Development of a Göttingen Miniature Pig Finite Element Model for Investigation of Injury Scaling Techniques

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Introduction

Traumatic brain injuries (TBI) are a major cost of both money and life in the USA with about 50,000 deaths per year. Many of these injuries are due to motor vehicle collisions and they can be prevented or lessened in severity by better design of the vehicle and safety systems. To do this requires the ability to predict TBI likelihood and severity at known loading conditions. Available data on the human brain is sparse and often real world injuries are the result of complex loading, so the development of injury metrics relies heavily on animal testing. Animal testing can bridge many of the gaps in knowledge, but the kinematics must be scaled to apply the data to the human brain. However, current scaling methods are very simple, mainly based on the mass of the brain. The objective of our study was to develop finite element model of Göttingen mini-pig, which allows the response of the brain at a tissue level to be studied and compared to human finite element models. This type of pig is often used for brain studies because it has similar properties to a human brain.

Methods

In this study, an FE model of a Göttingen miniature pig brain and skull was created from MRI and CT images. These pigs' brains have several characteristics in common with human brains that that make them suitable for testing such as shape and material properties. The regions of the brain were divided into white/gray matter, and the ventricles each with viscoelastic material properties. To validate this model, tests were conducted using Göttingen pigs in a translation/rotation injury device (Fig. 1) subjecting the pig skull to a linear acceleration from 40-96 g's and an angular acceleration from 1,000-3,800 rad/s2 [1]. Four of these pigs' brains were embedded with neutral density targets (NDT's) to track the motion of the brain with a biplanar X-ray system and these drop tests were from the same height. Fifteen pigs were also tested without markers at varying levels of impact to quantify injuries. The impact was then simulated in LS-Dyna, and the motion of nodes closest to the marker locations was recorded.

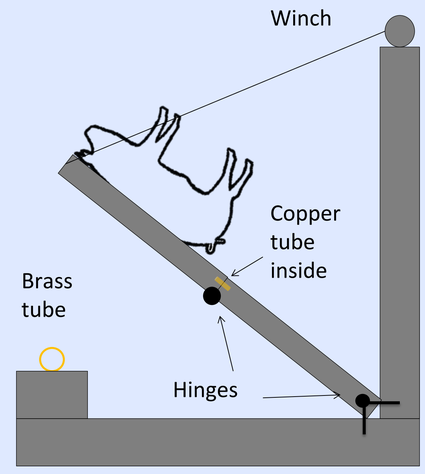

Figure 1. Impact test device

Results

The impact event subjected the pig brains (Fig. 2) to both linear and angular motion. Impact linear and angular velocity histories were used as the inputs to the finite element simulations (Fig. 3). The motion of the NDT markers was compared with nodes closest to the marker locations to calibrate the model material properties as well as the contact definitions at the skull brain interface. The brain material properties were assigned as a Kelvin-Voight viscoelastic (Table 1). The skull brain interface was modeled as a sliding contact with friction to approximate the mechanical effects of the meninges. The motion of the FE nodes was compared with the motion of the experimental NDT markers to validate the model (Fig. 4-5). The FE nodes have an acceptable fit of magnitude and phase. Additionally, to evaluate the model's sensitivity to different levels of impact, the highest impact from the experimental tests as well as the lowest were simulated. The injuries were quantified by cumulative strain damage measure (a volume fraction of elements receiving strains above a threshold [2]) at a strain level of 2.5% (Fig. 6).

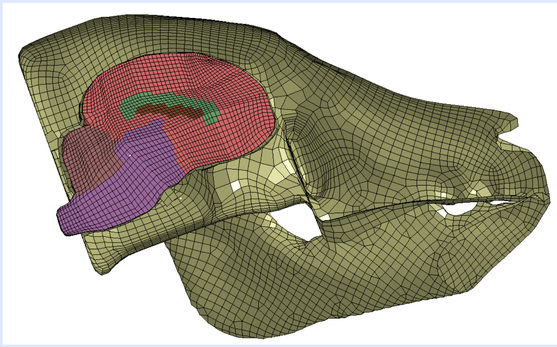

Figure 2. Pig skull and brain FE model showing the brainstem, cerebellum, cerebrum, corpus callosum and ventricles. The skull was modeled as a rigid object.

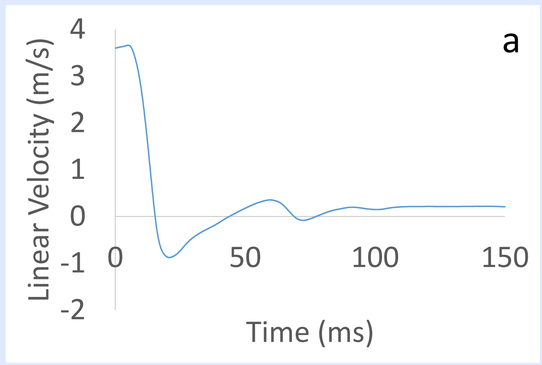

Figure 3. Sample linear (a) and angular (b) velocity history inputs for the test shown at right.

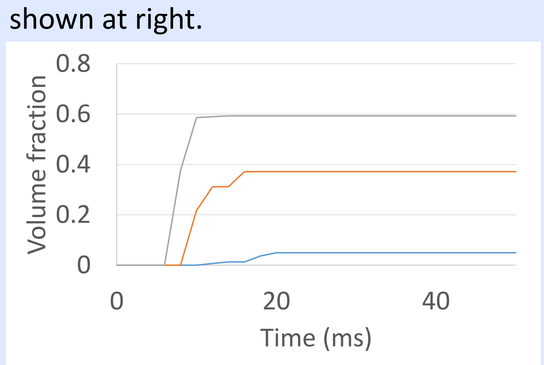

Figure 6. Cumulative strain damage measure for high (gray), medium (orange), and low (blue) impacts.

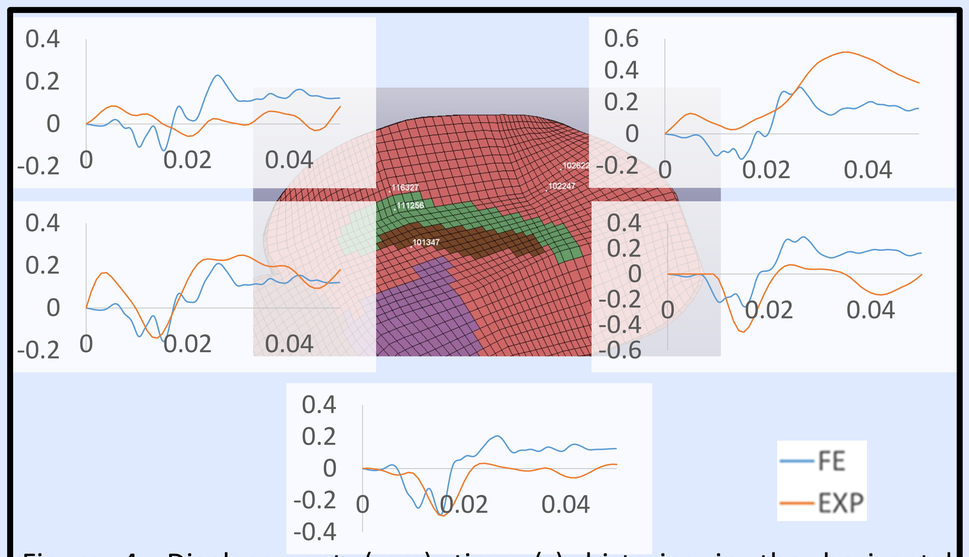

Figure 4. Displacement (mm) time (s) histories in the horizontal direction for FE node, experimental marker pairs.

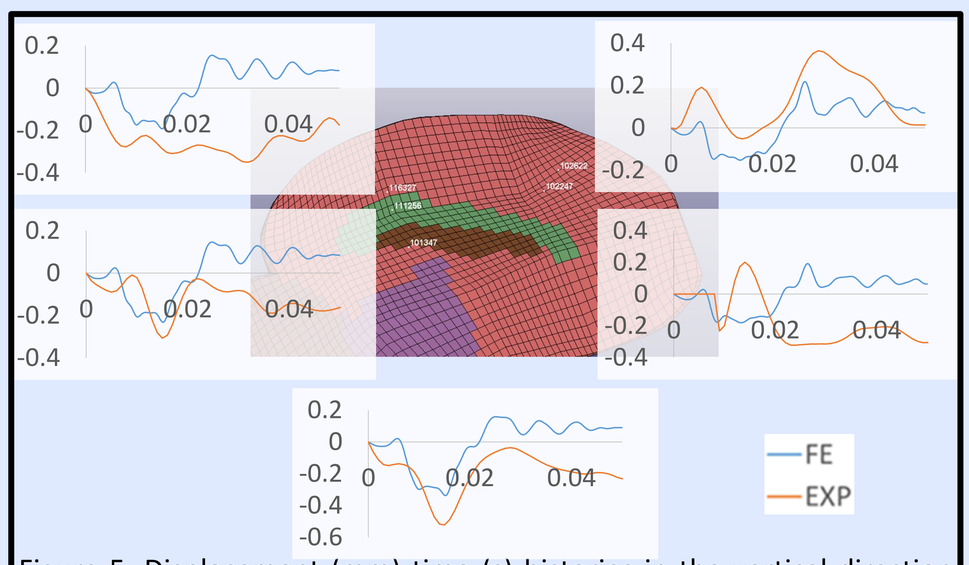

Figure 5. Displacement (mm) time (s) histories in the vertical direction for FE node, experimental marker pairs.

Table 1. Pig brain material properties of Kelvin/Voigt Viscoelastic

	Density (kg/m³)	Bulk Modulus (MPa)	Short Time Modulus (MPa)	Long Time Modulus (MPa)	Time constant (1/s)
Grey Matter	1040	2190	0.007	0.002	.01
White Matter	1050	2190	0.0104	0.0038	.01
Ventricles	1040	2190	0.00075	0.0002	.01

Discussion

- The model is able to replicate the motion of markers in the center of the brain
- Strains are seen throughout the brain as seen in concussive blows
- The model is sensitive to varying levels of impact suggesting an ability to predict injury for many loading scenarios
- Model can be used in tandem with human models to develop better methods to scale animal test data to the human brain

Future Work

- Compare injury metrics with human models such as the SIMON model [3] GHBMC head models [4]
- Determine method to scale input kinematics to match injuries
- Test more pigs to develop graded risk functions

Acknowledgement

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References

[1] Fievisohn, E.M., et al., Evaluation of impact-induced traumatic brain injury in the Göttingen Minipig using two input modes. Traffic injury prevention, 2014. 15(sup1): p. S81-S87.

[2] F. A. Bandak and R. H. Eppinger, "A three-dimensional finite element analysis of the human brain under combined rotational and translational accelerations," SAE Technical Paper 0148-7191, 1994.

[3] E. G. Takhounts, S. A. Ridella, V. Hasija, R. E. Tannous, J. Q. Campbell, D. Malone, et al., "Investigation of traumatic brain injuries using the next generation of simulated injury monitor (SIMon) finite element head model," Stapp Car Crash J, vol. 52, pp. 1-31, 2008.

[4] H. Mao, L. Zhang, B. Jiang, V. V. Genthikatti, X. Jin, F. Zhu, et al., "Development of a finite element human head model partially validated with thirty five experimental cases," Journal of biomechanical engineering, vol. 135, p. 111002, 2013.