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Simulation of Automobile Crash Related Cranial Injury Using Finite Element Analysis

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This paper was presented at the 19th Annual Workshop on Human Subjects for Biomechanical Research. It has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

Introduction

The incidence of head injury in automobile accidents and its long term consequences in both economic and human terms is staggering. In 1985, 32% of fatal accidents in the United States were a result of automobile accidents [Faigin B. M.], most of which involved head or spinal cord injuries. Based on 1979 NASS statistics there were 47,000 automobile fatalities, 33,000 of which had injuries to the head, neck, or back. 18,000 fatalities had the most severe injury to the brain, skull, or spinal column [Scott W. E.]. In addition, 1974 NASS data confirms almost half of the new cases of head injury were a direct result of motor vehicle accidents as shown in Figure 1 [Harris B. S. H., et al.].

Many researchers have attempted to construct mathematical models describing the response of the human brain to loading conditions, however with limited success. The majority of these studies have been highly labor intensive and required the use of large mainframe computers. The authors propose conducting a study using advanced finite element modelling software which is both user friendly and capable of running on a personal computer. The ease of use of the software will permit repeated iterations in an ultimate attempt to simulate the contrecoup injury phenomenon.

Biomechanics

Two events may take place in the course of a head impact. Initially, there may be a contact phenomenon where the head physically strikes a

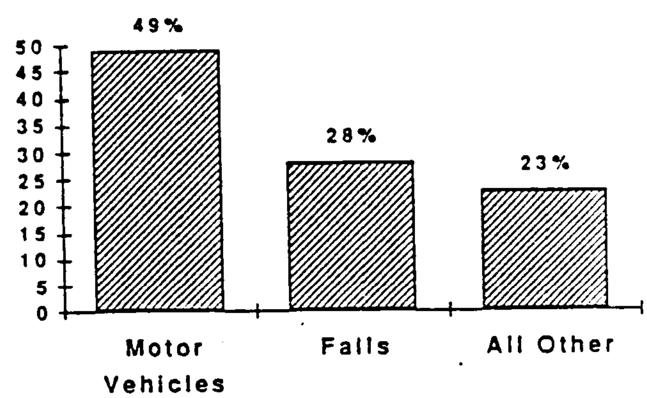

Figure 1. New Cases of Head Injury.

fixed object. Subsequently, there is an inertial loading of the head and its contents [Demann D., et al.]. There have been documented cases in which no physical contact occurs, and head injury resulted solely from inertial loading of the head and its contents during acceleration.

The basic mechanisms causing brain damage can be divided into three categories a) the establishment of large cerebrospinal pressure gradients, b) flexion/extension and/or bending of the upper cervical cord during motion of the head-neck junction, and c) simultaneous skull deformation and angular acceleration of the head [Demann D., et al.].

Large pressure gradients within the cranial vault can be caused by several phenomenon. The absolute motion of the brain and its displacement relative to the skull during acceleration can lead to formation of steep-fronted waves in the brain which can cause injury. Concurrently, large intracranial flows through the foramen magnum can initiate shear stresses in the brainstem. In addition, the collapse of cavitation bubbles initially formed by the negative pressure at the antipole from the impact point (the contrecoup point) can cause separation of the brain from the cranial wall in this region [Demann D., et al.].

Methods

Investigation of head injuries in the laboratory is typically achieved through either experimentation with cadavers, *in vivo* animal experiments, or mathematical modelling [Liu Y. K.]. In the proposed study, a graphic model of the human skull and brain will be created and analyzed under acceleration using finite element analysis.

The software which will be used is COSMOS/M version 1.65 produced by Structural Research & Analysis Corporation (1661 Lincoln Boulevard, Suite 200, Santa Monica, California 90404). This software is capable of generating and analyzing a model comprised of up to 32,000 nodes and elements with up to 100,000 degrees of freedom. The software offers a variety of analytical capabilities, including linear static analysis, linear dynamic analysis, heat transfer analysis, advanced dynamic analysis, nonlinear structural analysis, design optimization, and fluid flow analysis. Minimum hardware requirements are an IBM PC with 640K RAM, a floppy disk drive, 20 MB hard disk drive, EGA color graphics, a color monitor, MS DOS, a math co-processor (8087, 80287, or 80387), and a mouse. A 33 megahertz non-interlaced YKE 486 PC will be used for this analysis.

A three-dimensional model of the human brain and skull will be created. Based on anatomic geometry, elements will be generated (see Figures 2, 3 and 4). Material properties for the brain, cerebrospinal fluid, skull, and facial structure will be assigned. The model will be accelerated under a variety of loading conditions to simulate frontal, side, and rear impact.

Discussion

This study is an attempt to simulate the contrecoup phenomenon of brain injury using mathematical modelling on a personal computer. The user-friendly nature of the software permits easy modification of the model and numerous iterations under varying loading conditions.

This software also permits import of graphics images from CAD. Although the resulting model is less easily modified, this feature provides the option of constructing a graphics model of the brain from computer tomography images. Such a model would be of interest in comparing computer generated results to the results of *in vivo* experiments.

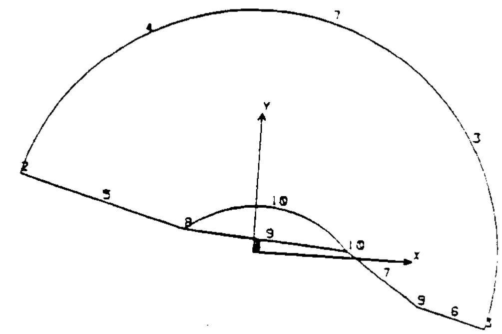

Figure 2. Model Generation.

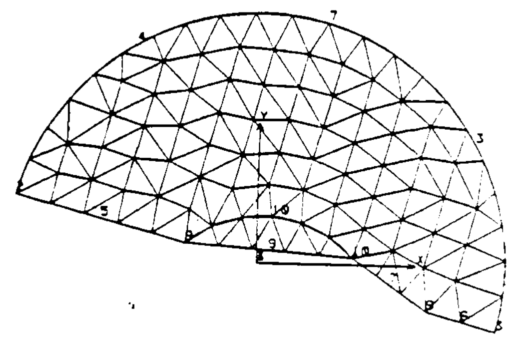

Figure 3. Meshing of Model.

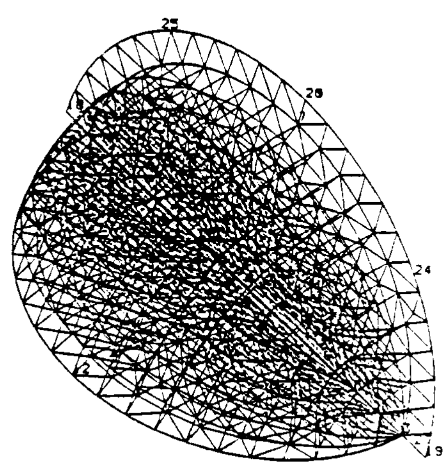

Figure 4. Generation of Three Dimensional Model.

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DISCUSSION

PAPER: **Simulation of Automobile Crash-Related Cranial Injury using Finite Element Analysis**

SPEAKER: Linda Mars

QUESTION: Guy Nusholtz, Chrysler

How are you planning to model the interface between the brain and the dura? You have the skull and the dura, you have the dura and the brain and somehow you have to develop a contact algorithm between those three.

A: The dura will be the outside membrane you just saw there. The brain we can overlay another line, if you will, on top of the dura and then specify that that will be the shell, the thin shell, element. So the difference in the material properties will be in there, we will have to face the task of modeling any frictional components between the skull and the dura and the dura and the brain. Also you have to take into account the cerebro-spinal fluid. So between the skull and the dura, that will simply be two materials sitting adjacent to each other.

Q: Do you have a contact interface between the nodes?

A: Yes, the nodes you can merge between the two so that the skull will literally be attached to the dura. It will have the same node point as the dura so as the skull moves so does the dura move and if the stresses on the skull exceed that which the dura can absorb then the dura will be allowed to fracture whether or not the skull fractures and vice versa, the skull can fracture and the dura can remain intact.

Q: So you have a failure mode in the node, but it's possible the dura can actually move say, as if it's attached by a spring of some kind?

A: We'll have to make a choice there whether or not we'll merge the nodes of the skull with the nodes of the dura or whether we'll simply allow them to overlap each other. If we don't merge the nodes and maintain two separate nodes there, then the dura can move in one direction while the skull can literally move in the other direction. It's a decision we're just going to have to face. It will not be a difficult decision once we run the program with them unmerged then we can quickly go back and merge those nodes.

Q: How are you going to handle the cavitation phenomena?

A: The material properties of the cerebro-spinal fluid will be input into the model and we're hoping that the explanation of cavitation that we're basing this on is that cavitation is an air-pocket that is formed when the pressure exceeds the gas pressure for the cerebro-spinal fluid. If that assumption proves correct....

Q: So you will actually be able to have air expand (vapor expansion) inside the ....

A: If the pressure exceeds the gas pressure for the cerebro-spinal fluid then it will form a gas pocket there. That assumption may not be correct.

Q: I noticed that you're using a lot of triangular elements, is there a reason for that?

A: We have about 6 different elements that we can choose from. These were actually tetrahedrons. The triangular elements are simpler to work with geometrically and will conform better to a curved surface than a geometrically complicated surface.

Q: They tend to be stiffer than other elements.

A: That may be the case; you can add more elements though.

Q: Clay Gabler, NHTSA

We have some work going on in this area also and one of the problems in brain modeling is getting some of the properties of the brain. What do you plan to do as far as getting some of those properties, you know the modulus...those are very tricky to get...

A: I'm having the same problem obtaining those properties. Perhaps we could compare notes after the session and between us, I've got some properties; I need more, and perhaps we could compare notes and help each other out on that.