Biological Tissue Mathematical Constitutive Models in Human Body Models for Enhanced Human Safety

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1 Overview of the Field

Improving safety for human vehicle occupants and vulnerable road users is critical to reduce severe injuries that may lead to fatalities, and low–severity injuries with high societal cost and long–term consequences to quality of life [1]. Computational Human Body Models (HBM) provide a new paradigm for improving human safety through enhanced understanding of injury causation leading to improved safety systems and reduction of injury in impact scenarios [2, 3].

HBMs have evolved significantly over the past decade owing to advanced imaging techniques providing detailed anatomy, high–performance computing enabling large models needed to represent the human body at the tissue level, and the availability of accurate vehicle models and restraint systems to simulate real crash scenarios. However, much of the current research and development for HBM relies on the use of existing biological material data (e.g. stress–strain response for individual tissues) and the implementation of this data in appropriate constitutive models. Biological materials have well–known characteristics of being non–linear, viscoelastic, anisotropic, heterogeneous, and highly variable from person to person. These characteristics, often unquantified in the literature, pose both analytical and numerical challenges when used for simulating impact and injury. Furthermore, owing to the focal nature of impact in crash scenarios, including high deformation rates (up to $\sim$1000 1/s) and large deformations, special requirements exist for numerical stability and accurate representation of material response.

Recently, interest in varying occupant postures and positions within the vehicle associated with autonomous vehicles and driver assist systems (e.g. automated braking) have resulted in the need to simulate the human body before impact in loading conditions separate from impact (such as active musculature response, repositioning and unloading in tissues). In addition, there is large variability in the published experimental data and testing methods for tissues which further compounds these challenges. Thus, there is a need to arrive at generally accepted procedures, properties and constitutive models that can be used to model tissues in contemporary HBM.

2 Workshop Objectives

The overall objective of this workshop was to collaborate with academic and industry experts in the field of computational HBM to discuss the current state of the science on the types of biological tissue models used in current HBMs, the status of material properties in the literature, and the opportunities for improved constitutive models to enhance HBM response and injury prediction. There were four specific aims of the workshop:

1. Review the current state–of–the–art constitutive models and material data for hard and soft tissues, and identify key limitations. This objective was achieved through contributed presentations from the participants, followed by broad and focused group discussions.

2. Investigate current mathematical formulations of constitutive models and discuss the benefits of constitutive model formulations with respect to representation of properties, computational efficiency, and numerical stability at high deformation rates and large deformations.

3. Collaboratively develop a framework for evaluating, verifying and validating proposed constitutive models and implementations.

4. Create a strategy for implementing new constitutive models or material data into HBM and organize follow–on meetings to discuss the outcomes from the workshop.

3 Presentation Highlights and Scientific Progress Made

The workshop included 24 formal presentations on topics ranging from a broad overview of the state–of–the–art and future directions; to whole body models and validation with experimental data; to constitutive model development and tissue testing; to body region modeling such as the head, neck and spine modeling; to soft tissue modeling such as flesh and adipose tissue; and to numerical challenges and best–practices for HBM. The presenters included academics, industry and students. Two break–out sessions, were held with three groups of 8 participants including three group leaders. The first break–out session identified current challenges in HBM, while the second session led to identification of strength and challenges in this field along with future directions. The breakout session discussions were summarized and shared with the workshop participants.

4 Outcome of the Meeting

The meeting was a unique opportunity to assemble a diverse group of international experts from academia and industry to discuss the current state of knowledge and to identify challenges. Experts from many countries (Canada, USA, Mexico, United Kingdom, Sweden, Austria, Czech Republic) came together to discuss the development, validation and application of HBMs, and to address a critical need for improved biological tissue mathematical models required for widespread use of these models with particular interest in improving human safety in transportation. This was the inaugural meeting of this group, and the overall consensus was that this type of workshop was needed for the trauma biomechanics research community. Furthermore, the group identified that:

1. the current technical challenges in modeling techniques for soft tissues is a major limiting component in advancing contemporary HBMs,

2. that more experimental tissue data tested in appropriate loading regimes is required for improving the accuracy of the HBMs,

3. that formalized “best practice” protocols are needed for the implementation and use of constitutive models for HBM.

The participants were encouraged by the progress made at this meeting and by the potential for future meetings to continue to working towards common goals. Based on this feedback, a meeting of the group organizers is scheduled for the fall of 2019 to plan for the next steps.

References

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