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DATA ANALYSIS
OF
A SIMULATED
WHIPLASH MOTION
ON
ANAESTHETISED PIGS

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This report is written in order to fulfil the second trainee period of Mr. W.D. van Driel, student Medical Engineering at the Technical University of Eindhoven, The Netherlands.

The trainee period was carried out at the Department of Injury Prevention, Chalmers University of Göteborg, Sweden. Within this department the research is currently going on in several areas with the emphasis on biomechanics, biomaterials science and ergonomics.

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1. INTRODUCTION

Injuries to the neck have been an increasing problem in recent years. One of the most common neck injuries is the so called whiplash injury. Usually, a swift extension-flexion motion of the cervical spine causes whiplash injuries. The mechanism of this motion has been described earlier (States, 1979).

The largest contribution to the whiplash injuries comes from rear-end collisions, and they often occur at low impact velocities (< 30 km/h). According to Nygren (1984) some 10% of the injured car occupants involved in rear-end collisions sustained an injury to the neck with at least 10% disability. In other types of car accidents 4% of the injured car occupants are permanently disabled with at least 10% disability (Nygren, 1984).

Whiplash injuries to the neck and cervical spine consist of conditions on a scale from paralysis (tetraplegia) to unaffected mobility but with symptoms like dizziness, headaches, hyperesthesia, pricking fingers and pain in the neck, shoulders and arms (States, 1979; Nygren et al., 1985). Even at low velocity rear-end collisions the car occupants often lose consciousness immediately after the collision even when no signs of impact to the head can be found. Probably, damage to nervous tissue causes these symptoms. The symptoms often occur even though no signs of skeletal injury or injury to the vertebral disks or ligaments can be diagnosed (Maimaris et al., 1988). The mechanisms causing damage to the nervous tissue but leaving the surrounding tissues virtually unaffected have not yet been given a satisfactory explanation.

In earlier efforts to explain whiplash injuries the main interest has been directed towards the vertebra, discs and ligaments and their response and tolerance to injury. The predominant theory of the injury mechanisms for the nervous tissue of the central nervous system has been mechanical stretching and compression of cervical nerve roots (McMillan and Silver, 1987).

In a recent study a new model for explaining the whiplash injuries caused by rear-end collisions was presented by Aldman (1986). Aldman claimed that the pressure gradients, caused by fluid motion under shortening of the spinal canal at extension movement, lead to damage to the nervous tissue of the central nervous system.
Later on, Svensson et al. (1989) developed a theoretical model and tried to determine the pressure phenomena in the central nervous system under whiplash motion and their effects on the nervous system according to the hypothesis presented by Aldman (1986).

The aim of the project presented in this report was to further investigate the pressure phenomena in the central nervous system and their relations with velocity and acceleration of the head-neck motion and the occurred damage of the nervous tissue.
2. MATERIALS AND METHODS

2.1 Measurements

We have used pigs as animal models to measure accelerations and pressures under a simulated whiplash motion. The pigs are easily available at a relatively low cost and the dimensions of the spine are fairly similar to those of the human spine.

This year two initial test series of eleven anaesthetised pigs have been made. In February 1992 three pigs were tested and in October 1992 eight pigs. The body masses of the tested animals were in the range of 20-25 kg. The pig's head and neck were subjected to a simulated whiplash motion. In order to analyse this motion the following measurements were made:

- a videotape recording of the motion to calculate linear and angular displacement;
- accelerations of the pig's head in two perpendicular directions;
- pressure in the spinal canal and inside the skull to investigate the pressure phenomena.

Figure 1 shows the experimental set-up. The pig's head is mounted on a metal plate. A special designed "pulling device" is connected to the metal plate to subject the pig's head and neck to a simulated whiplash motion. The pulling force is generated by a 16 mm thick rubber strap that is pre-tensed with the help of the crank.

We used the following experimental equipment (figure 2):

A catheter tip pressure sensor was placed in the subdural space in the spinal canal at the level of T1 (first thoracic vertebra). The sensor was introduced into the subdural space at the level of T12 and guided to the level of T1. The sensor has a diameter of 1 mm.

A hole was drilled through the cranial vault and a peizo resistive pressure transducer (Endevco 8510-100) was screwed into the hole. The transducer
measured the intracranial pressure. Efforts were made to avoid air entering the cranial cavity.

Two accelerometers (Entran EGA 125-100 DSC) were attached to the metal plate. The measuring directions of the accelerometers were parallel to the sagittal plane.

During both initial test series the pigs were put to death after the simulated whiplash motion. During the second initial test series the damage to the nervous tissues of the cervical spine was analysed. These analyses are done by the department of histology of the University of Göteborg and the FOA (Försvarets forsknings ansalt).

They used three different methods for injury detection. The first one is a Evans blue analysis. Evans blue is a pigment that can be traced inside damaged nerve cells. The pigment was entered in the blood system before the pig's head and neck was subjected to the simulated whiplash motion. When the cell-membrane is damaged during this motion the pigment will cross "the blood-brain barrier" and enter into the cell body.

The second method is a C-fos analysis. This analysis detects the C-fos protein inside nerve cells. A nerve cell will generate this protein if it is damaged.

The third method is a S-100 analysis. This analysis detects S-100 in the cerebro spinal fluid (CSF). S-100 is a calcium-ion binding protein that leaks out of the glia cells into the CSF if their membranes are damaged.
Figure 1. The experimental set-up.
1. accelerometers
2. pressure transducer
3. catheter pressure transducer cable
4. spinal canal
5. nuchal crest
6. cranial cavity
7. skull

Multi channel Amplifier - Johne+Reilhofer 8 MV 1
Tape recorder - Kyowa RTP-510A

Figure 2. The experimental equipment.
2.2 Analysis

The analysis of the measurements consisted of two parts:

- an analysis of the cassette tape containing the acceleration and pressure measurements;
- an analysis of the video tape containing the kinematic parameters of the simulated whiplash motion.

2.2.1 Analysis of the cassette tape

To analyse the cassette tape I used the so called Labview software designed by National Instruments. I took the information from the cassette tape by way of a NB-MIO-16 I/O connector and a NB-MIO-16(H/L)-9 board into the Labview software. The software ran on a Macintosh IIci computer.

Problems occurred because the raw data contained two kinds of noise. First there was an offset of approximately 45 mV on every channel. It was easy to reduce this offset. Secondly there was a distorted 50 Hz frequency sinus noise (figure 3). The main source for this noise is the electricity net because of the 50 Hz frequency.

Figure 3. The 50 Hz noise.
I used several filtering techniques (Butterworth LowPass and Butterworth BandStop) to reduce this noise but they were all not sufficient. The solution was to take the pure noise from an unrecorded channel into the Labview software and subtract it from the other channels since the noise proved to be identical in all the tape recorder channels.

2.2.2 Analysis of the video tape

To digitise the video tape I used the so called Image software designed by National Instruments. I captured every frame (20 ms) of the video tape by way of a LG-3 Scion Scientific Frame Grab into the Image software. This grabber card had a limited quality and we returned it to the suppliers to repair it.

We used LED's (Light Emitted Diodes) mounted to the metal plate of the "pulling device" to follow the motion of the pig's head. One LED blinked every 1 ms, the other one every 8 ms. Figure 4 shows the orientation of the LED's. I used the lower frequency to calculate the motion of the metal plate.

We assumed the pig's head centre of gravity to be in the middle of the metal plate. In this case it was easy to calculate the linear and angular motion of the pig's head and neck.
Figure 4. The pig's head fixed to the metal plate of the "pulling device". The LED's are placed in the three free corners of the plate.
3. RESULTS

The results presented in this report are a selection from the two initial test series. I selected test numbers 03 and 08 from the October 1992 initial test series and test numbers 01 and 03 from the February 1992 initial test series. These tests can be graded in different severity levels of the simulated whiplash motion.

From the October 1992 initial test series the results of the video tape analysis are presented (figures 5-7). From the February 1992 initial test series the results of the cassette tape analysis are presented (figures 8-11).

The initial position of the pig's head corresponds to a zero displacement, velocity or acceleration.

Figure 5 shows the trajectory of the pig's head. The x and y displacement are parallel to the sagittal plane. Figure 6 shows the angular displacement of the head. Figure 7 shows the angular velocity of the head calculated from 9th-degree polynomial curve fits of the results presented in figure 6.

Figures 8 and 9 show the acceleration of the pig's head in x and y direction respectively. Figure 10 shows the pressure inside the pig's skull. Figure 11 shows the pressure inside the spinal canal at T1 level.
Figure 5. Trajectory of the pig's head.

Figure 6. Angular displacement of the pig's head.
Figure 7. Angular velocity of the pig's head calculated from 9th-degree polynomial curve fits of the results presented in figure 6.
Figure 8. Acceleration of the head in x direction.

Figure 9. Acceleration of the head in y direction.
Figure 10. Pressure inside the skull.

Figure 11. Pressure inside the spinal canal at T1 level.
4. DISCUSSION

Figures 5-7 show the difference in severity between test numbers 03 and 08. A higher severity level is reached within test number 08. Both tests show generally the same pattern for the trajectory, angular displacement and angular velocity of the head. The head first moves upwards until approximately 20 centimetres (in both tests) displacement in x direction. There after, the head moves downwards until it reaches its highest extension angle of approximately 70-80 degrees. The human maximum extension angle for the cervical region is approximately 75 degrees (Kapandji, 1974). Finally, the head moves backwards due to elastic rebound.

Figure 7 shows a peak value of the angular velocity at the beginning of the motion. Test number 08 is more severe as suspected from figure 6. When the angular velocity changes sign, the head is moving backwards.

The method of making polynomial curve fits of the angular displacement curves and using them for calculation of angular velocity was employed since the measurements from the digitised video tape proved to have too much "noise" for calculating derivatives.

In the next test series the "pulling device" will be improved. Linear and angular potentiometers will be added to measure the kinematic parameters of the simulated whiplash motion with a better precision. Also, a force transducer will be added to enable a more precise determination of the tension in the rubber strap.

Figures 8 and 9 show the difference in severity between test number 01 and 03. A higher acceleration in x direction is reached in test number 03 (12 g versus 8 g). The difference between both tests in acceleration in y direction is smaller (15 g versus 14 g). This difference might be caused by an added angular acceleration because the accelerometers are not positioned in the centre point of gravity.

Figures 10 and 11 show generally the same patterns for both test for the pressures in the skull and the spinal canal. We assume that the values of the pressures at the beginning and at the end of the simulated whiplash motion are caused by the cyclic pulsation of the heart.

The complexity of the pressure curves is a major problem. The contour indicates that several pressure phenomena occur simultaneously. Svensson et al. (1989) suggested the phenomena to be pressure gradients due to flow resistance, flow acceleration, and the acceleration of the skull. An other pressure phenomenon
that could be of significance is a pressure increase due to a flow velocity induced occlusion of the vein bridges in the intravertebral foramina.
The analysis of the pressure curves is even a bigger problem. It is difficult to find any relations between the pressure's pulse shape and the acceleration's pulse shape. An acceleration peak value does not necessary lead to a pressure peak value at the same time. We do not even know if the threshold of the whiplash injury is exceeded.
Another problem is the comparison between two tests since the initial posture of the pig's head and neck varies within each test.

In the next test series the spinal canal pressure will be measured at two different levels to be able to see the difference within the spinal canal. The C3 (third cervical vertebra) to C4 level is expected to be the centre of pressure generation.
5. CONCLUSIONS

- The results from the data analysis of the simulated whiplash are satisfactory since they correspond with theoretically suspected whiplash motion.

- With the experimental set-up and equipment it is possible to acquire more detailed information about the kinematic parameters and the pressure phenomena inside the spinal canal during a simulated whiplash motion.

- With modified equipment it will be possible to expose the pig's head and neck to a more well defined severity level which will exceed the injury level of the whiplash trauma.
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