for complex blast injury and protection (virtual man)*'.

Bouamoul, A and Lévesque, H. 2007. Development and validation of a finite element human torso model under blunt ballistic impact. DRDC Valcartier, TM 2006-560. Recherche et développement pour la défense Canada.

Table of contents

List of figures

List of tables

This page intentionally left blank.

1. Introduction

In recent years, the use of non-lethal weapons by military forces has increased. Non-lethal weapons are designed to control rioting crowds or disruptive individuals without causing severe or lethal injuries, although some severe injuries and fatalities have been reported [Refs. 1, 2, 3, 4, 5]. To efficiently design non-lethal weapons, the injuries caused by their projectiles must be clearly specified.

The most accurate way to investigate level of injury is to perform experimental tests on post mortem human subjects (PMHSs) and animals and establish a database of injury threshold criteria for specific projectiles [Ref. 1]. However, it is almost impossible experimentally to cover all types of projectiles, impact velocities and impact locations. Testing new non-lethal or lethal projectiles is a costly process in terms of money and time, not to mention ethical considerations. Instead, accurate numerical simulation can be used as a vulnerability assessment tool. Numerical simulation is advantageous in many ways. If the model is well calibrated and validated, parametric studies for different types of projectiles and different impact conditions can be done quickly and efficiently.

A simplified finite element (FE) model of a human torso is presented. The model was developed to investigate and predict the biomechanical response of an actual torso to blunt ballistic impacts. In real riot-control situations, only 16% of all injuries occur to the torso [Ref. 3], but 36% of the severe torso injuries are caused by non-lethal projectiles [Ref. 3]. Other critical parts subject to severe injury (the head, neck and abdomen [Ref. 3]) will be considered in future studies.

The main goal in this study was to calibrate and validate, using experimental data, the biomechanical responses of a human torso model to blunt ballistic impact. Blunt ballistic impacts are caused by projectiles that have a weight of 20 g to 200 g and a velocity of 20 m/s to 250 m/s [Ref. 6]. The performance of the torso model was compared to experimental tests on PMHSs [Ref. 6]. The chest dynamic deflection, dynamic force applied to the chest and force applied to the chest as a function of chest deflection were used to compare and validate the response of the numerical model.

2. Model description

A numerical torso model and the hydrodynamic FE computer code LS-DYNA [Ref. 7] were used to simulate projectile impacts on a human torso. LS-DYNA is an explicit/implicit three-dimensional FE code used to analyze large deformations and high strain rate response in elastic and inelastic structures.

2.1 Torso model

The model described in this section was initially developed by the University of Waterloo under contract number W7701-024463/001/QCA to reproduce human torso biomechanical response under blast loading [Refs. 8, 9, 10, 11]. The Waterloo model was comprised of four hexagonal elements to approximate a 14 mm section of the mid-torso between the fifth and sixth ribs. Because projectiles involved in this study have a diameter of 37 mm, the Waterloo mesh model was modified. The initial thickness of the torso section was extruded from 4 hexagonal elements to 48, representing a thickness of 168 mm (see Fig. 2). Figure 1 shows a comparison between the top view of a real human torso slice and the numerical model, in which the components are labelled. Figure 2 shows the result of the extrusion of the torso layers and a real human rib cage. As one can note, there are some differences between the numerical model and a real torso.

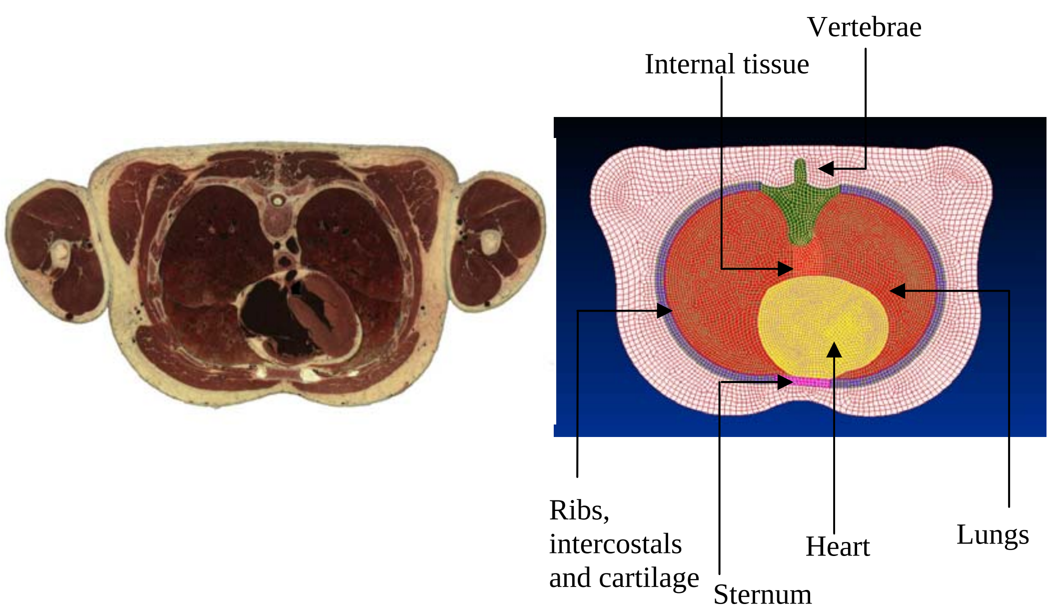

Figure 1. *Torso components comparison and identification – top view [Ref. 12]*

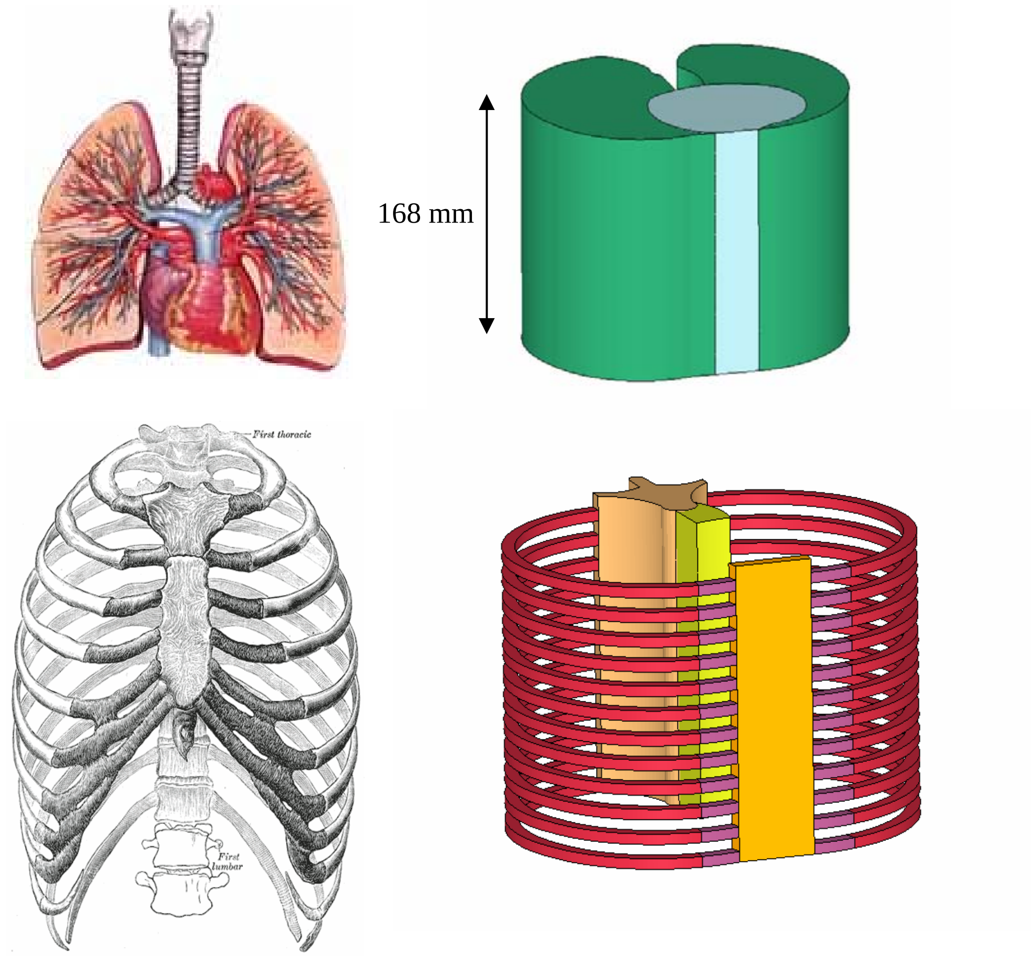

Figure 2. *Comparison between the FE model and a real human torso.*
a. internal organs, b. rib cage [Refs. 13, 14]

2.2 Comparison between real human torso and FE model

The numerical model is a simplified representation of the human torso. There are several differences between the numerical model and an actual human torso. Considering the anatomical complexity of the human torso, only the major differences between the numerical model and an actual human torso are discussed here. These differences are classified in two main categories: anatomy and contact between components.

2.2.1 Differences in anatomy

Anatomical differences are mainly a result of the extrusion of the initial mid-torso section from 4 hexagonal solid elements to 48. There are 24 ribs in the numerical model compared to 20 in a real rib cage. The first seven pairs of ribs in a real thorax are connected to the sternum in front. The eighth, ninth, and tenth are attached in front to the cartilaginous portion of the next rib above, which is not the same as the numerical model. Finally, the lower two, are not attached in front which differ from the numerical model. These dissimilarities may cause the FE model to respond more rigidly to blunt impact.

Cartilage is a type of dense connective tissue that links each rib to the sternum. At the top of a human rib cage, the lengths of the cartilage sections are shorter than the ones in the bottom. In the FE model, they were modeled all with the same length. This dissimilarity will probably give a stiffer response to blunt ballistic impact.

The heart in the numerical model is cylindrical and measures 168 mm in length. A human heart has a more spherical shape and a diameter of about 120 mm [Ref. 15]. Also, the model does not include blood flow, bronchial tree or arteries.

The lungs in the FE model are cylindrical, whereas real human lungs are conical, with more volume in the lower portion of the rib cage.

2.2.2 Contact between components

The biological materials that link or divide thoracic components are complex. All the numerical model components have their nodes merged together to avoid using a FE algorithm for contact which help reduce the computation time.

2.2.2.1 Ribs, intercostals and lungs

Rib and intercostal nodes have been merged with the lungs to limit lung movement in the thoracic cavity. Real human lungs are not constrained, so they can move during respiration. Pleural cavities, which are between the parietal cavities and visceral pleural membranes, contain a small quantity of lubricating fluid that allows the lungs to move. Finally, merging the lung nodes with the intercostal/rib nodes may over-restrict the movement of the chest when it is impacted. Further enhancements can be made to the torso model by allowing contact between the lungs and other chest components.

2.2.2.2 Sternum and cartilage

Nodes between the sternum elements and cartilage elements were merged together. In real human chest, ligaments join these two parts. Ligaments, which do not have a plastic phase, have an ultimate tensile strength of 0.2 kg/mm^2 at 160% of elongation [Ref. 16]. For some impact conditions, fractures, tearing and dislocation have been observed at the interface of the sternum and cartilage [Ref. 6]. With the sternum and cartilage nodes merged, these consequences cannot be simulated.

2.3 Constitutive material models

A literature review was conducted to characterize the material properties of each torso component [Ref. 8]. Table 1 lists the material properties of each part of the FE torso and their corresponding LS-DYNA material model. Muscle, heart, internal tissue and intercostals were modeled using the MAT_SIMPLIFIED_RUBBER model. This material allows strain rate sensitive behaviour without viscoelastic behaviour [Ref. 7]. Ribs, costal cartilage, vertebrae and sternum were modeled using the MAT_ELASTIC model [Ref. 7]. This model requires density, Young's modulus and Poisson's ratio. Fracture, tearing and plastic strain are prohibited with the MAT_ELASTIC model. Human autopsies have shown that bones exhibit elastic-plastic behaviour. Fractures were reported mainly on ribs and sternum in some specimens under specific impact conditions [Ref. 6].

Table 1: *Material properties for each part of the torso*

PART	MATERIAL MODEL	DENSITY (kg/m^3)	YOUNG MODULUS (Pa)	POISSON RATIO	BULK MODULUS (Pa)
Muscle					
Heart	MAT_SIMPLIFIED_RUBBER	1050	N/R	N/R	2.2 E9
Internal tissue					
Intercostals					
Ribs	MAT_ELASTIC	1561	7.9 E9	0.379	10.9 E9
Lungs	MAT_NULL	200	N/R	N/R	N/R
Vertebrae	MAT_ELASTIC	1644	9.6 E9	0.376	12.9 E9
Costal cartilage	MAT_ELASTIC	1281	49 E6	0.400	81.6 E6
Sternum	MAT_ELASTIC	1354	3.5 E9	0.387	5.2 E9

N/R: Not required

2.4 The PVC projectile

The projectile shown in Fig. 3 was modeled as a non-compressible polyvinyl chloride (PVC) cylinder to represent the plastic baton round used in real crowd-control situations [Refs. 2, 3, 4, 6]. The MAT_ELASTIC model was used for the PVC projectile. The mechanical properties of the projectile are given in Table 2. The projectile is a cylinder 37 mm in diameter and either 28.5 mm or 100 mm long.

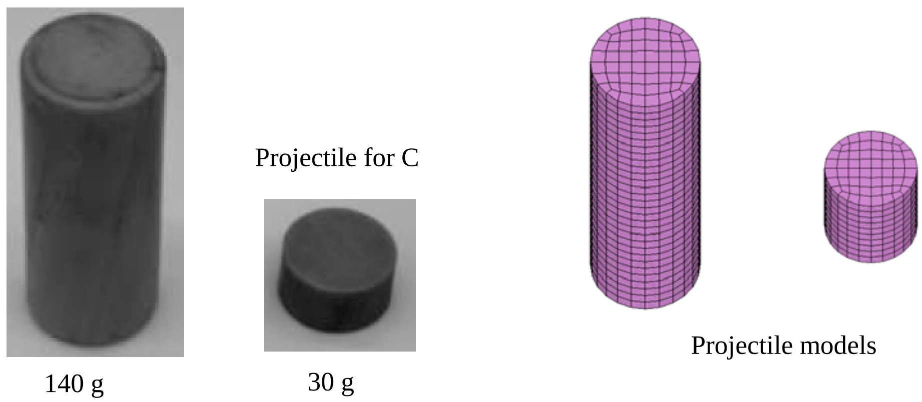

Figure 3. *Projectile models – 140 g and 30 g [Ref. 17]*

Table 2*: Material properties for the PVC projectile [Ref. 17]*

PROJECTILE	**MATERIAL MODEL**	**DENSITY** (kg/m^3)	**YOUNG MODULUS** (Pa)	**POISSON RATIO**
PVC	MAT_ELASTIC	1380	2.3 E9	0.33

3. Model validation

To validate the torso biomechanical responses under blunt ballistic impact, the data from the experimental tests on PMHSs done by Bir were used [Ref. 6]. The test conditions used by Bir were reproduced numerically, and the force applied by the projectile versus time, the deflection of the torso versus time and the force versus deflection were computed and compared to the experimental test data. The force-deflection results are given in Annex A. The projectile force-time and the torso deflection-time are presented in this section.

The torso model was impacted with a PVC projectile in the middle of the torso at different conditions, which are listed in Table 4.

Table 3: *Impact conditions with PVC projectiles*

IMPACT CONDITION	Mass (g)	Length (mm)	Diameter (mm)	Speed (m/s)
A	140	100	37	20
B	140	100	37	40
C	30	28.5	37	60

Considering differences in biomechanical response for each experimental specimen, Bir proposed a biomechanical probability zone corridor to represent responses to impact [Ref. 6]. The upper and lower limits of this biomechanical corridor were generated only from the loading phase induced by real projectile impacts. Experimentally, Bir used a video camera shooting 6000–9000 frames per second and an accelerometer operating at 20 kHz to compute the biomechanical responses. Numerically, torso deflection and projectile deceleration were computed at 0.1 ms intervals.

3.1 Deflection-time curves

Comparisons between the torso deflection computed by the numerical model and the experimental data for impact conditions A, B and C are shown in Figs. 4, 5 and 6 respectively. Table 5 shows the maximum compression (C_{max}) and its corresponding time in the experimental tests and the numerical model.

The deflection under impact conditions A, B and C were mainly within the biomechanical corridor. For these impacts, the numerical torso deflection followed approximately the same trend. The numerical deflection peak was lower than the experimental values. Under impact condition B, and after 1 ms, the numerical curve reaches its maximum which does not correspond to the experimental values. During the first millisecond under impact conditions A and C, the torso deflection was close to the upper limit of the corridor.

Table 4. *Summary of the deflection-time values*

Impact condition	Experimental data		FE model	
	C_{max} (mm)	Time (ms)	C_{max} (mm)	Time (ms)
A	25.9 ±3.1	4 to 5	17.5	2.9
B	54.7 ±14.6	4 to 5	24.6	2.5
C	20.1 ±7.8	N/A	12.5	1.9

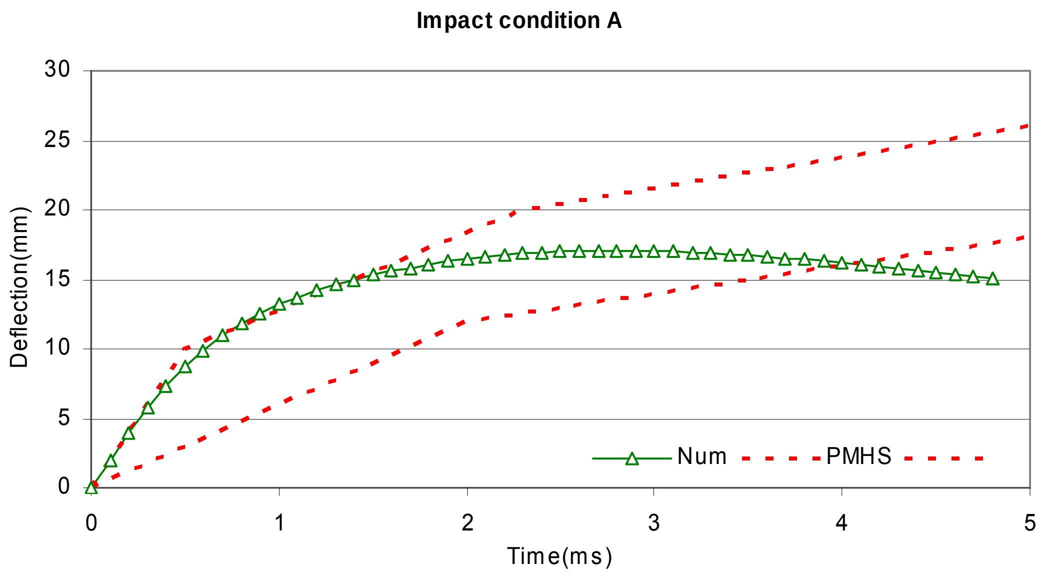

Figure 4. *Deflection-time curve for impact condition A*

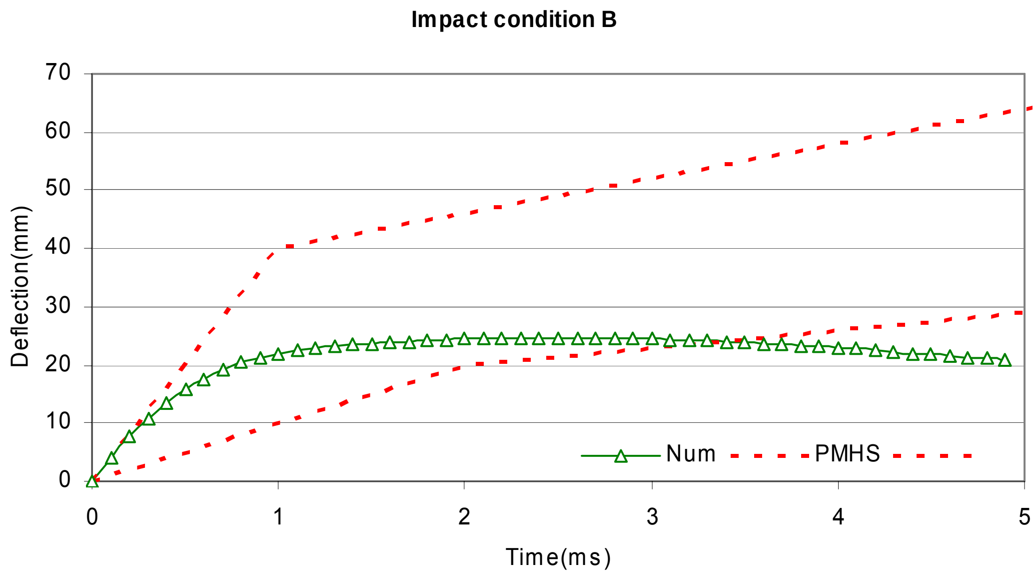

Figure 4. *Deflection-time curve for impact condition B*

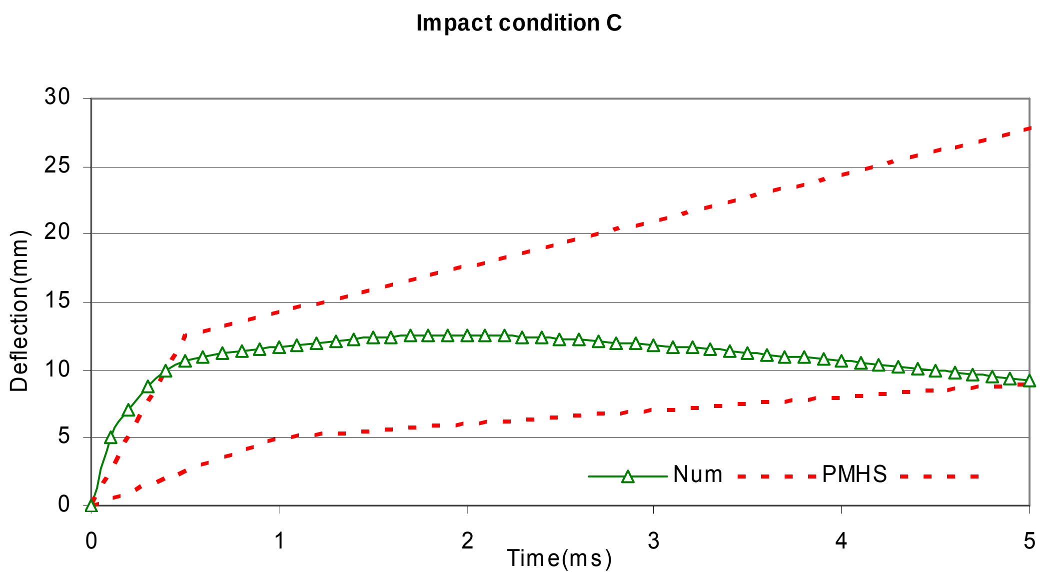

Figure 4. *Deflection-time curve for impact condition C*

3.2 Force-time curves

The total force applied on the torso by the projectile was calculated by multiplying the projectile mass by its acceleration (F=ma). A comparison of the average forces recorded experimentally and computed numerically is shown in Table 6. Figs. 7, 8 and 9 show a comparison between the computed values and the experimental test data in terms of the force applied by the projectile under impact conditions A, B and C, respectively. The force computed for impact conditions A and C showed a peak higher than the experimental values. This observation is consistent with the deflection curves seen in the previous section. For impact condition B, the dynamic force applied by the projectile is comparable to the experimental values.

Table 5. *Summary of the force-time values*

Impact condition	Experimental data		Model	
	F_{max} (N)	Time (ms)	F_{max} (N)	Time (ms)
A	3380 ±760	0.5	5565	0.3
B	10620 ±2220	0.4	8010	0.3
C	3160 ±310	0.25	3860	0.1

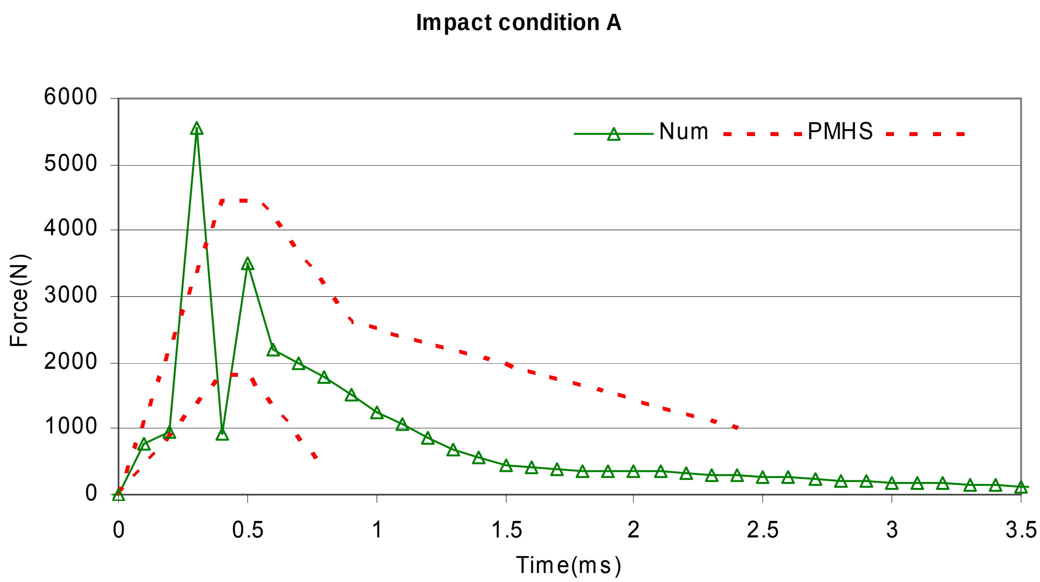

Figure 7. *Force-time curve for impact condition A*

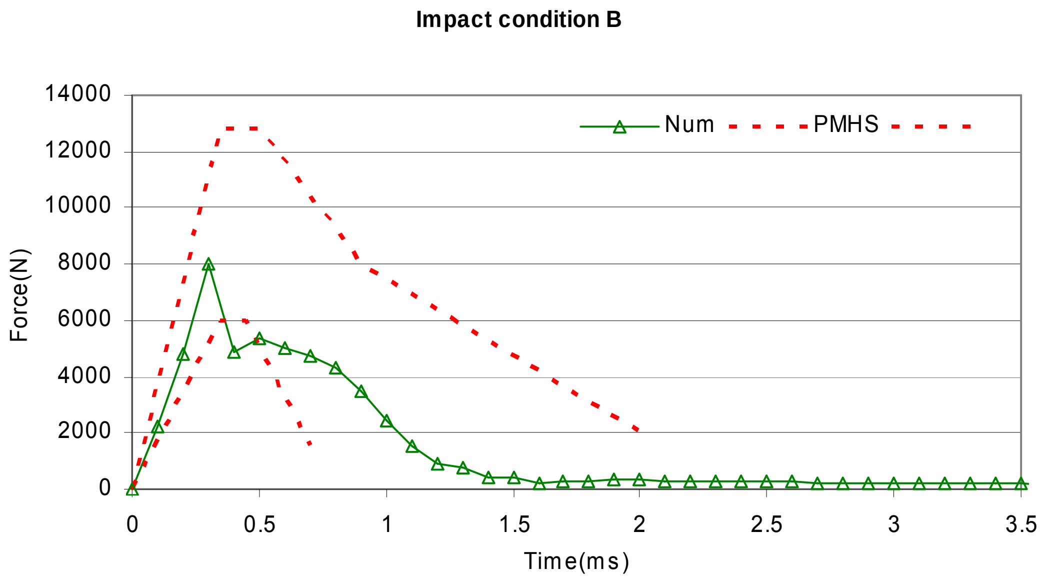

Figure 8. *Force-time curve for impact condition B*

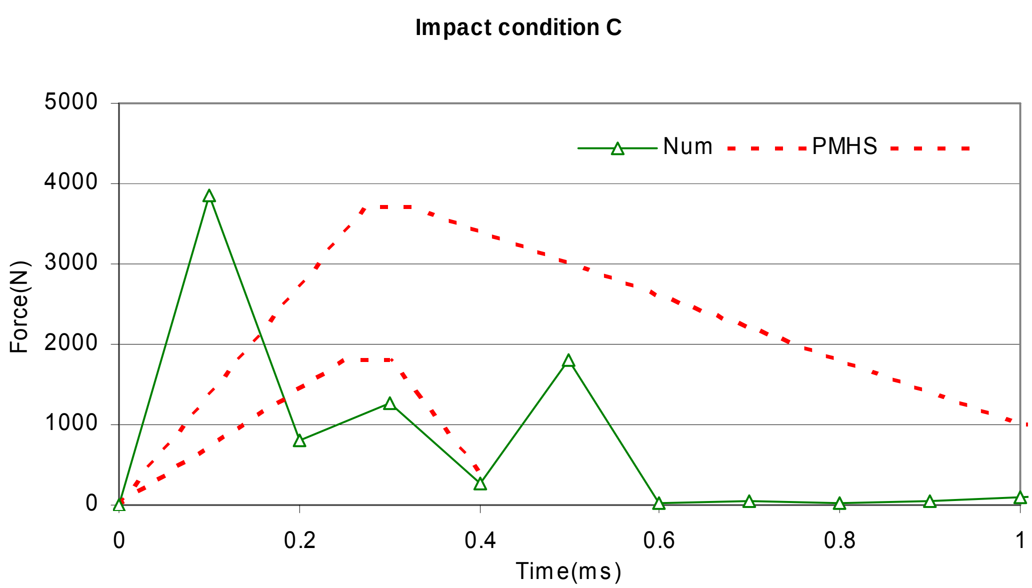

Figure 9. *Force-time curve for impact condition C*

4. Conclusion

The purpose of this study was to evaluate and validate the biomechanical response of the numerical torso model with the results of ballistic blunt impact experiments on post mortem human subjects. The chest dynamic deflection, the dynamic force applied on the chest and the force applied on the chest as a function of chest deflection were compared and validated with the PMHS corridors. Overall, substantial agreement between the numerical model and the experiments was achieved despite the fact that the deflection peak was reached sooner in time and was lower than the experimental values.

The model will be developed further to make it more representative of actual human biomechanical responses to blunt ballistic impact. Development work will include refinement of torso component geometries, implementation of better contacts between individual torso components and modification of some material properties.

5. References

1. Bir, C.A. and Viano, D.C., *Design and Injury Assessment Criteria for Blunt Ballistic Impacts*. Journal of Trauma, Vol. 57, No. 6, pp. 1218-1224, 2004.

2. Ritchie, A.J., *Plastic bullets: significant risk of serious injury above the diaphragm*, Injury: The British Journal of Accident Surgery, Vol. 23, No. 4, pp. 265-266.

3. Steele, J.A., McBride, S.J., Kelly, J., Dearden, C.H., and Rocke, L.G., *Plastic bullet injuries in Northern Ireland: experiences during a week of civil disturbances*. Journal of Trauma, Vol. 46, No. 4, pp. 711-714, 1999.

4. Eileen, K., Seamus, P., *The Anatomy of Plastic Bullet Damage and Crowd Control*. International Journal of Health Services, Vol. 17, No. 2, 1987.

5. Vlesis, A.A., Trunkey, D.D., *Non-penetrating Injury of the Thorax*. Scientific Foundations of Trauma, Cooper, G.J., Dudle, H.A.F., Gann, D.S., Little, R.A., Maynard, R.L., Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford, pp. 127-143, 1997.

6. Bir, C.A., *The evaluation of blunt ballistic impacts of the thorax*, Ph.D. Thesis, Wayne State University, Detroit, 2000.

7. Hallquist, J., *LS-DYNA Users Manual – Version 970*, Livermore Software Technology Corporation, Livermore, CA, 2003.

8. Cronin, D., Salisbury, C. and Greer, A., *Numerical Modeling of Blast Injuries – Phase I Report*, Technical Report for DRDC Valcartier, March 2004.

9. Salisbury, C., Cronin, D. and Greer, A., *Numerical Modeling of Blast Injuries – Phase II Report*, Technical Report for DRDC Valcartier, October 2004.

10. Salisbury, C., Cronin, D. and Greer, A., *Numerical Modeling of Blast Injuries – Phase III Report*, Technical Report for DRDC Valcartier, March 2005.

11. Salisbury, C., Cronin, D. and Greer, A., "*Numerical Modeling of Blast Injuries – Phase IV Report*", Technical Report for DRDC Valcartier, October 2005.

12. National Library of Medicine, *The visible human project*, http://www.nlm.nih.gov/research/visible/applications.html, (Feb 2006)

13. Orange Afro, *MY LUNG VS. YOUR NHS*, http://www.orangeafro.com/article.php?id=197, (Feb 2006)

14. Wikipedia, *The Free Encyclopedia*, http://en.wikipedia.org/wiki/Rib_cage, (Feb 2006)

15. Grabowski, S.R. and Tortora, G.J., *Principles of Anatomy & Physiology*, Wiley, Tenth edition. 2003.

16. Yamada, H. and Gaynor Evans, F., *Strength of Biological Materials*, Williams & Wilkins, 1970.

17. Matweb, *The Online Materials Information Resource*, http.//www.matweb.com/ (Feb. 2006)

6. Annex A – force-deflection curves

The numerical data representing torso biomechanical responses were compared with the data from the experimental tests on post morten human subjects [Ref. 6]. The following curves demonstrate that the mechanical properties used in the numerical simulations are a valid representation of the true mechanical properties.

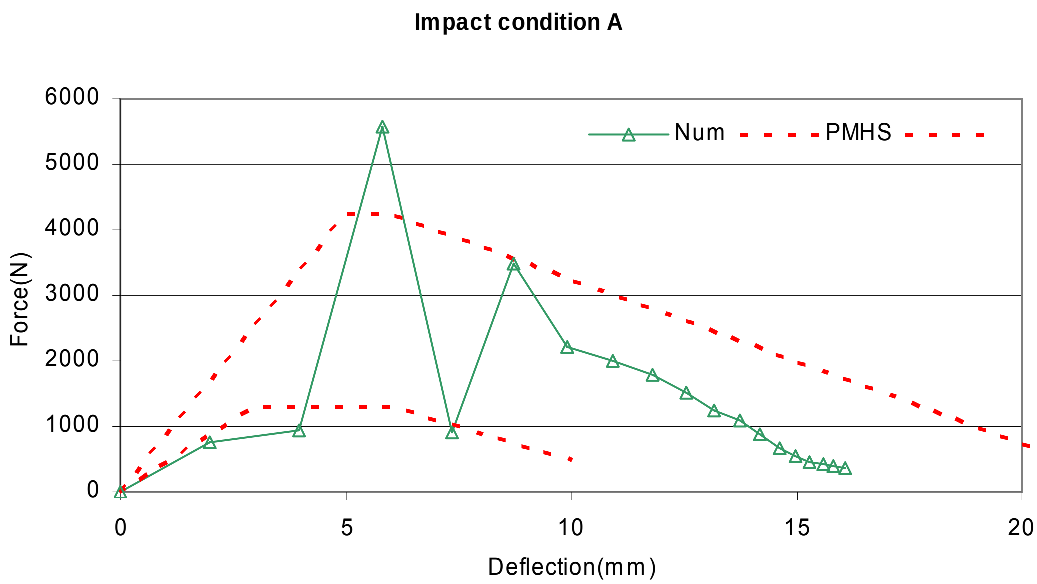

Figure 10. *Force-deflection curve for impact condition A*

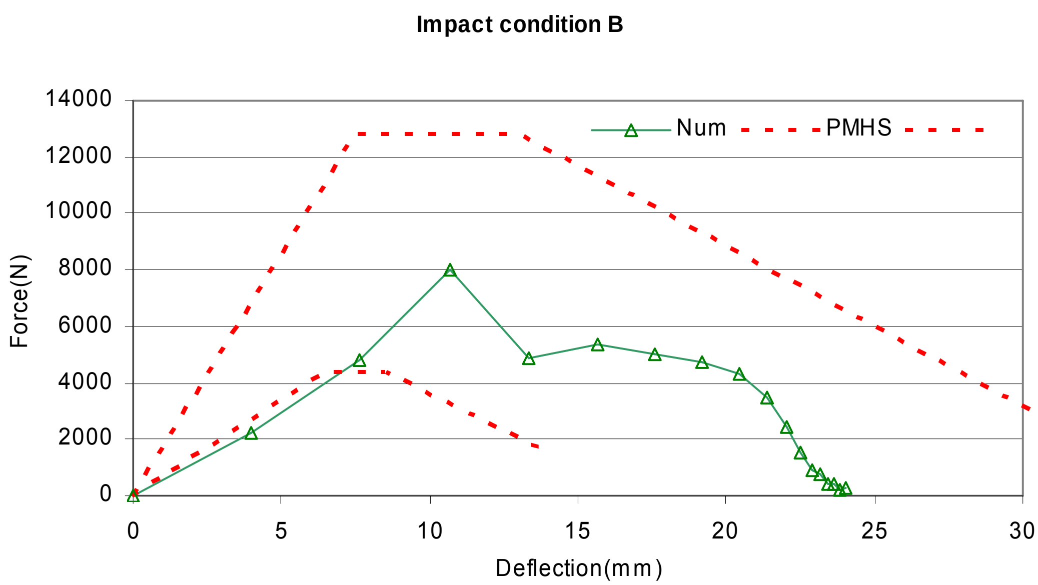

Figure 11. *Force-deflection curve for impact condition B*

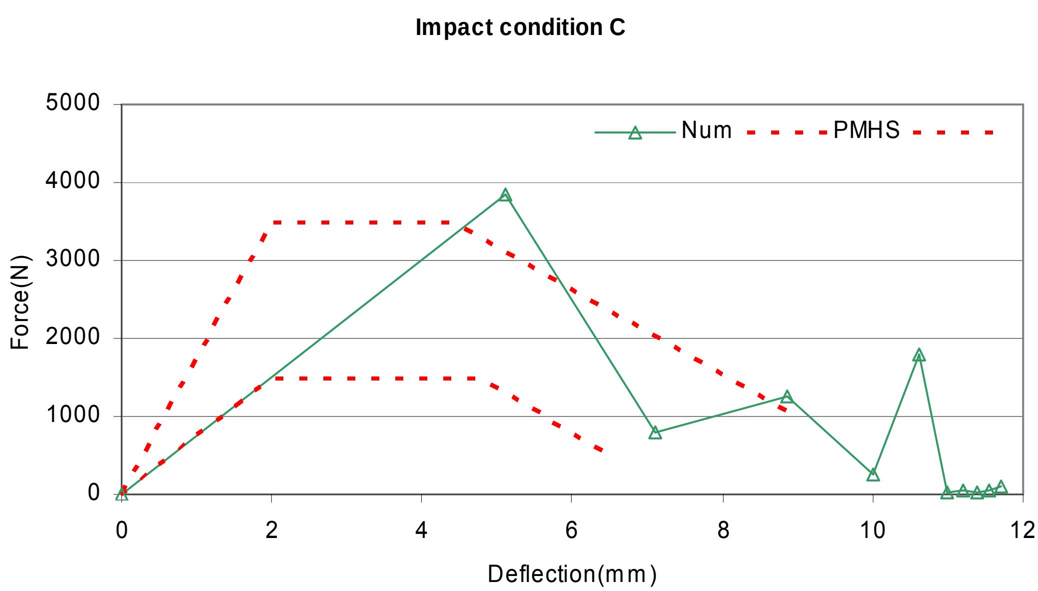

Figure 12. *Force-deflection curve for impact condition C*

7. Distribution list

DRDC Valcartier TM 2006-560

Internal Distribution

1- Director General

3- Document Library

1- Dr. Amal Bouamoul (Author)

1- Hugo Lévesque (Author)

1- Dr. Claude Fortier

1- Dr. Grant McIntosh

1- Dr. Kevin Williams

1- Daniel Bourget

DRDC Valcartier TM 2006-560

External Distribution

1- Director R&D Knowledge and Information Management (PDF file)

DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address) DRDC Valcartier 2459 Pie-XI Blvd. North Quebec, Qc G3J 1X8	2. SECURITY CLASSIFICATION (Including special warning terms if applicable) UNCLASSIFIED

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S, C, R or U)
Development and validation of a finite element human torso model under blunt ballistic impact (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)
Amal Bouamoul, Hugo Lévesque

5. DATE OF PUBLICATION (month and year) December 2007	6a. NO. OF PAGES 27	6b. NO. OF REFERENCES 17

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)
DRDC Valcartier Technical Memorandom

8. SPONSORING ACTIVITY (name and address)
12ra project

9a. PROJECT OR GRANT NO. (Please specify whether project or grant)	9b. CONTRACT NO.
10a. ORIGINATOR'S DOCUMENT NUMBER DRDC Valcartier TM 2006-560	10b. OTHER DOCUMENT NOS N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

- [x] Unlimited distribution
- [ ] Contractors in approved countries (specify)
- [ ] Canadian contractors (with need-to-know)
- [ ] Government (with need-to-know)
- [ ] Defense departments
- [ ] Other (please specify) CANADIAN DEPARTMENT OF NATIONAL DEFENCE

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)
Yes

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

A simplified finite element model of a human torso has been developed in order to investigate and predict the biomechanical response of an actual torso to blunt ballistic impacts. The model consists of a simplified three-dimensional human torso. The torso was impacted with a non-compressible polyvinyl chloride cylinder. The projectile is a cylinder 37 mm in diameter and either 28.5 mm or 100 mm long. The purpose of this study was to validate the biomechanical response model with the results of experiments on post mortem human subjects published in the open literature. The chest dynamic deflection, the dynamic force applied to the chest and the force applied to the chest as a function of chest deflection were compared and validated with the experimental data. Substantial agreement between the numerical model and the experiments was achieved.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Finite elements, blunt impcat, human torso.