# THE RELATIVE MOTION CONCEPT OF BRAIN INJURY

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## ABSTRACT

Relative motion between the brain and the cranial cavity has been postulated as a cause of injury to the brain and of rupture of the bridging veins. This concept can be examined by comparing the shape of the cranial cavity to the location of lesions on or near the surface of the brain and to the presence of subdural haematomas. The shape of the cranial cavity is recorded by preparing a cast at autopsy. This information is then compared with the results of a neuropathological examination of the brain and with information on the impact to the head derived from investigation of the accident. Four cases are presented to illustrate this procedure.

## INTRODUCTION

It is generally recognized that relative motion between the brain and the cranial cavity can be a cause of injury to the brain and to the bridging veins [1-5]. The purpose of this paper is to describe and illustrate a procedure which has been developed to facilitate the further study of this phenomenon.

## BACKGROUND

In South Australia a coronial autopsy is conducted on almost all persons who die from injuries sustained in a road traffic accident. In 1982, at the request of the senior author of this paper (AJM), the Coroner gave permission for the intact brain to be examined by a neuropathologist. That procedure is now routine [6,7].

In cases involving a pedestrian or a motorcyclist or, more recently, a car occupant, the circumstances of the crash are investigated in detail [6,7].

The combination of the crash data and the results of the neuropathology examination has enabled us, in about one-fifth of the pedestrian cases, to relate the nature and severity of the impact to the head to the nature and severity of the injuries to the brain [7].

In 1986, at the suggestion of David Viano and with support from General Motors Research Laboratories, work commenced on the development of a means of recording the shape of the cranial cavity, with the ultimate aim of including the information obtained in this way in our investigation of brain injury mechanisms.

METHOD

The shape of the cranial cavity is recorded by making an epoxy resin and fibreglass cast from a silicone rubber mould formed at autopsy. Before applying the silicone rubber the dura is removed and the surface of the bone is cleaned and dried. Photographs are taken before the cleaning process. The foramen magnum is plugged to prevent the silicone rubber from flowing into the spinal canal. Preparation of the rubber mould takes about 45 minutes.

A replica of the cranial cavity is then made from the rubber mould using an epoxy resin. Successive coats of resin are applied, allowing 30 minutes setting time for each coat, until a thickness of between 5 and 8mm has been achieved. Strips of fibreglass mat are then layered on to strengthen the otherwise brittle replica. A total of 8 coats of epoxy resin are usually necessary to ensure a satisfactory result.

The preparation of the rubber mould and the epoxy/fibreglass cast is described in greater detail elsewhere [8].

The dimensional accuracy of the replica was checked in two cases by making four holes with a fine drill through the in situ rubber mould and into the skull. These small holes in the mould were reproduced as small protrusions on the inner surface of the cast. The distances between these holes/protrusions differed by less than two per cent [8].

Illustrative Cases

Four cases are presented here in which a cast was prepared and in which information was available on the circumstances of the crash. A total of 30 casts have been made but, although the neuropathology data are available, there is little or no information on the object struck by the head in most of the remaining cases.

Case 1: Motorcyclist; concentrated impact in left occipital region.

A 17 year old male motorcyclist fell from his motorcycle on a bend and slid across the road, possibly striking the edge of a concrete kerb before coming to rest under the front of a stationary Toyota Land Cruiser. The rider sustained an "egg shell" fracture of the skull approximately 1 to 2cm wide by 6cm long. The fracture was located parallel to and immediately above the transverse sinus in the left occipital region. There was an associated network of small (about 2cm long) fractures in the left posterior cranial fossa extending into the left sigmoid sinus. Both these sinuses were torn, with resulting haemorrhage. The rider's crash helmet, which remained on his head and was not damaged, may have been displaced forwards at the moment of impact.

The youth did not regain consciousness and brain death was certified 20 hours after the accident. He had no other injuries apart from minor abrasions and contusions.

On neuropathological examination, the distribution of injuries to the brain was as shown in Figure 1. There were numerous contusions of the left tempero-parieto-occipital lobes in the region of the extensive fracture above the left transverse sinus and bilateral gliding contusions anteriorly, mainly to the left of the falx. There was some limited contusion of the inferior frontal lobes which were of interest for two reasons: the anterior cranial fossae were relatively small (of which more later) and comparatively rough. The former characteristic might be associated with a reduced risk of injury to the inferior frontal lobes and it would seem to be reasonable to postulate that the latter characteristic would be associated with an increased risk of injury. There was marked swelling of the brain, primarily in the left hemisphere.

Case 2: Motorcyclist; upper frontal impact on helmeted head.

A 43 year old male motorcyclist ran off the road at high speed on a right hand bend and hit a small tree. There were no significant marks on his full-face helmet but there was a slight bruise on his forehead. He sustained a small fracture of the left anterior cranial fossa. There was also traumatic subarachnoid haematoma over the entire surface of the brain and a small subdural haematoma along the midline. The other injuries comprised multiple rib fractures, a fractured sternum and a small laceration of the right upper lobe of the lung. The rider did not regain consciousness and was pronounced brain dead 25 hours after the crash. There was generalised brain swelling and terminal coning of the brain stem.

The neuropathological examination revealed a few scattered petechial haemorrhages in the cortex of the inferior frontal lobes (Figure 2). The surface profile of the anterior cranial fossa was much smoother than in the case described above.

Case 3: Pedestrian; impact to the upper right rear of the head.

A 65 year old male pedestrian was struck on the left side by the front of a Mitsubishi Sigma station wagon. The tempered glass windshield was shattered and a dent made in the leading edge of the roof. The pedestrian sustained fractures of both femurs, left tibia and fibula, right humerus, multiple rib fractures and spinal fracture/dislocations at C 1/2, C 5/6 and T 9/10. There was an extensive abrasion over the upper right rear of his bald head with a fracture running vertically through the right temporal bone, both possibly a result of the head striking the road surface. A small left subdural haematoma was present.

Recent subarachnoid haemorrhage was scattered over both cerebral hemispheres in the parasagittal regions, the frontal pole, Sylvian fissure and parietal convexity on the left side. There was also extensive hypoxic brain damage. The brain was swollen. There was no obvious correlation between the brain injuries and the bony anatomy of the cranial cavity, apart from the skull fracture.

The pedestrian died about 12 hours after being struck by the car.

Case 4: Pedestrian; left frontal impact on head.

A 16 year old school boy was hit on the left side by a car which was travelling at 50 km/h. His head struck the laminated windshield, resulting in estimated head accelerations of 2,500 m/s/s (linear) and

11,000 rad/s/s (angular). A skull fracture extended vertically down the left lateral aspect of the frontal bone and across the anterior cranial fossa to just short of the midline. A circumferential fracture of the sella turcica with extension along the greater wing of the sphenoid on the right was also present, together with extensive facial fracturing.

On external inspection the brain was swollen. There was patchy subarachnoid haemorrhage over the right parietal lobe, small contusions of the left inferior frontal lobe, and right temporal lobe. Microscopic examination revealed diffuse axonal injury, and small haemorrhages of grey and white matter in both cerebral hemispheres (see Figure 3), small contusions of the right inferior posterior temporal lobe and left inferior frontal lobe, and bilateral gliding contusions. There was also extensive diffuse hypoxic injury.

The pedestrian also sustained a dislocation of the left shoulder, disruption of the right knee, and fractures of the neck of the right fibula and the left tibial plateau. He died one week after the accident without regaining consciousness at any stage.

The impact resulted in a clockwise rotation of the head, viewed from above. The lesions of the right inferior posterior temporal lobe could therefore have been associated with a contre-coup phenomenon. The surface of the middle fossa and the temporal bone contained some pronounced tuberosities (ridges, etc.), more so than in the cranial cavity of Case 2, for example. The lesions of the left inferior frontal lobe were adjacent to a skull fracture but the vertical distance from the centre of the left anterior cranial fossa to the border adjacent to the ethmoid bone was 14mm, the same as in Case 1 but greater than in Case 2 (11mm) or Case 3 (10mm). This could increase the possibility of a clockwise rotation of the head, as in this case, resulting in injury to the inferior surface of the frontal lobe.

Dimensions of the Cranial Cavity

It is emphasised that this paper is intended to describe a method of investigating the relative motion concept of brain injury. The cases presented are illustrative only and should not be taken as an indication of the extent of normal variation in the bony anatomy of the cranial cavity. With this proviso, the following comparisons are made of selected dimensions from the cranial cavities in the four cases described above. These cases were chosen because of the availability of a wide range of data, not because of any known characteristic of the dimensions of the cranial cavity.

Figure 4 shows the cranial cavity dimensions which are listed in Table 1 for each of the four cases. Dimension A is the maximum internal width of the cranial cavity; B is the length, measured to a point below the transverse sinus of the occipital bone. The maximum length is usually greater than this, when the measurement is taken above the transverse sinus, but two of the casts did not extend above the sinus. Dimension C is measured horizontally from the forward-most point of the cranial cavity to a point above the back of the foramen magnum (the opening to the spinal canal). D provides an indication of the length of the anterior fossa.

In Table 1 the four linear dimensions are also standardized against those for Case 1, simply to facilitate comparisons between cases. The greatest variability is in the anterior fossa dimension,

where Case 4, at 57mm, was about 23 per cent greater than Case 2. There was even greater variability in brain mass, with Case 3 being 28 per cent less than Case 1. This difference may partly reflect the difference in the ages of these two individuals.

## DISCUSSION

A practicable method for the preparation of a replica of the base of the cranial cavity has been developed. However, the method is somewhat time consuming which may be a major problem, depending on the work load in the mortuary. In Adelaide a recent administrative decision has been made to conduct all post mortem examinations at the central Forensic Science Centre, rather than at a hospital mortuary in the case of death after arrival at hospital. This may mean that we will have to consider alternative approaches for recording the shape of the cranial cavity, such as stereophotogrammetry or three dimensional reconstruction from CT scans.

The variability in cranial cavity dimensions shown in Table 1 suggests that a more formal investigation is warranted. We plan to extend this comparison to the remaining casts but a much larger number of cases will be needed. It is important to recognize that the four cases presented here were all caucasian males; when females and other racial groups are included, differences in relative dimensions exceeding 50 per cent may well be observed. Such a difference could have a major bearing on the response of the brain to an impact to the head, even if the response varied with differences in the linear dimension, let alone to a higher power. Goldsmith [9] has noted that "The significant differences in pressure profiles and cavitation processes noted between the shell and skull models imply that the geometric and especially the material properties of the cranial vessel dominate the system response in model impacts". It seems reasonable to assume that that observation would apply also to the actual human skull/brain system.

## ACKNOWLEDGEMENTS

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REFERENCES


1. Holbourn AH. The mechanics of brain injuries. Brit Med Bull, 3: 147-149, 1945.

2. Gurdjian ES, Gurdjian ES. Cerebral contusions: re-evaluation of the mechanism of their development. J Trauma, 16: 35-51, 1976.

3. Gurdjian ES, Gurdjian ES. Acute head injuries. Surg Gyn Obstet, 146: 805-820, 1978.

4. Viano DC. Biomechanics of head injury toward a theory linking head dynamic motion, brain tissue deformation and neural trauma. In: Proceedings 32nd Stapp Car Crash Conference. Warrendale: Society Automotive Engineers, 1988.

5. Khalil TB, Viano DC. Critical issues in finite element modelling of head impact. In: Proceedings 26th Stapp Car Crash Conference. Warrendale: Society Automotive Engineers, 1982.

6. Gibson TJ, McCaul KA, McLean AJ, Blumbergs PC. Investigation of head injury mechanisms in motor vehicle accidents - a multi-disciplinary approach. In: Field accidents; data collection, analysis, methodologies and crash injury reconstructions. Warrendale: Society Automotive Engineers, 1985.

7. Ryan GA, McLean AJ, Vilenius ATS, Kloeden CK, Simpson DA, Blumbergs PC. Head impacts and brain injury in fatally injured pedestrians. In: Proceedings International Conference on Biokinetics of Impacts. Bron: INRETS-LCB, 1989.

8. Palmer GJ, De Nardi EJ, Fisk WE, Blumbergs PC, McLean AJ. Replica casting of the skull base. J Forensic Sc Soc, 29: 407-412, 1989.

9. Goldsmith W. Some aspects of the physical and mathematical modeling of loading to head/neck systems and implications of current DOT injury criteria. In: Head and neck injury criteria; a consensus workshop. Washington: NHTSA, 1981.

TABLE 1: Comparison of Cranial Cavity Dimensions

| | | Case Number | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| Age (years) | | 17 | 43 | 65 | 16 |
| Dimension: (mm) | A | 125 (100)[1] | 140 (112) | 132 (106) | 140 (112) |
| | B | 170 (100) | 164 (96) | 168 (99) | 177 (104) |
| See Fig. 4 | C | 132 (100) | 139 (105) | 138 (105) | 150 (114) |
| | D | 47 (100) | 46 (98) | 56 (119) | 57 (121) |
| Brain mass (gm) | | 1734 (100) | 1504 (87) | 1240 (72) | 1706 (98) |

[1] Measurements standardized against case number 1.

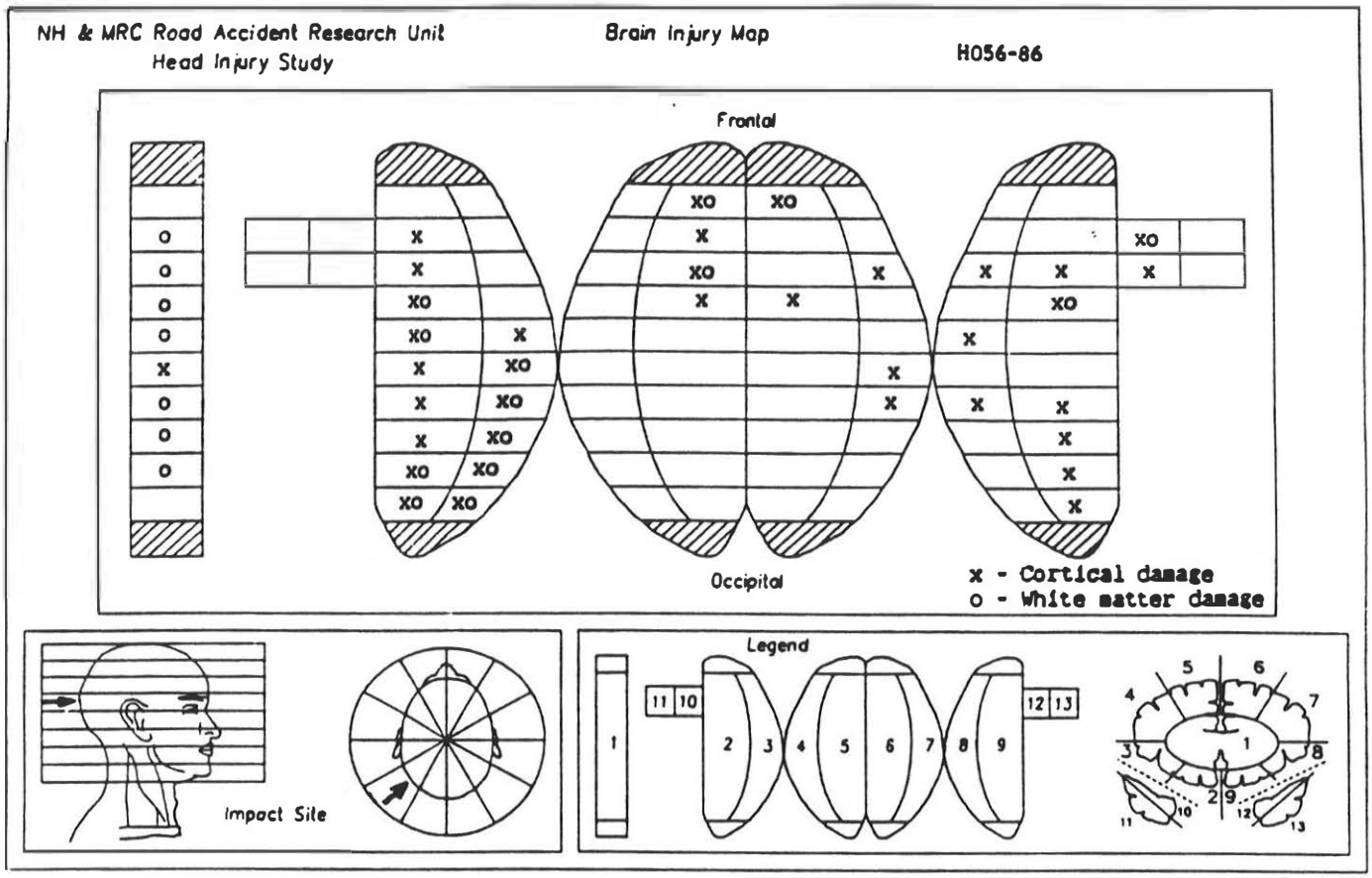



FIGURE 1: BRAIN INJURY MAP (Case 1)

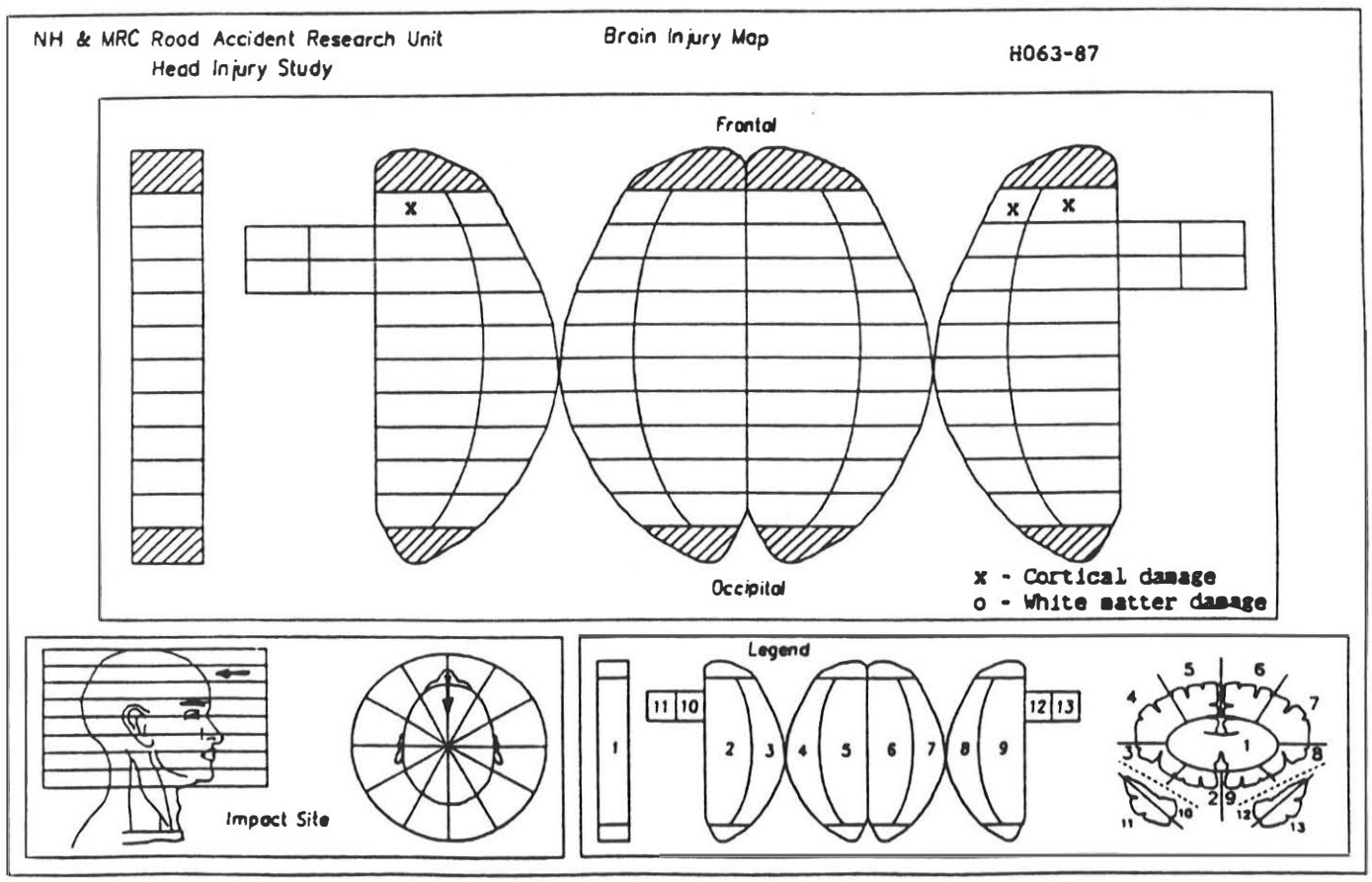



FIGURE 2: BRAIN INJURY MAP (Case 2)

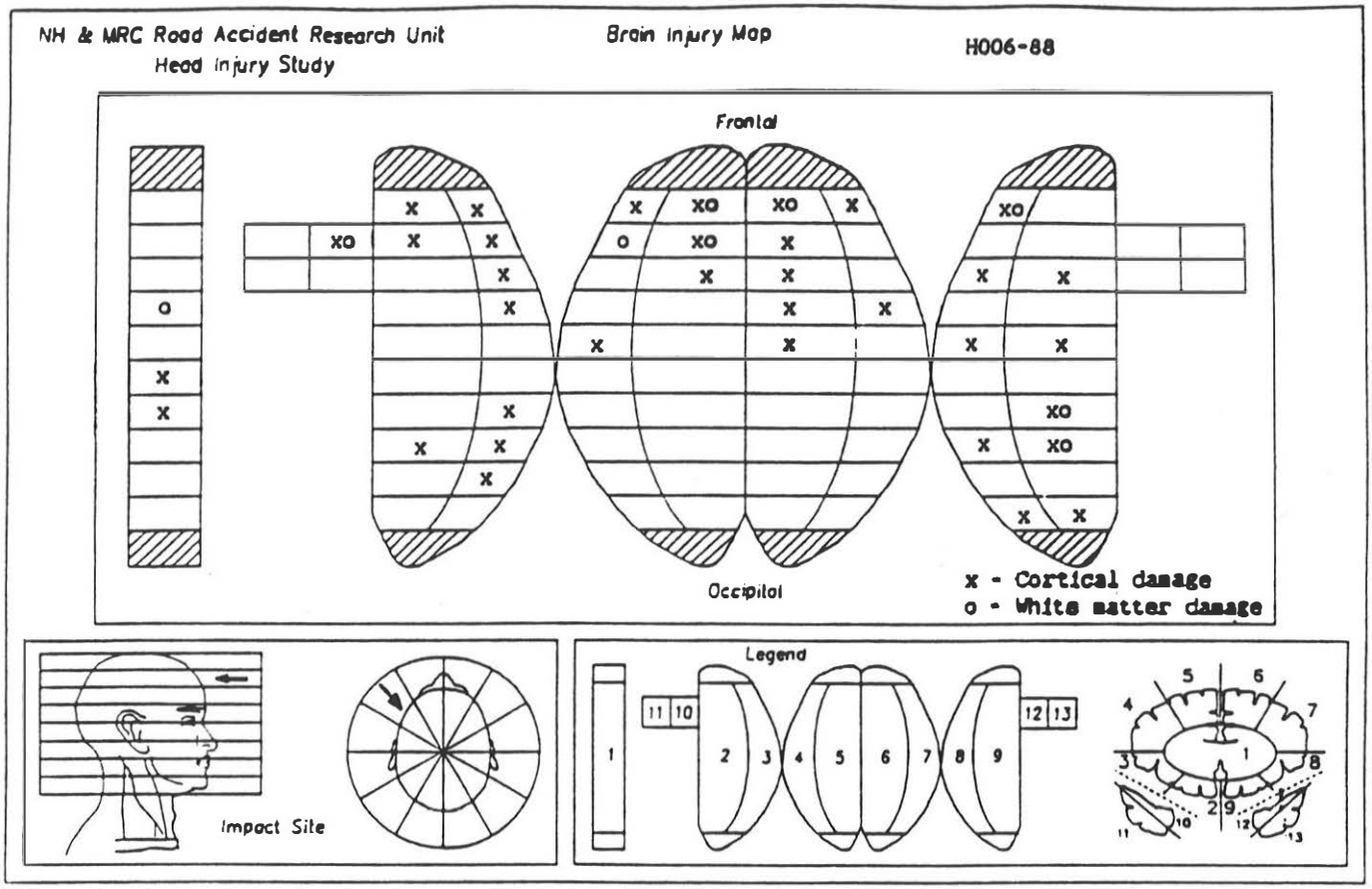
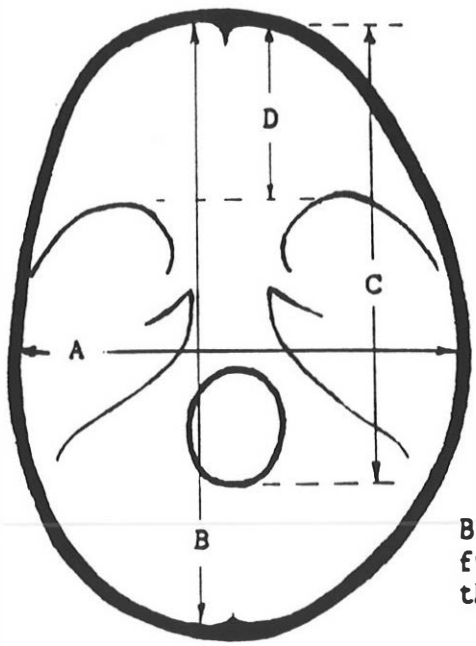



FIGURE 3: BRAIN INJURY MAP (Case 4)




B is measured to the furthest point below the transverse sinus

FIGURE 4: CRANIAL CAVITY DIMENSIONS
(Refer to Table 1)