A STUDY ON THE BIOMECHANICS OF AXONAL INJURY

dedicated to Ingrid and Benjamin

A study on the biomechanics of axonal injury

Robert W. G. Anderson

Road Accident Research Unit
and the
Department of Mechanical Engineering
The University of Adelaide
South Australia 5005

Abstract

The current focus of research efforts in the area of the biomechanics of traumatic brain injury is the development of numerical (finite element) models of the human head. A validated numerical model of the human head may lead to better head injury criteria than those used currently in crashworthiness studies. A critical step in constructing a validated finite element model of the head is determining the mechanical threshold, should it exist, for various types of injury to brain tissue.

This thesis describes a biomechanical study of axonal injury in the anaesthetised sheep. The study used the measurements of the mechanics of an impact to the living sheep, and a finite element model of the sheep skull and brain, to investigate the mechanics of the resulting axonal injury. Sheep were subjected to an impact to the left lateral region of the skull and were allowed to survive for four hours after the impact. The experiments were designed specifically with the numerical model in mind; sufficient data were collected to allow the mechanics of the impact to be faithfully reproduced in the numerical model. The axonal injury was identified using immunohistological methods and the injury was mapped and quantified. Axonal injury was produced consistently in all animals. Commonly injured regions included the sub-cortical and deep white matter, the hippocampi and the margins of the lateral ventricles. The degree of injury was closely related to the peak impact force and to kinematic measurements, particularly the peak change in linear and angular velocity. There was significantly more injury in animals receiving fractures.

A three-dimensional finite element model of the sheep skull and brain was constructed to simulate the dynamics of the brain during the impact. The model was used to investigate different regimes of material properties and boundary conditions, in an effort to produce

a realistic model of the skull and brain. Model validation was attempted by comparing pressure measurements in the experiment with those calculated by the model. The distribution of axonal injury was then compared with the output of the finite element model. The finite element model was able to account for approximately thirty per cent of the variation in the distribution and extent of axonal injury, using von Mises stress as the predictive variable. Logistic regression techniques were used to construct sets of curves which related the extent of injury, to the predictions of the finite element model, on a regional basis.

The amount of observable axonal injury in the brains of the sheep was clearly related to the severity of the impact, and was related to the predictions of a finite element model of the impact. Future improvements to the fidelity of the finite element model may improve the degree to which the model can explain the variation in injury throughout the brain of the animal and variations between animals.

This thesis presents results, and a methodological framework, that may be used to further our understanding of the limits of human endurance, in the tolerance of the brain to head impact.

All experiments reported herein conformed with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

Foreword

To the best of my knowledge and belief, all the material presented in this thesis, except where otherwise acknowledged, is my own original work and has not been published previously for the award of any other degree or diploma in any university. If accepted for the award of the degree of Doctor of Philosophy, I consent that this thesis be made available for loan and photocopying.

ROBERT ANDERSON

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1. Affiliations are given as they were at the time. Some of these affiliations may have changed.

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