Lung tissue modelling under non-penetrating impact: a comparative investigation on numerical injury criteria

M. Bodo and S. Roth

Laboratoire Interdisciplinaire Carnot de Bourgogne UMR CNRS 6303, Univ. Bourgogne Franche-Comte, UTBM, Belfort, France

KEYWORDS Lungs; impacts; finite element analysis; soft tissue

1. Introduction

In a military framework, human body protection appears to be of great interest with an aim of developing and designing efficient armor for soldiers or law enforcement officers. Indeed, in the context of non-penetrating impact, the understanding of injuries caused by a 'less lethal weapons' is a critical point (Suyama et al. 2003). Focusing on the thoracic part of the human body, the influence of such loading have been widely explored, attempting to derive injury criteria from experimental tests or numerical biomechanical analysis. In the framework of less-lethal impacts, experimental tests conducted by Bir et al. (2004) are considered as reference in the literature. Biomechanical corridors derived from these tests, allowing some experimental data for the validation of numerical models. Biomechanical models are considered as biofidelic, if their numerical responses in terms of impact force and sternum deflection time histories are within these corridors. In addition to these biomechanical corridors, this study of Bir et al. also provided interesting progress in thoracic less-lethal impact investigation, these kind of non-penetrating impacts often leading to lung injuries. Indeed, clinical cases related to less lethal impacts often report these kind of trauma (Wahl et al. 2006). Thus, for numerical replications of thoracic impacts, the way to simulate these hollow tissues is crucial in order to derive biofidelic injury criteria. Several ways are described in this paper, attempting to investigate the influence of the modelling of the lungs, and the ability to provide biofidelic numerical response, based on the replication of reference cases of the literature.

2. Methods

2.1. Various soft tissue modelling for less lethal impacts

Less lethal impacts conducted by Bir et al. (2004) were replicated with a previously developed finite element model of the thorax (Roth et al. 2013). In order to investigate thoracic injury criteria, both bones and lungs behaviour were investigated, using different way to model soft tissue:

- The whole volume of the lung is considered as soft tissue, with no pulmonary cavity (NPC).
- Empty space is considered to represent pulmonary cavity (ES).
- The pulmonary cavity is filled with air (PCA).
- Empty space is considered to represent pulmonary cavity with initial pressure within the inner surface of the lung (IPL).

Typical global parameters were recorded in the different simulations such as force versus deflection curves as well as $V_{C_{\text{max}}}$ value defined as the maximum value of the product between the compression and the velocity of compression. Pressure being considered in the literature as an important mechanical parameter which may lead to lung injuries (Bouamoul and Williams 2010), this particular parameter was also investigated for the four simulations.

2.2. Mechanical constitutive model

Mechanical characterization of soft tissues is an important issue in the literature. In order to overcome the difficulties of these characterizations, some biofidelic soft tissue simulants are often used for experimental tests, as well as for numerical simulation. Ballistic gelatine being considered as an interesting substitute, constitutive law based on this biofidelic material was used for lung modelling (Taddei et al. 2015). The Mie-Gruneisen equation of state is used to model the pressure evolution coupled to the Johnson–Cook equation to model the strength of the material. An hydrodynamic constitutive law was used to model the air inside the lung.

3. Results and discussion

The three configurations of less-lethal impacts of Bir were simulated (cylindrical projectile impacting the sternum...
skeletal parameter could be raised, and it seems essential to investigate local parameters (such as pressure), to explore soft tissue trauma, and to make a link between the dangerousness of a thoracic impact (AIS score) and a dedicated mechanical parameter. Then an accurate modelling of lung tissue appear essential for these kind of impacts. Further simulations are under progress in a blast framework, where pressure values were of particular interests for the evaluation of lung damage.

4. Conclusions

Non-lethal experimental impacts of the literature have been replicated with a thorax FE model, with four different types of lung modelling. These simulations led to the validation of the biomechanical model with regards to typical mechanical parameters: force, deflection, VC max. In addition, lung pressure was also investigated providing some directions to accurately describe the lung behaviour with an aim of pulmonary trauma assessment.

Funding

This work was financially supported by the Region Franche-Comté.

References

Bir C, Viano D, King A. 2004. Development of biomechanical response corridors of the thorax to blunt ballistic impacts. J Biomech. 37:73–79.

Bouamoul A, Williams K. 2010. Effect of human and sheep lung orientation on primary blast injury induced by single blast, Personnal Armour System Symposium, (PASS 2010). Québec city, Canada; p. 149–156.

Roth S, Torres F , Feuerstein P , Thoral-Pierre K. 2013. Anthropometric dependence of the response of a Thorax FE model under high speed loading: validation and real world accident replication. Comput Methods Programs Biomed. 110:160–170.

Suyama J, Panagos PD, Sztajnkrycer MD, FitzGerald DJ, Barnes D. 2003 Aug. Injury patterns related to use of less-lethal weapons during a period of civil unrest. J Emerg Med. 25(2):219–227.

Taddel L, Awoukeng Gountcha A, Roth S. 2015. Smoothed particle hydrodynamics formulation for penetrating impacts on ballistic gelatine. Mech Res Commun. 70:94–101.

Wahl P, Schreyer N, Yersin B. 2006. Injury pattern of the flash-ball, a less-lethal weapon used for law enforcement: report of two cases and review of the literature. J Emergency Med. 31(3):325–330.