PAEDIATRIC SPINAL CORD INJURY IN MOTOR VEHICLE ACCIDENTS: A PROSPECTIVE POSTMORTEM STUDY OF 33 CASES OF PAEDIATRIC MOTOR VEHICLE VICTIMS.

BY

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in the

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PREFACE

The study described in this dissertation was carried out in the Department of Forensic Medicine, University of Cape Town.

The work was done under the supervision of Professors G J Knobel and J C De Villiers.

This study represents original work by the author and has not been submitted in any form to another University. Where use was made of the work of others, it has been duly acknowledged in the text

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Signed

David R Fowler

19 June 1991

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I extend sincere thanks to the many people who contributed to the compilation of this thesis, and especially to:

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I dedicate this work to my wife Carolyn, a constant source of inspiration and encouragement, with grateful thanks for suffering through the many drafts.

David R Fowler.

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GLOSSARY

AIS	Abbreviated injury scale
DAI	Diffuse axonal injury
CSI	Cervical spine injury
DVI	Diffuse vascular injury
ISS	Injury severity score
SCI	Spinal cord injury
SCIWORA	Spinal cord injury without radiological abnormality
SD	Standard Deviation

CHAPTER ONE

INTRODUCTION

1.1 EPIDEMIOLOGY

In the developed world "accidents are the leading cause of death and injury to children after the age of one year"(22). In South Africa, in the under-four-year group, deaths related to infection form approximately 42% of the total for that age group, but above the age of four years injury causes 42-43% of deaths, and infectious causes, the second largest group, only 13-15% per annum(25).

In the Cape Peninsula, Knobel and co-workers found, that 54,4% of non-natural deaths in the under 15 age group were attributable to road traffic accidents(26). The rates of road deaths for children under 15 years have not increased significantly in White, Asian and "Coloured" children for the period 1968-1985.(25) Data for Black children are unreliable(25) so changes in rates cannot be calculated. Despite this, motor vehicle-related multiple trauma accounted for 31% of all injury mortality in children under the age of 14 years in the Republic of South Africa during the period 1981 -1985.(24)

As a child becomes more mobile the risk of injury and injury-related death increases. The proportion of male to female injury-related deaths is variable, ranging from 1,3:1 in the under one year group with a steady increase to 2,1:1 in the 10 - 14 age group(24).

1.2 BACKGROUND TO THE STUDY

A retrospective study by the Child Head Injuries Team, U.C.T., of all post-mortem examinations performed for paediatric head and multiple injuries at Salt River Police Mortuary during the period June 1983 to June 1985, revealed marked observer bias in the reporting of spinal injury (CJ Fowler, personal communication). As the spinal cord is not examined routinely, the observer bias may have been generated when pathologists assessed the incidence of spinal injury using only external examination of the spinal column and physical stress examinations. Opening of the cervical spinal column is a difficult and time consuming dissection which is often omitted in the motor vehicle collision patient who has sustained multiple, severe injuries and whose cause of death is not obscure.

In 1986, Professor J C de Villiers, Head of the Department of Neurosurgery and of the Child Head Injuries Research Team, suggested that a prospective study be considered to determine the exact incidence of cervical spinal injuries in paediatric motor vehicle collision victims who are admitted to Salt River Police Mortuary.

1.3 STUDY DESIGN

The primary aim of the study was to assess, prospectively, the incidence of spinal cord injury (SCI) in children admitted to Salt River Police Mortuary, following motor vehicle collisions.

The available literature on SCI indicated that Magnetic Resonance Scanning may be of major value in the diagnosis of SCI. In addition it was noted that, on plain x-ray, an entity called "spinal cord injury without radiological abnormality" (SCIWORA) was being reported. It was decided, therefore, to extend the study to include these two investigations, where possible, to try to compare the literature findings of predominantly clinical studies with the pathology seen at post mortem.

All motor vehicle collision victims under 14 years of age were chosen to be part of the study, regardless of their injuries, so that data could be correlated with that collected by the Child Head Injuries Research Team.

1.4 STRUCTURE OF THE REPORT

The methodology of the study is presented in Chapter 2. Thereafter, some basic anatomic information is included in Chapter 3 so that comparison can be made between the expected results as suggested by the literature review, and those actually observed. Several excellent texts on these subjects are available should more detailed information be required(5,23,27,40,45). The results are presented in Chapter 4 and discussed in Chapter 5 together with the available literature on cervical spinal injuries and radiodiagnostic methods used in spinal cord injury. Conclusions and recommendations are reported in Chapter 6.

CHAPTER TWO

DESIGN AND METHODOLOGY

The study population consisted of 33 children between the ages of 0 and 14 years who were admitted consecutively to the Salt River Police Mortuary, following a motor vehicle collision, between 21 October 1988 and 22 May 1989.

2.1 POST MORTEM PROCEDURE.

To reduce the possibility of differing technique or observer bias in the proposed study, all postmortems were performed by the author using a standard technique. After the full standard autopsy was performed(30) on the chest and abdomen, the central nervous system was examined with the following procedure:

After circumferential sawing through the skull the cranial cap was removed(30) (Figures 2.1 and 2.2). The cadaver was then turned over into a face-down position and the soft tissues covering the spinal cord, posteriorly down to the level of the second thoracic vertebra, were reflected to the left and right of the midline (Figure 2.3). A posterior approach to the central nervous system was used as follows: two saw cuts were made from the edge of the remaining cranium down to the lateral aspects of the foramen magnum. This fashioned a rhomboid with the wide base of the rhomboid superiorly, and the narrow section of the rhomboid present at the foramen magnum(30) (Figure

2.4). This section of skull was then removed, giving excellent access to the craniocervical junction at the level of the foramen magnum. In order to preserve the craniocervical junction, the brainstem was divided at the medullo-pontine junction, the brain removed from the cranial cavity and preserved for later detailed dissection, after fixation (Figure 2.5). The spinal cord was then carefully examined *in situ*, with special attention being paid to the atlanto-occipital joint. Once this examination was complete, the atlanto-occipital joint was disarticulated by severance of the ligaments and musculature at this level (Figure 2.6). The cervical spinal column was then removed from the body by transecting the spinal column and spinal cord at the level of T2. The removed specimen, which consisted of the cervical spinal column with the spinal cord intact and surrounded by some of the paravertebral musculature, was then placed in formalin together with the brain (Figure 2.7). A wooden prosthesis and cotton waste padding were then used to pad out the neck and reconstitute the normal surface features of the body.

REMOVAL OF THE CERVICAL SPINE

1) REFLECTION OF THE SCALP

Figure 2.1

REMOVAL OF THE CERVICAL SPINE

2) REMOVAL OF THE SKULL CAP

Figure 2.2

REMOVAL OF THE CERVICAL SPINE
3) REFLECTION OF THE CERVICAL SKIN

Figure 2.3

REMOVAL OF THE CERVICAL SPINE
4) REMOVAL OF THE OCCIPITAL BONE FLAP

Figure 2.4

REMOVAL OF THE CERVICAL SPINE
5) REMOVAL OF THE BRAIN

Figure 2.5

REMOVAL OF THE CERVICAL SPINE
6) DISARTICULATION OF ATLANTO-OCCIPITAL JOINT

Figure 2.6

REMOVAL OF THE CERVICAL SPINE
7) THE REMOVED CERVICAL SPINE

Figure 2.7

2.2 RADIOLOGICAL EXAMINATION

Plain x-rays of the formalin-fixed specimen were taken utilising anteroposterior and lateral views. The x-rays had to be taken in the fixed state as, at the time of the study, no adequate x-ray facilities existed at the Salt River Mortuary for the production of high quality plain x-rays. The anteroposterior and lateral films obtained were similar to those obtained in a trauma unit. No extension or flexion stress x-rays could be undertaken due to the fixed material used.

As discussed in 5.1.3 the fixed cervical spinal columns were then subjected to magnetic resonance imaging using both T1 and T2 WEIGHTED scans in order to assess the accuracy of magnetic resonance imaging (MRI) in diagnosing acute spinal trauma. A total of 12 spines was examined with MRI. Constant evaluation of these showed that little or no additional indication of trauma was being found in these cases, and because of financial restrictions and the limited machine time available, no further cases were scanned. This decision was taken during the study period once new data on MRI(29) became available (Chapter 4.2.2).

2.3 PATHOLOGICAL EXAMINATION

The whole cervical spinal column was then placed in a decalcifying solution, consisting of nitric acid and urea(12,16), for a period of approximately one week with several changes of the decalcifying solution during this period. After adequate decalcification, serial sections were made at the level of each cervical vertebra and additional histological samples were taken of the craniocervical junction and the medullary area. Each section was photographed macroscopically (Figure 2.8) and then the spinal cord and surrounding dura were removed and processed for histological examination using sections stained with haematoxylin and eosin. Histological examination of these spinal cords was then undertaken to ascertain the extent of haemorrhage, and other evidence of trauma, at each level in the extradural, subdural and subarachnoid spaces and within the spinal cord itself.

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

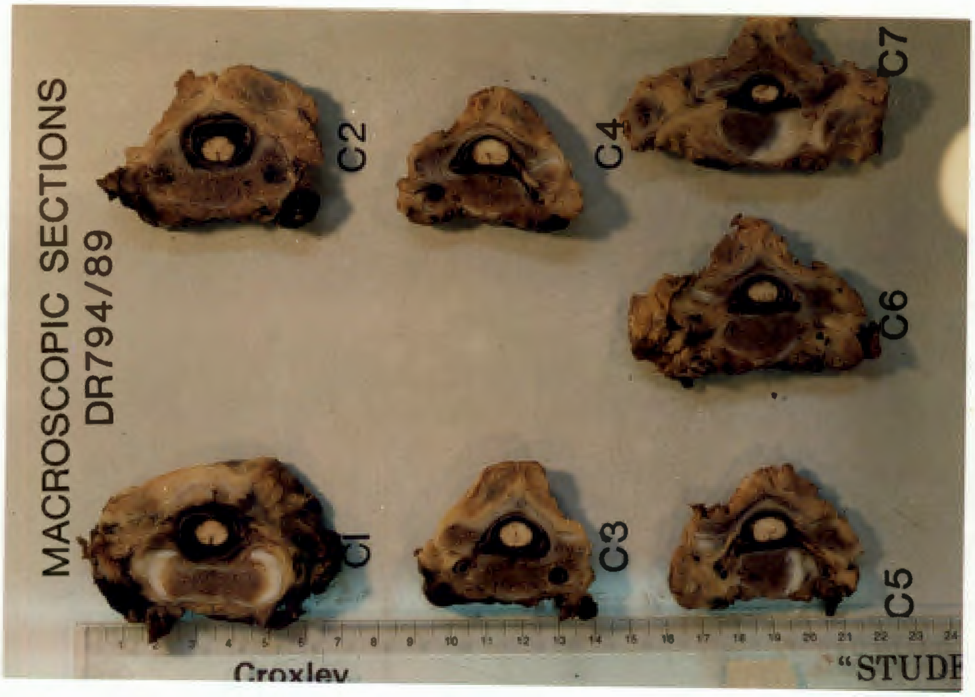


Figure 2.8

2.4 INJURY CODING

The results of the postmortem examination were coded using the Abbreviated Injury Scale 1985 revision (AIS '85)(1). This coding system divides the body into the following regions: face; head and neck; external; extremities; chest; and abdomen. All injuries are grouped according to these regions and injury is allocated a score, ranging from 0 (no injury) to 6 (unsurvivable injury), as specified in the AIS '85 manual. The highest score in each region is defined as the score for that entire region. To calculate an injury severity score the scores for the three highest scoring areas are squared and then added. This score is a useful indicator of the severity of the injuries and the possible chance of a survivable or fatal outcome. Although a 1990 revision of the AIS is now available, AIS '85 is used in this study so that a comparison of data, with that of the Child Head Injuries Research Team which used AIS '85, can be undertaken.

2.5 STATISTICAL ANALYSIS

The data from this study was entered onto a report sheet generated using *Epi Info Version 5.0.* Statistical analysis of the data was done using *Epi Info Version 5.0* on an IBM compatible personal computer(19).

2.6 APPROVAL FOR STUDY

The protocol for this study was approved by the Higher Degrees Committee and the Board of the Faculty of Medicine.

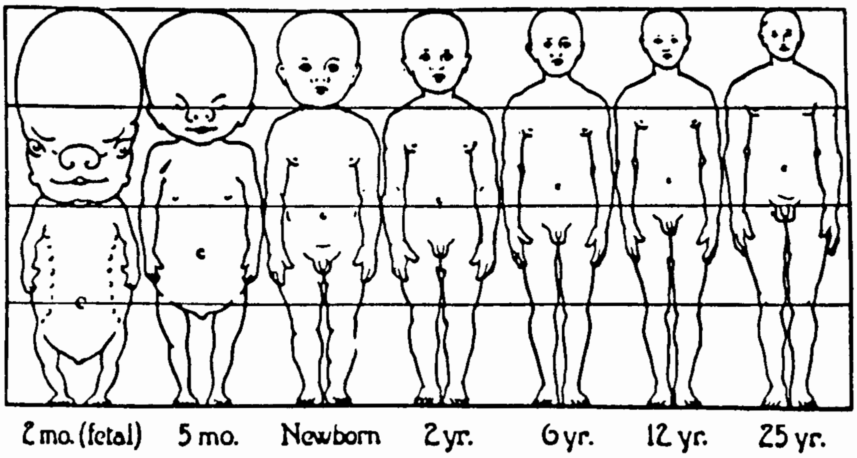
CHAPTER THREE

ANATOMICAL CONSIDERATIONS

3.1 GROWTH, DEVELOPMENT AND COMPARATIVE ANATOMY.

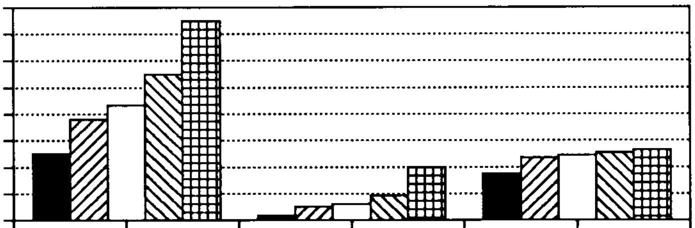
"The body proportions of newborn infants differentiate them sharply from older infants, children or adults"(34).

CHANGES IN BODY PROPORTIONS FROM SECOND FOETAL MONTH TO ADULTHOOD



NELSONS TEXTBOOK OF PAEDIATRICS PAGE 8(34)

Figure 3.1



	LENGTH (Cm)	WEIGHT (Kg)	HEAD CIRC. (Cm)
BIRTH	50.5	3.27	34.8
ONE YEAR	76.1	10.16	47
TWO YEARS	87	12.34	49.2
FIVE YEARS	110	18.7	51
TWELVE YEARS	149.7	39.78	53

■ BIRTH ▨ ONE YEAR ☐ TWO YEARS
▧ FIVE YEARS ▦ TWELVE YEARS

GRAPHIC PRESENTATION OF INFORMATION EXTRACTED FROM NELSONS TEXBOOK OF PAEDIATRICS(34)

Figure 3.2

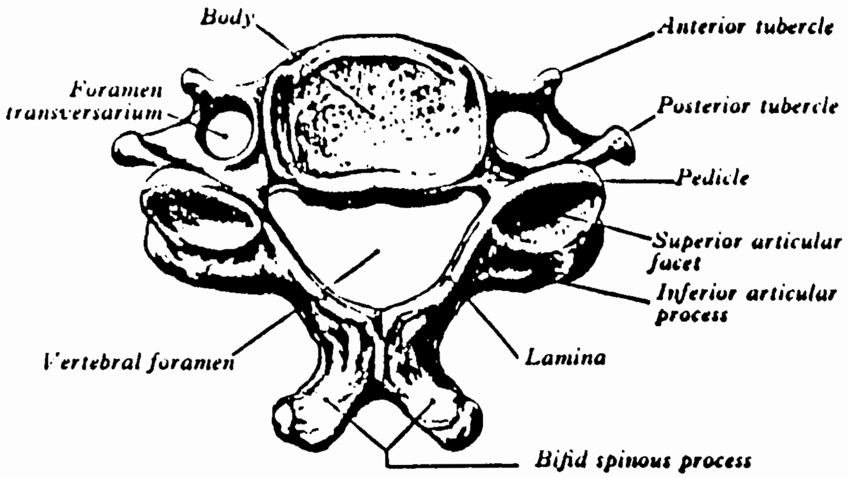
Figure 3.2 shows that head circumference increases by approximately 52% from birth to 12 years of age. The mass of the head increases by a slightly greater percentage due to facial development, while the body length increases by 300% and the weight by over 1000% during the same period. It can also be seen that the majority of the central nervous system growth occurs during the first year when the child is non-mobile. There is a small increase, from 47-53cm, in head circumference from the age of one year to 12 years. This growth is proportionately far less than that which the musculoskeletal system undergoes during this period. This disproportionate growth places an extremely heavy central nervous system on top of a relatively (compared to an adult) weak cervical spine and musculature. During the second year of life, the rate of growth, especially of the central nervous system, continues to decelerate. However, the myelination of the nervous system progresses so that by 18 months the average child can climb stairs with assistance, and by 24 months, the child is able to run well and falls infrequently.

From 18 months to 24 months the average child is extremely vulnerable as he is able to move quickly from relatively safe environments into a position of danger. By 12 years of age, the central nervous system has virtually reached adult proportions, whereas the musculoskeletal system still has to complete a significant proportion of growth through the pubertal growth spurt. However, as by this age the musculature is generally relatively well developed and the extreme ligamentous laxity seen in the young infant and toddler has now decreased markedly, the adolescent more closely approximates the adult model(34). In addition to these physical considerations the limited cognitive development of the young child limits his ability to assess or appreciate some of the dangers of the traffic environment, hence the selective vulnerability of this age group.

3.2 ANATOMY OF THE CERVICAL SPINE(5,23,40,45)

The anatomy of the cervical spine is briefly reviewed here because a knowledge of the anatomy is fundamental to the understanding of the research findings.

A TYPICAL CERVICAL VERTEBRA.
SUPERIOR ASPECT.



SOURCE: GRAYS ANATOMY 35TH EDITION P. 234 (46)

Figure 3.3

3.2.1 The vertebrae

The cervical vertebral column is an elastic and flexible structure. It starts at the atlanto-occipital joint and terminates at the junction of the seventh cervical vertebra and the first thoracic vertebra. The vertebrae are joined by various ligaments and interposed by cartilaginous intervertebral discs which allow much of the elastic movement of which the cervical spine is capable.

There is no intervertebral disc between the atlas and the axis, the first occurring between the second and third cervical vertebrae. Each vertebra consists of the vertebral body anteriorly and the vertebral arch, which consists of a pair of pedicles and a pair of laminae posteriorly. There are seven processes present: four articular, two transverse and one spinous. Between the vertebral bodies and the arch is the vertebral canal which contains and protects the spinal cord. The articular processes arise at the junction of the laminae and pedicles and each has a superior and inferior articular facet. These articular surfaces help to control and restrict the range of vertebral movement. The other processes provide attachments for ligaments and muscles. There are great variations in the size and shape of the cervical vertebrae and the first two are highly specialised in order to provide greater rotational movements of the head.

3.2.2 The Intervertebral discs

The intervertebral discs, found between the vertebral bodies, are closely attached anteriorly and posteriorly to the anterior and posterior longitudinal ligaments respectively. Together these form the chief connections of the vertebrae. The discs have a central fluid matrix containing collagen fibrils. This, the *nucleus pulposus*, is soft to gelatinous at birth and consists of mucoid-like material. By the age of 10 years, the mucoid material has, however, to a large extent, been replaced by fibrocartilage derived from the *annulus fibrosis* surrounding the *nucleus pulposus* and from the cartilaginous plates covering the upper and lower surfaces of the vertebrae. This decreases the elasticity of the disc and renders the *nucleus pulposus* far less distinct. The thickness of the intervertebral discs is greater in the cervical and lumbar regions, and provides the normal lordosis in these regions.

3.2.3 The Ligaments

The *ligamentum flavum* and the anterior and posterior longitudinal ligaments are the three major ligaments present in the cervical spine. The anterior longitudinal ligament has its origin at the *tuberculum anterius* of the atlas. It consists of longitudinal fibres firmly fixed to the intervertebral discs anteriorly and to the adjacent parts of the vertebral bodies, and passes downwards terminating at the sacrum. It is less firmly attached at the central section of the vertebral body. The posterior longitudinal ligament lies within the spinal canal and is fixed to the posterior surfaces of the vertebral bodies and discs. Its origin is at the axis and it terminates at the sacrum. The more elastic *ligamentum flavum*, consisting of predominantly yellow elastic fibres, connects the laminae of adjacent vertebrae. Its origin is the anterior surface of the lower margin of the superior laminae and it's insertion is on the posterior surface of the upper margin of the laminae of the vertebra below. This ligament serves to control the movements of the vertebrae by preventing excessive flexion. The *ligamentum nuchae* in man is merely a fibrous band which extends from the external protuberance of the occiput and travels down to the seventh cervical vertebra as a partition between the muscles on the back of the neck. Supra-spinous and inter-spinous ligaments connect the spinous processes, and intertransverse ligaments, which have connections with the deep back muscles and are found interposed between the transverse processes are insignificant in the cervical region.

3.2.4 The Muscles

The muscles of the neck and the upper back, which attach to the vertebral column via the laminae, spinous and transverse processes, provide the majority of the movement and supportive stability of the cervical spine. Their physical attachments centrally, with wide-based attachments to the shoulder girdle and back muscles, provide stay-like supporting structures suitable for supporting the weight of the head on the cervical spinal column.

3.2.5 The Spinal Cord

The spinal cord contained within the spinal canal arises at the junction with the *medulla oblongata* and extends caudally from approximately the level of the atlanto-occipital joint to the second lumbar vertebra. Because of the brachial plexus outflow in the cervical area the cord has a cervical enlargement extending from the third cervical vertebra (C3) to the second thoracic vertebra (T2) with the greatest diameter present at the level of the fifth to sixth cervical vertebrae. At each vertebral level the spinal cord gives off a pair of anterior and posterior spinal nerve roots. There are eight cervical pairs which run almost horizontally to enter the intervertebral foramina. The first and second cervical segments lie at the level of the spinous process of C1 and the third cervical segments lie at the level of the spinous process of C2.

The spinal cord is covered by the same three layers of meninges which surround the brain. Centrally to peripherally these are: pia, arachnoid, and dura mater respectively.

The spinal dura mater is a continuation of the inner layer of the cerebral dura. The outer layer of the cranial dura, the endosteal layer, terminates at the *foramen magnum*. Its position within the cervical column is occupied by the *periosteum* lining the vertebral canal. The *periosteum* and *dura mater* are separated by the extradural (epidural) space which contains fat and a venous network. The dura continues to envelop the spinal roots until they pass through the intervertebral foramina. The cervical dura contains relatively more fibrous tissue and less vascular supply than that of the cerebral dura.

The arachnoid, which is a continuation of the cerebral arachnoid, is a fine membrane predominantly of elastic fibrous tissue and contains vessels of varying sizes which are potentially large enough to cause extensive haemorrhage. The arachnoid also dips into the anterior median fissure and the posterior median sulcus. The subarachnoid space contains cerebrospinal fluid.

The *pia mater* is also a continuation of the *pia mater* surrounding the brain and is firmly adherent to the spinal cord and follows the surface of the spinal cord, dipping into all of the fissures. The pia thickens laterally, forming the *ligamentum denticulatum* and is fixed along the inner side of the dura.

The spinal cord consists of grey and white matter, as does the rest of the central nervous system. The grey matter runs centrally throughout the spinal cord and has a butterfly shape on cross section consisting of anterior, lateral and posterior horns. In the centre of the grey matter is the central canal containing cerebrospinal fluid (not in 12% of adults). Histologically the grey matter consists of neurones and supporting tissues. The white matter consists predominantly of three columns: the anterior, lateral and posterior, and these contain the ascending and descending tracts which conduct afferent and efferent impulses to and from the central nervous system.

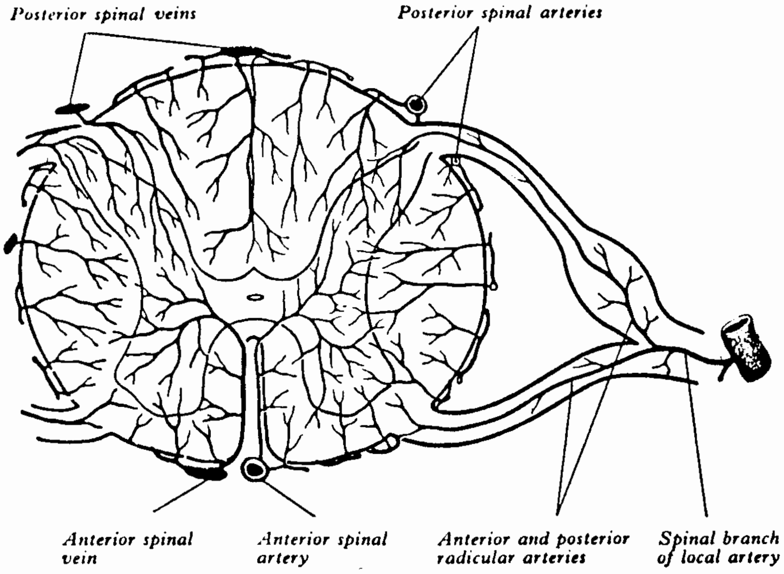
3.2.6 The vascular supply of the spinal cord.

The vascular supply of the spinal cord is described from anterior to posterior surface. The anterior spinal artery originates as branches of the cranial end of the vertebral arteries at the cervico-medullary junction. The junction of these two branches forms a single artery which runs down the anterior median fissure of the spinal cord into the upper thoracic region. Radicular branches, derived from the cervical part of the vertebral artery, also join the anterior spinal artery. Some of these radicular branches are noted to be variable, although those between the fifth and sixth cervical segments are normally constant. From the anterior spinal artery sulco-commissural branches pass into the anterior median fissure to supply the anterior and lateral white tracts, and all of the grey matter (with the exception of the posterior part of the posterior horn).

The posterior arteries also arise from the vertebral arteries, but do not join, and descend as a pair of arteries in a caudal direction along the medial border of the posterior roots. These two vessels also receive numerous segmental feeding vessels. The posterior spinal arteries supply the remainder of both posterior horns and the posterior white tracts.

The arterial supply of the cord can be seen in Figure 3.4.

THE BLOOD SUPPLY OF THE SPINAL CORD



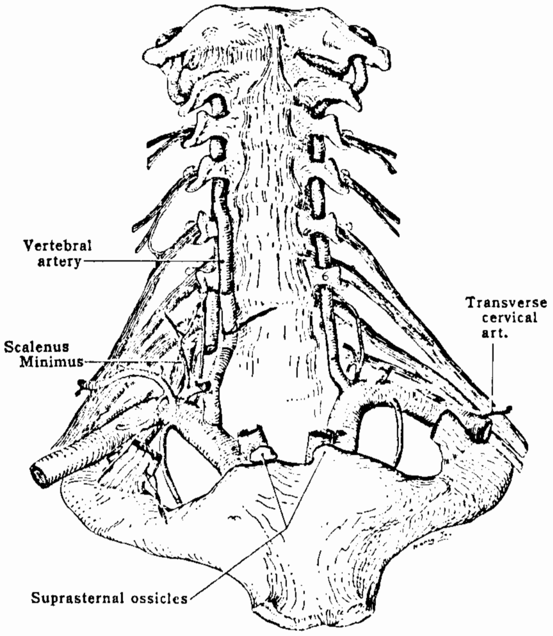
SOURCE: GRAYS ANATOMY 35TH EDITION P. 839(45)

Figure 3.4

3.2.7 Vertebral arteries.

The vertebral arteries, while not supplying the spinal cord directly but via the feeding vessels, are found in such intimate relation to the cervical vertebrae that there is great potential for them to be damaged by any movement at the atlanto-occipital junction or in their cervical course. Therefore, their basic anatomy is summarised here. The vertebral artery arises from the first portion of the subclavian artery and ascends between the *scalenius anterior* and *longus cervicus* muscles behind the common carotid artery to the transverse process of the sixth cervical vertebra. It then ascends through the transverse foramina of the upper six cervical vertebrae, accompanied by autonomic nerves and a venous plexus. From the foramen transversarium of the axis it runs upwards and laterally to the transverse foramen of the atlas. As it emerges from this foramen on the medial side of the *rectus capitus lateralus* it curves backwards, behind the lateral mass of the atlas, to come to lie in a groove on the upper surface of the posterior arch of the atlas. It enters the spinal canal by passing below the lower arched border of the posterior atlanto-occipital membrane, pierces the dura and arachnoid mater and ascends the front of the medulla oblongata to the lower border of the pons where it unites with the vertebral artery of the opposite side to form the basilar artery.

THE ANATOMY OF THE VERTEBRAL ARTERY



SOURCE: GRANTS ATLAS OF ANATOMY P. 9-83(8)

Figure 3.5

3.3 APPLIED ANATOMY

In motor vehicle collisions, especially those involving pedestrians, considerable force is applied to the body. Adult models of force transference, and the resulting trauma, are not applicable to children, for several reasons: firstly, the force is usually applied to a different part of the body as a result of the child's small stature and the different position relative to the motor vehicle. Secondly, children have a distribution of body mass which is very different from that of adults. As mentioned previously the musculoskeletal system develops far more slowly than the central nervous system, resulting in a much larger head to body ratio.

This differential development leaves a central nervous system that is vulnerable to injury. The cervical spinal column has the greatest potential for injury in a child because, while in an adult the head comprises approximately four percent of the body mass(34), the relative head to body mass ratio is far greater. It would seem that the heavy head balanced on a spinal column supported by muscles that have, as yet, to develop much of their bulk and strength predisposes the cervical column to injury(36).

The most vulnerable time for traffic-related cervical spine injury would seem to be when a child is mobile and has a maximal head to body ratio. This corresponds to the age group that have just learnt to walk ie, the two to four year olds. The above factors are dependent on the child's exposure to risk, and if the child is well supervised, while in, or protected from the traffic environment his vulnerability is not at issue.

In South Africa the young child involved in a motor vehicle collision is usually a pedestrian(24). As a result, the child is subjected to acceleration and deceleration forces often, although not always, applied directly to the head. The child is unique in this respect as the head is low enough to be struck directly. In addition the child who is top heavy, if launched, by impact with a vehicle will usually land "head first." These acceleration-deceleration forces must be transmitted to the rest of the body via the only anatomic connection: that of the neck muscles, the spinal vertebrae, disks, and the spinal ligaments.

Although the child certainly has a disproportionately larger head size to neck musculature ratio than the adult, it is not known exactly how flexible the child's cervical column is compared with that of an adult, and whether the adult pattern of stress releases by fracture and rupture of ligaments will occur. It is well documented that radiological examination of cervical spines in children will often not reveal any injury(13,36,46).

One expects the different paediatric age groups to show a variation in the type of injury. Apple *et al* showed, in a review of 29 cases, that in the under 12 year age group the injury is at the C1, C2, or atlanto-occipital area whereas those in the over 12 year group show an adult pattern of lower cervical injuries(6). Since the younger the child the greater the head to body mass ratio, presumably the younger children may be at greater risk.

Many theories have been offered to explain this vulnerability of the high cervical spine in young children:

- i) the natural fulcrum in this age group which appears to be one or two segments higher than the adult;
- ii) the laxity of the interspinous ligaments and joint capsules;
- iii) horizontally orientated vertebral joint facets making subluxation easier;
- iv) the vertical height of the vertebral body is greater posteriorly than anteriorly making movement on the one below easier.(44)

3.4 CONCLUSION

The anatomic structure of the cervical spine in the child is of major importance in understanding the type of injury that may occur. A biomechanical model of the childhood cervical spine may provide useful information in predicting how the forces applied to this area are dissipated. It is, however, quite apparent that the adult model of cervical injury is not adequate as a predictor in the under 12 year old age group.

CHAPTER FOUR

RESULTS

4.1 PATIENT PROFILE

Between 21 October 1988 and 22 May 1989 thirty three children under the age of 14 years were admitted consecutively to the Salt River Police Mortuary, following a motor vehicle collision. Of these (81,8%) were pedestrians and their ages ranged from one year to twelve years with a mean of six years (SD=3,27). Males comprised 72,7% of the cases: a M:F ratio of 2,7:1.

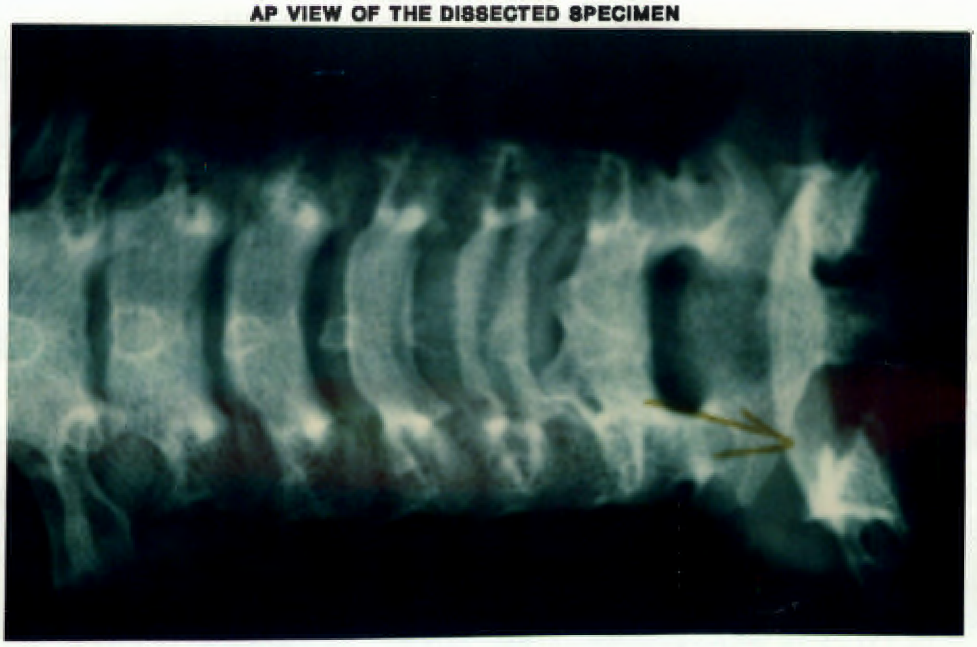
After all investigations were complete the cause of death was limited to the head and neck region in nine (27,3%) of the children. The remainder had significant injuries in multiple regions.

4.2 RADIOLOGICAL EXAMINATION

4.2.1 PLAIN X-RAYS

X-ray studies of the fixed postmortem cervical spines, using anteroposterior and lateral studies, showed evidence of damage in only one (3.0%) of the 33 cases. Unfortunately, because of the dissection technique discussed previously in sections 2.1 and 2.2, the atlanto-occipital joint could not be assessed in this study. As, on post mortem examination, six cases (18,2%) had disruption of the atlanto-occipital joint with severe damage to the cord, it is likely that if this joint had been preserved the number of positive x-ray studies would have been greater. The positive X-ray study (AP and lateral views) is shown in Figures 4.1 and 4.2 respectively.

CERVICAL SPINE DR 169/89
AP VIEW OF THE DISSECTED SPECIMEN



COURTESY OF DR M KRAMER CONRADIE HOSPITAL.

Figure 4.1

Figures 4.1 and 4.2: (AP and Lateral views of the postmortem specimen): "There is lateral displacement of a lateral mass of the Atlas. The arch-dens distance is 5mm which is at the upper limits of normality. The interspinous space between C1 and C2 is considerably widened. These features are consistent with an atlanto-axial injury." (Dr M Kramer)

Figures 4.3 to 4.5, photographs of sections through the first three cervical vertebrae of the same child, show an absence of spinal cord at C1, and haemorrhage into the paravertebral muscles. The defects seen on the x-rays are not clearly seen on these sections. This may be explained by the fact that the sections were taken according to the standard methodology of the study and not specifically for any injury.

CERVICAL SPINE DR 169/89

LATERAL VIEW OF THE DISSECTED SPECIMEN

COURTESY OF DR M KRAMER CONRADIE HOSPITAL.

Figure 4.2

CERVICAL SPINE DR 169/89
PHOTOGRAPH OF SECTION THROUGH C1

Figure 4.3

CERVICAL SPINE DR 169/89
PHOTOGRAPH OF SECTION THROUGH C2

Figure 4.4


CERVICAL SPINE DR169/89
PHOTOGRAPH OF SECTION THROUGH C3

Figure 4.5

4.2.2 MAGNETIC RESONANCE SCANS (MRI)

As discussed in sections 5.1.3.3 and 2.2, 12 cases were scanned before it was decided to discontinue this investigation. No significant cervical pathology was visualised in any of the scans (epidural, subdural, subarachnoid or paravertebral haemorrhage). The MRI investigation, in this study, also suffered from limitations similar to the plain x-ray studies, in that the partially dissected specimen prevented all of the available information being obtained.

An example of an MRI scan together with photographs of the corresponding transverse cut sections of the same specimen, is shown in Figures 4.6 to 4.16. All seven cervical vertebral segments are shown to illustrate the severity of the injury. Although the MRI scan showed no evidence of haemorrhage into the epidural and subdural spaces the photographs clearly show a small epidural haemorrhage at C1 and C2, and subdural haemorrhage from C2 to C7 becoming more severe in the lower cervical segments. This example illustrates why, in consultation with the Neuroradiologist, Dr F Lotz, no further scans were undertaken. The full explanation why MRI has not shown these injuries will be discussed in Chapter 5.1.3.3.

CERVICAL SPINE DR 794/89
MRI SCAN OF THE DISECTED SPECIMEN

COURTESY DR F LOTZ CITY PARK MRI

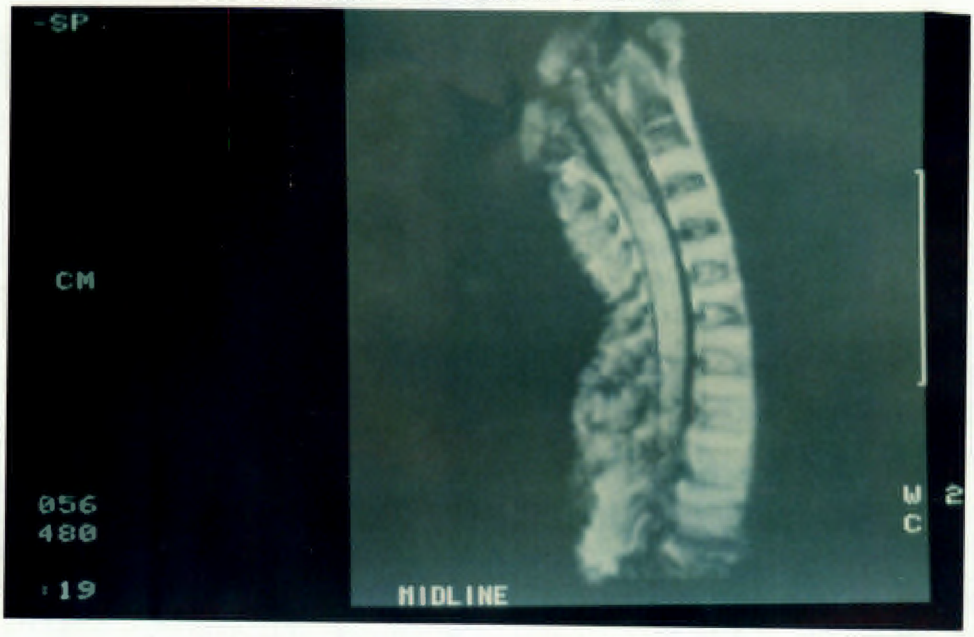
Figure 4.6

CERVICAL SPINE DR 794/89
MRI SCAN OF THE DISECTED SPECIMEN

COURTESY DR F LOTZ CITY PARK MRI

Figure 4.7

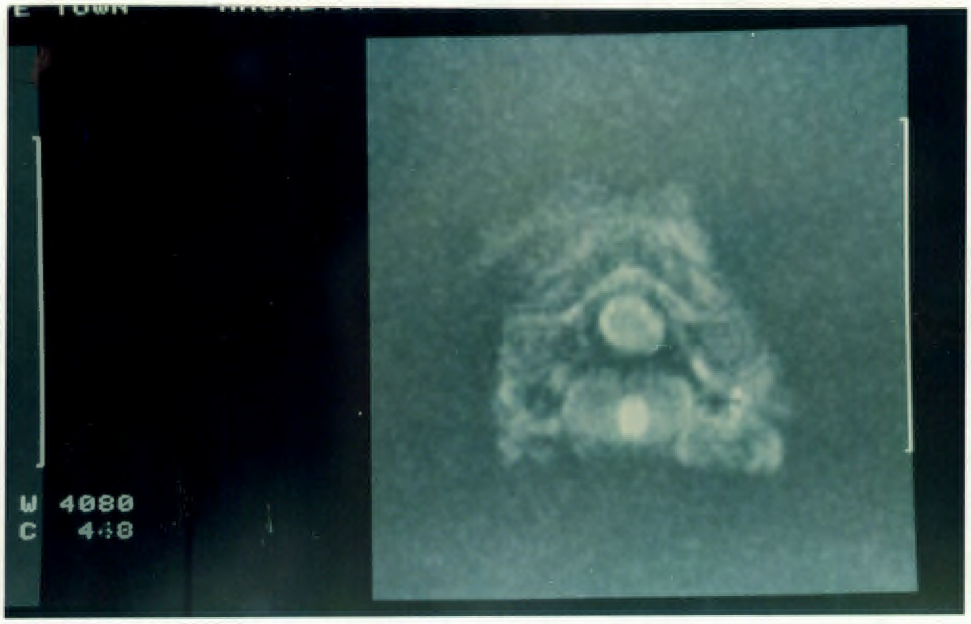
CERVICAL SPINE DR 794/89
MRI SCAN OF THE DISECTED SPECIMEN



COURTESY DR F LOTZ CITY PARK MRI

Figure 4.8

CERVICAL SPINE DR 794/89
MRI SCAN OF THE DISECTED SPECIMEN



COURTESY DR F LOTZ CITY PARK MRI

Figure 4.9

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.10

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.11

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.12

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.13

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.14

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.15

CERVICAL SPINE DR 794/89
PHOTOGRAPH OF TRANSVERSE SECTIONS

Figure 4.16

4.3 POST MORTEM FINDINGS

4.3.1 CERVICAL SPINE

Physical assessment of the cervical spine *in situ* at the time of the post mortem, revealed signs indicative of cervical spine injury in 12 of the 33 children (36,4%). Of these, six (18,2%) showed macroscopic injury to the spinal cord (transection), the remainder consisted of cases where "greater than normal laxity" of the spinal column was noted.

After a full investigation of each case, 31 of the 33 cases (93.9%) showed injury to this area. This figure includes all cases in which there was evidence of injury, however minor. Of greater significance is the fact that 23 cases (69.7%) had petechial haemorrhage into the spinal cord. This is indicative of severe damage to the neural tissue, similar to that seen in Diffuse Axonal Injury (DAI) of the brain(2,3).

Cross tabulation of postmortem data with the histological examination findings data revealed that three of the 12 cases initially thought to have cervical spine injury showed no evidence of microscopic injury to the spinal cord. In addition 14 cervical spine injury cases were "missed" at postmortem (a false negative rate of 42 per hundred).

The frequency of the different types of haemorrhage observed during macroscopic and microscopic examinations of the cervical spine is shown in Table 4.1.

CERVICAL HAEMORRHAGES

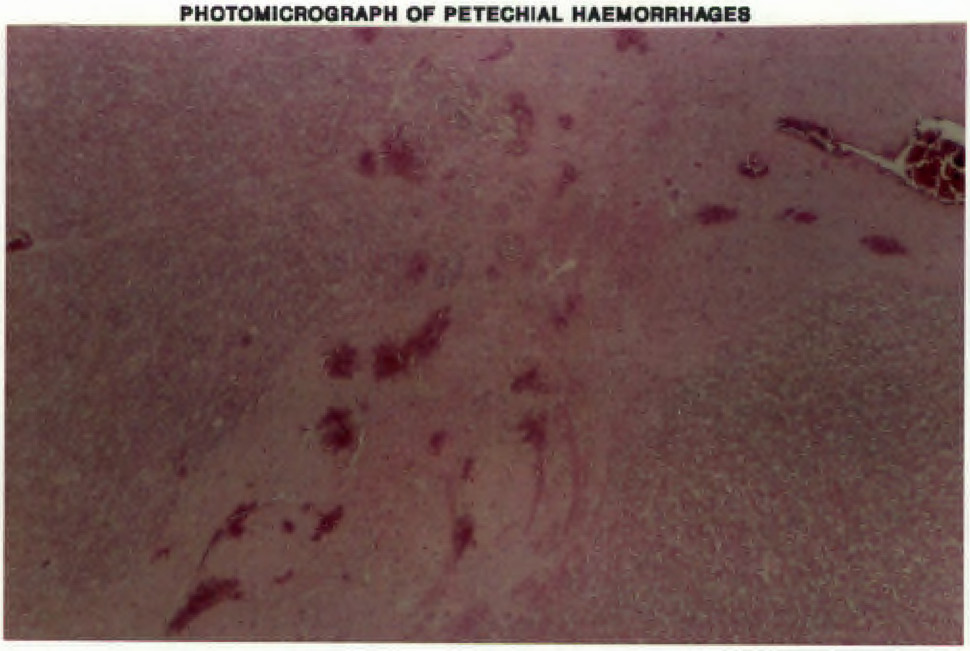
TYPE OF HAEMORRHAGE	NUMBER	% OF CASES
EPIDURAL (EXTRADURAL)	27	81.8%
SUBDURAL	24	72.7%
SUBARACHNOID	26	78.8%
SPINAL (INTRA-MEDULLARY)	23	69.7%
PARAVERTEBRAL BODY (MUSCULAR)	22	66.7%
PARAVERTEBRAL ARTERIES	17	51.5%
CRANIOCERVICAL JUNCTION (cervico-medullary junction)	11	33.3%

Table 4.1

The five photographs which follow illustrate:

- multiple petechial haemorrhages into the spinal cord (Figure 4.17);
- subdural haemorrhage surrounding a radicular branch of the vertebral artery (Figure 4.18);
- subdural and subarachnoid haemorrhage (Figure 4.19);
- epidural haemorrhage (Figure 4.20);
- contusion and laceration of cord at C6 at level of anterior ligament rupture (Figure 4.21).

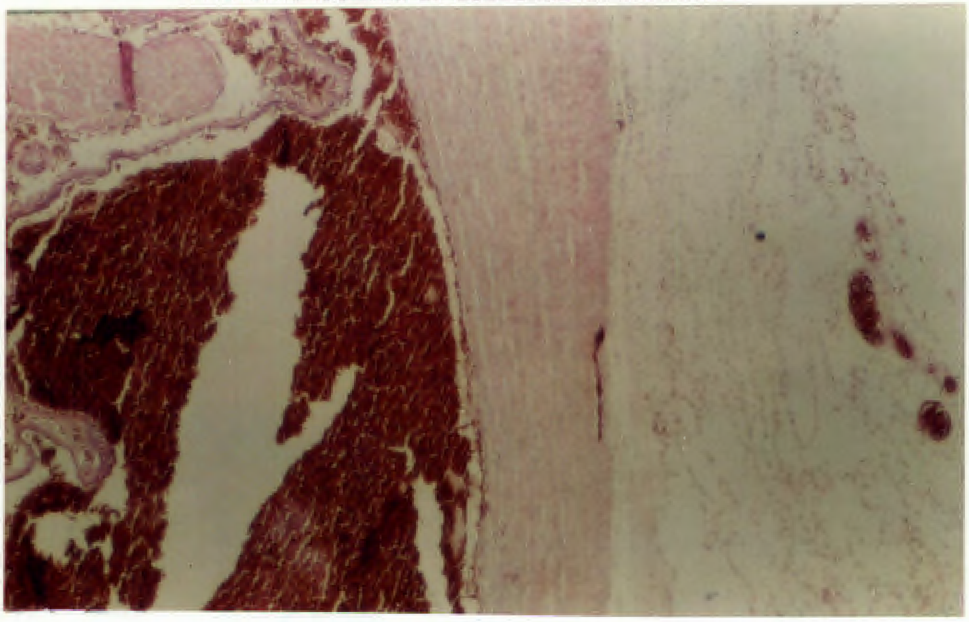
CERVICAL SPINE
PHOTOMICROGRAPH OF PETECHIAL HAEMORRHAGES



HAEMATOXYLIN AND EOSIN x 40

Figure 4.17

CERVICAL SPINE
PHOTOMICROGRAPH OF SUBDURAL HAEMORRHAGE

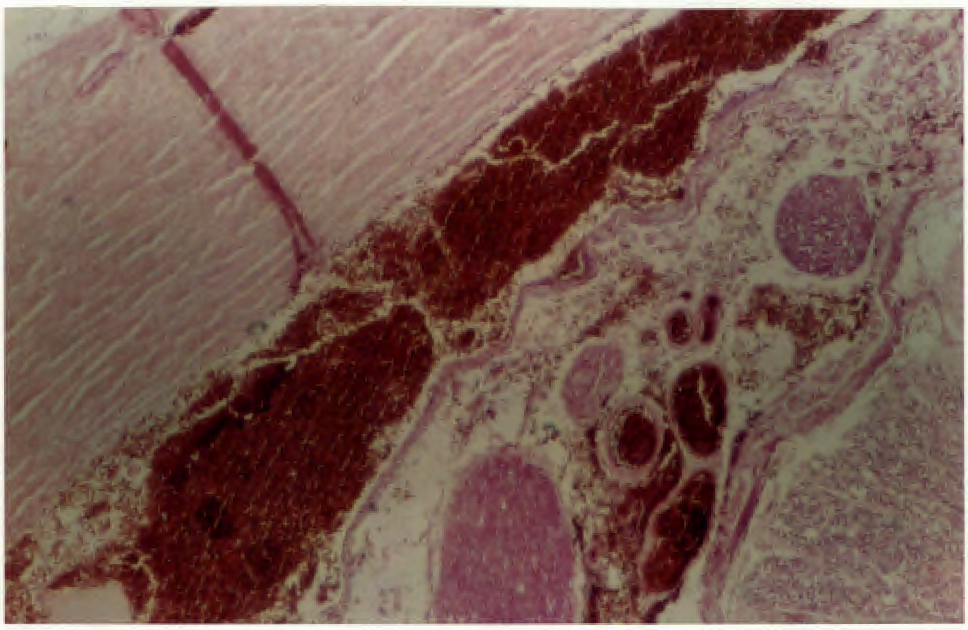


HAEMATOXYLIN AND EOSIN x 40

Figure 4.18

CERVICAL SPINE

PHOTOMICROGRAPH OF SUBDURAL AND SUBARACHNOID HAEMORRHAGE

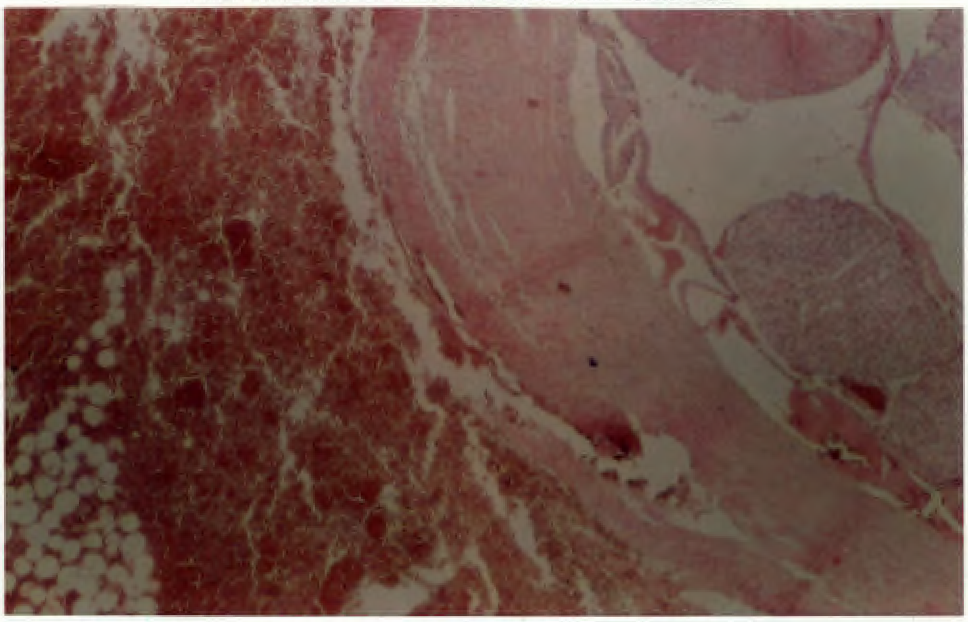


HAEMATOXYLIN AND EOSIN x 40

Figure 4.19

CERVICAL SPINE

PHOTOMICROGRAPH OF EPIDURAL HAEMORRHAGE

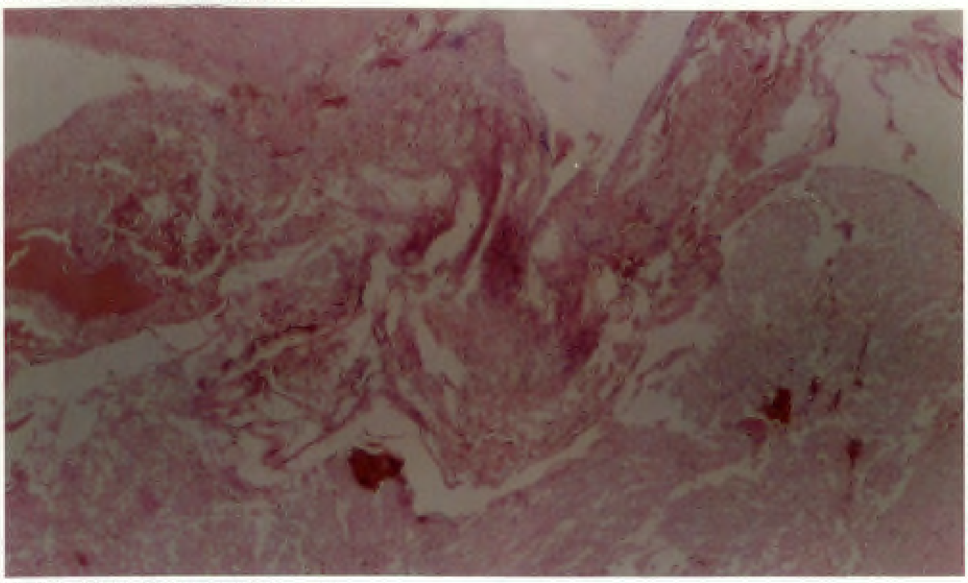


HAEMATOXYLIN AND EOSIN x 40

Figure 4.20

CERVICAL SPINE

THE SECTION SHOWS CONTUSION AND LACERATION OF THE POSTERIOR ASPECT OF THE CORD AT THE LEVEL OF AN ANTERIOR LIGAMENT RUPTURE. NOT SEEN ON THIS FIGURE IS THE MASSIVE EPIDURAL HAEMORRHAGE ANTERIORLY.



HAEMATOXYLIN AND EOSIN x 40

Figure 4.21

So that the severity of cervical injuries can be interpreted in the light of the total injuries sustained by the child, injuries to the head and other regions of the body are presented briefly.

4.3.2 CRANIAL INJURIES

Skull fractures were seen in 36,4% of the cases. The various types of intracranial haemorrhage are shown in Table 4.2. Injuries in this area follow a pattern similar to that of the cervical cord, in that macroscopic examination alone proved insufficient to document the severity of the injuries. In his original description of DAI, Adams(2) stated that if haemorrhage was noted in both the rostral brainstem and the corpus callosum, the diagnosis of DAI is appropriate. There is now an indication that for a diagnosis of diffuse axonal injury (DAI), axonal spheroids should be seen, and in the absence of these, a diagnosis of diffuse vascular injury (DVI)(3) is more appropriate. As these spheroids only appear after approximately 18 hrs the diagnosis of DAI cannot be made in these cases, but those with multiple haemorrhages in the brain can be classified as having (DVI)(2,3). In this study all those with multiple intracranial haemorrhages were classified as DVI, but in reality it is likely that those with DVI are probably DAI although they do not fulfil all DAI criteria due to the short survival period.

THE INDICATORS OF INTRA-CRANIAL INJURY ARE:

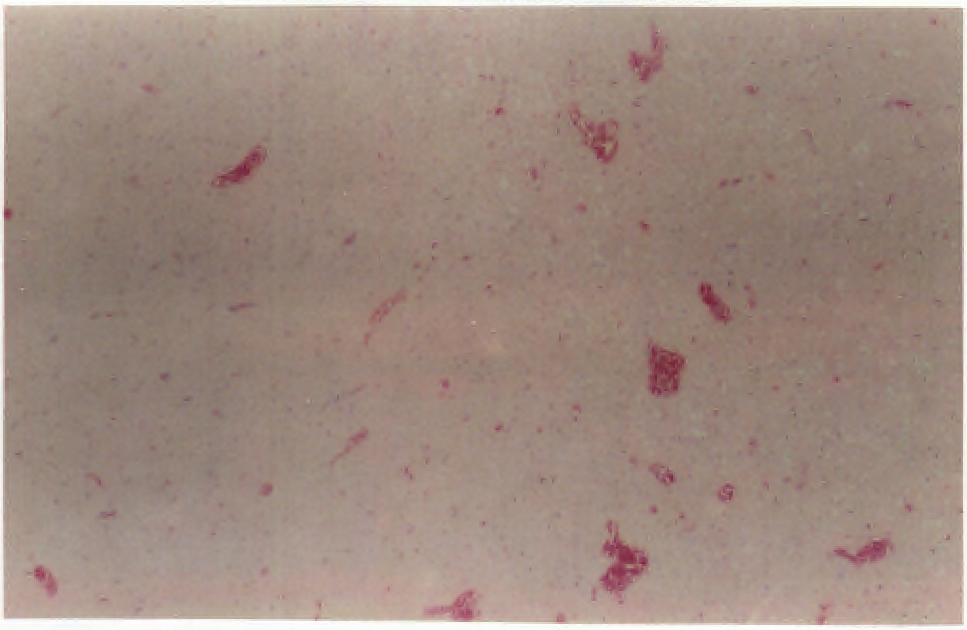
INDICATOR OF INJURY	NUMBER	% OF CASES
SWELLING	23	69,7%
EPIDURAL HAEMORRHAGE	2	6,1%
SUBDURAL HAEMORRHAGE	6	18,2%
SUBARACHNOID HAEMORRHAGE	27	81,8%
INTRAVENTRICULAR HAEMORRHAGE	8	24,2%
INTRA-CEREBRAL HAEMORRHAGE	13	39,4%
CORPUS CALLOSUM HAEMORRHAGE	15	45,5%
PARAHIPPOCAMPUS HAEMORRHAGE	20	60,6%
MIDBRAIN HAEMORRHAGE	14	42,4%
CEREBELLAR HAEMORRHAGE	1	3,0%
DVI	17	51,5%

Table 4.2

Figure 4.22 and 4.23 show examples of haemorrhage into the *corpus callosum* and *parahippocampal gyrus* respectively.

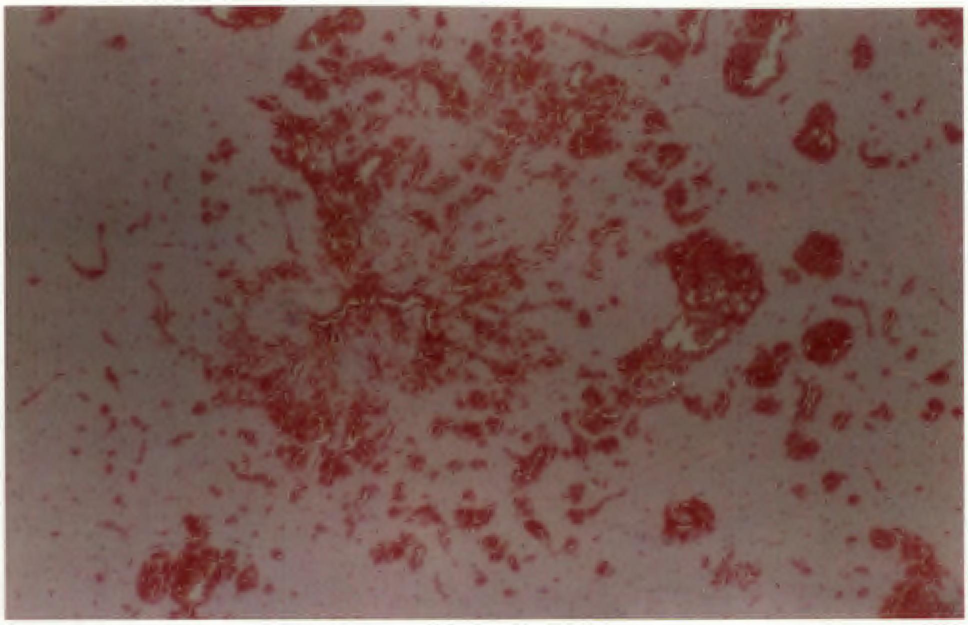
CORPUS CALLOSUM

PHOTOMICROGRAPH OF PETECHIAL HAEMORRHAGES



HAEMATOXYLIN AND EOSIN x 40

Figure 4.22



PARAHIPPOCAMPAL GYRUS
PHOTOMICROGRAPH OF PRIMARY HAEMORRHAGES

HAEMATOXYLIN AND EOSIN x 40

Figure 4.23

4.3.3 INJURIES TO OTHER REGIONS OF THE BODY

Data on injuries to other regions of the body are tabulated below. This information is included so that the relative severity of the craniocervical injuries can be assessed. Further discussion on this data is not included here but is included in chapter five.

Chest injuries were not a common finding at autopsy and were only noted in seven children (21,2%) in this study. Table 4.3 has a summary of these injuries.

CHEST INJURIES

INJURY	NUMBER	% OF CASES
FRACTURED RIBS	3	9,1%
CONTUSED LUNGS	6	18,2%
CONTUSED HEART	0	0%
RUPTURED MAJOR BLOOD VESSEL	0	0%
RUPTURED DIAPHRAGM	1	3%

Table 4.3

Lacerations of the solid organs of the abdominal cavity were relatively common with the liver and spleen being the worst affected. Table 4.4 shows the injuries to the abdominal viscera in the 17 children (51,5%) who had injuries to this region.

ABDOMINAL INJURIES

INJURY	NUMBER	% OF CASES
LACERATED LIVER	7	21,0%
LACERATED SPLEEN	11	30,3%
LACERATED BOWEL	3	9,1%
KIDNEY INJURIES (avulsion, laceration, contusion)	1	3,0%

Table 4.4

Despite the high frequency of pedestrian and motor vehicle collisions in this study (81,1%), fractures of the limbs and pelvis are not common and may reflect the height of the child relative to the motor vehicle. Table 4.5 details the limb and pelvis fractures of the 12 children (36,4%) with these injuries.

FRACTURES

INJURY	NUMBER	% OF
CASES FEMUR	7	21,2%
TIBIA AND FIBULA	3	9,1%
PELVIS	2	6,1%
HUMERUS	0	0%
RADIUS AND ULNA	1	3,0%

Table 4.5

Table 4.6 confirms the high frequency of minor lacerations and abrasions expected in motor vehicle collisions. Table 4.7 shows the injuries to the facial area. This area is delineated as a separate region in AIS '85.

EXTERNAL INJURIES

INJURY	NUMBER	% OF
CASES SEVERE	1	3,0%
MINOR	29	87,9%

Table 4.6

FACIAL INJURIES

SEVERE	1	3,0%
MINOR (Injuries are coded under external)		

Table 4.7

4.4 AIS RESULTS

The AIS system codes for lacerations, contusions, and clinical evidence of cord injury, but has no scores allocated for pathological changes in this area (other than the above). The AIS allocates a score of three for contusion of the cord, and since this was the closest category available it was assigned to any spinal cord that showed petechial haemorrhage. No defined scores exist for epidural, subdural or subarachnoid haemorrhage, so a score of 0 had to be allocated. This paucity of adequate scores for these injuries may reflect two issues, firstly that little adequate pathological information existed to enable the authors to assign realistic scores for them, or secondly, there is little indication that this pathological information may be of use. Of note the 1990 Revision of the AIS manual shows no alterations in this area. It is difficult to believe that a cervical spinal cord with petechial haemorrhages is not a serious, if not fatal, injury and only warrants a score of three. The same may be said for the epidural, subdural and subarachnoid haemorrhages scoring 0, although there may be no visible damage, macroscopically or microscopically, to the cord there still is evidence of injury to a very delicate area. In figure 4.24 the AIS score in each region for each child is plotted to show the relative severities of the injuries in each region. The graph shows that there are common injuries such as the external abrasions which score one and are noted in 29 (87,9%) of the children. The head and neck region shows a much higher number of children with higher scores. Of note in this region is that the AIS score largely reflects the head injury, unless there is a severe injury to the cervical spine (transection).

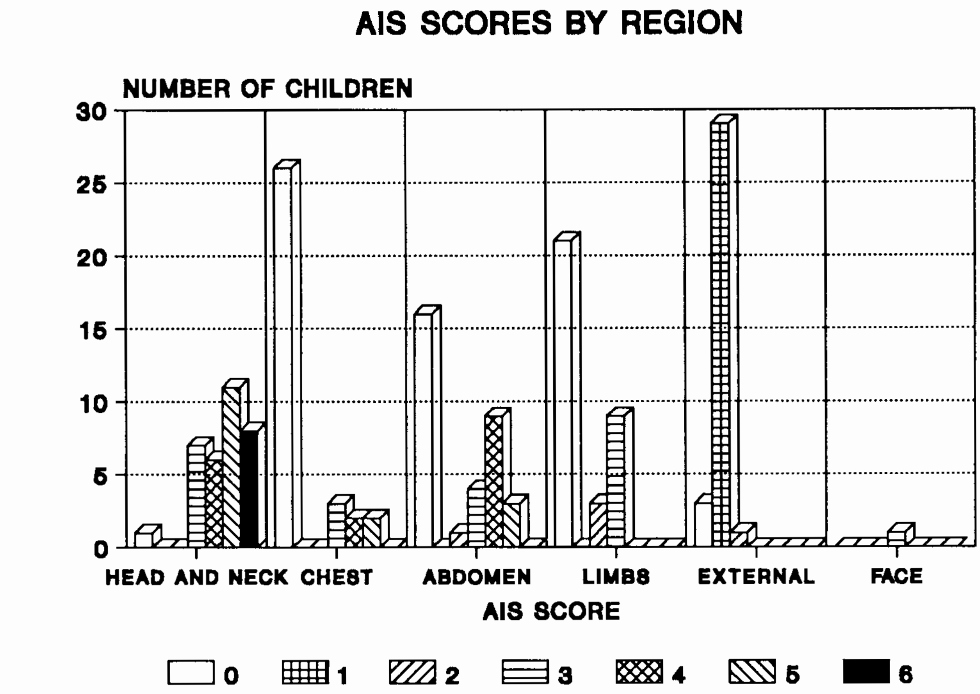


Figure 4.24

The Injury Severity Scores (ISS) for each case were first computed on the macroscopic postmortem findings, and then recalculated to incorporate the histology results. In the Forensic Medicine Department, routine histological specimens are not taken for motor vehicle collisions. The ISS scores calculated by the Head Injury Research Team, therefore, do not incorporate histological evidence of injury in their study. There are few areas of the body where microscopic evidence of blunt trauma injury will change the perceivable outcome, but the brain and spinal cord must be in that category.

The average ISS score for the children without histology is 38.7 (SD=22,4), and with histology the average score is 41,3 (SD=21,1). The change in these figures is due to the cases that were shown to have DVI of the brain on histology that was not seen macroscopically.

CHAPTER FIVE

DISCUSSION

5.1 RADIOLOGICAL INVESTIGATIONS.

5.1.1 PLAIN X-RAYS(4,7,13,38,42,46).

X-ray examination of the cervical spine is the commonest investigation in the diagnosis and management of any spinal injury. Anteroposterior and lateral x-rays are indicated in every case of suspected spinal injury and since head injuries and spinal injuries are often associated, x-rays of the cervical spine should be done in cases of suspected head injury.

As this is always considered an important investigation, x-rays of the spinal cords of the study cases were obtained. Although the original reason for this study was to determine the incidence of spinal cord injury in paediatric pedestrians, following motor vehicle collisions, it was felt that obtaining x-ray films of the cervical spine, before final sectioning of the cervical spines, might provide useful comparative information. It is realised that in this study, due to formalin fixation, no flexion or extension films could have been taken of these post mortem specimens, and this does limit the usefulness of the investigation to a certain extent. The possibility of finding no radiological evidence of spinal column injury, despite histological evidence, could be a result of various factors:

i) hyperextension type injuries will not be shown in the standard anteroposterior position or in the flexion films; and similarly

ii) flexion injuries usually require flexion film in order to make an absolute diagnosis;

iii) anterior subluxation also requires a flexion film of the lateral view in order to make or exclude this diagnosis;

iv) unilateral rotatory subluxations often require oblique views in flexion in order to ascertain this injury.

Plain radiographs of the spinal column are limited in their ability to visualise the intra-spinal and extra-spinal soft tissues. These include the spinal cord, nerve roots, *nucleus pulposus* and *annulus fibrosis*, together with ligaments, blood vessels, membranes and the contents of the epidural spaces. Convention dictates that the plain x-ray is the first imaging modality used following trauma to the head and neck. These plain x-rays can demonstrate the alignment of the structures adequately, delineate fractures of the vertebral bodies and indicate their degree of compression.

The alignment of the cervical spine on anteroposterior and lateral x-rays allows easy recognition of subluxations and dislocations. The vertebrae should align with those above and below them and the posterior vertebral margins should form a normally smooth and continuous line. There should be a degree of lordosis in the cervical spine.

The following fractures may be visualised by plain radiographs:

5.1.1.1 Fractures of the vertebral body.

The appearance of these is very variable and is dependent on the mechanism of the injury. These fractures may be linear and show cortical disruption or a decrease in the vertebral body height. Fragments may also be visualised.

5.1.1.2 Fractures of the pedicles.

Fractures of the pedicles tend to occur with hyperflexion injuries and more commonly in the lumbar area.

5.1.1.3 Fractures of the laminae.

These fractures are difficult to detect on x-ray. However, disruption of the normal overlapping of the cervical laminae on oblique view may indicate subluxation.

5.1.1.4 Fractures of the spinous processes.

The spinous processes may be fractured by direct or indirect trauma. The interspinous ligaments may be ruptured and this is often indicated by widening of the space between adjacent spinous processes on a lateral radiograph. This injury is normally associated with hyperflexion injuries.

5.1.1.5 Fractures of the articular and transverse processes.

Fractures of the more posterior parts of the vertebrae are more difficult to see on conventional plain x-rays due to overlying bony and soft tissues.

5.1.1.6 Rupture of the intervertebral disc.

The intervertebral disc space may widen anteriorly in hyperextension injuries and posteriorly in hyperflexion trauma. In compression injuries of the spinal column, the disc height may decrease due to disc tissue being extruded into the vertebral body. In cervical injuries this rupture is more common in the lower cervical spine than in the upper cervical spine.

5.1.1.7 Changes in the spinal canal.

On conventional radiograph, injury to this area is normally assessed by judging the width of the spinal canal. Any substantial narrowing may be caused by dislocation, fracture or the presence of fragments within the canal.

5.1.2 SPINAL CORD INJURY WITHOUT RADIOLOGICAL ABNORMALITY (SCIWORA)

SCIWORA is a recent and frequently reported entity in the paediatric age group, with incidences of injury to the cord of between 21% and 66% and of complete cord lesions of between 40% and 55%(36,41). SCIWORA is less frequently seen in the adult age group, and the majority of these are adolescents.

The potentially useful data in this investigation is reduced because of the limitation of not having obtained plain x-ray films before the postmortem procedure, as discussed in section 1.6.2. It is likely the plain x-rays would have revealed the fracture dislocations, in the six cases of atlanto-occipital disruption seen at postmortem examination.
Three percent showed evidence of cervical spinal damage on x-ray, however 93.9% showed haemorrhage in or around the cervical spine, and more significantly 69,7% showed petechial haemorrhage into the cord at post mortem. It must be pointed out that if it is presumed that the six cases with atlanto-occipital disruption would have been seen on plain x-ray then 12% of the children would have had positive x-ray findings. The discrepancy between the radiological findings and the evidence of cord trauma is consistent with (SCIWORA)(36,46). Pang describes two types of injury to the spinal cord. The first, that of a "juvenile" injury, in those under eight years of age predominantly affects the upper cervical spine with little indication of radiological abnormality. The second type, the standard "adult" injury, often with radiologically evident injury, predominantly affects the lower cervical spine(36).

The present study shows that there is a high percentage of children with cord, or para-cord injury, that was not suspected on x-ray examination. In a clinical study of spinal cord injuries (SCI) in 75 children, Yngve and co-workers found that those children with SCIWORA had a mean age of six years compared with 16 years for those with fractures. They also found SCIWORA to be associated with pedestrian injury, while those with fractures were predominantly passengers in automobiles or on motorcycles (62%), or injured in falls (31%).

SCIWORA is associated with a very poor clinical outcome(36,41,46,). Pang and Wilberger found that 66,7% of children under 16 years with SCI had SCIWORA, and 55% of the SCIWORA group had complete neurological injuries. These data similar to the 69,7% of the children with petechial haemorrhages in this study, suggest that the petechial haemorrhages may represent serious or complete neurological lesions of the cord.

Of the 33 children in this series 31 (93,9%) had evidence of a spinal injury and 23 (69,7%) severe cord injury, but only one (3,0%) *(seven (22,6%) if the atlanto-ocippital cases are included)* showed X-ray changes which leaves the balance of the SCI cases to fall into the category of SCIWORA.

Although this study population consisted predominantly of "dead on arrival" cases, and it is difficult to be sure how the pathological findings in these cases would have translated into clinical signs and symptoms, there is a strong similarity between the clinical data in the literature and the findings of this study.

The significance of these petechial haemorrhages is not entirely clear, but the experience of previous clinical studies and the data available on similar injuries to the brain, would suggest that further research, ideally a combined clinicopathological study, is needed. It is important that one determine the significance of the criteria regarding the petechial haemorrhages: the number, the size, the cervical segment affected, whether unilateral or bilateral. A study of this nature which would require a larger sample than was taken here, could, hopefully lead to the development of injury scoring criteria based on the above, to indicate the severity and survivability of any cervical injuries. This study would not have to be limited to children only, as it would be attempting to assess the potential outcome of cord injury, and not the mechanism of the injury.

5.1.3 MAGNETIC RESONANCE IMAGING (10,15,20,21.27,29,31,32,33,35,37,43).

Magnetic Resonance Imaging (MRI), although used in analytic biochemistry since 1946, was only recently developed into a diagnostic imaging modality. This non-invasive diagnostic tool does not use ionizing radiation and although contrast media can be used, this is often unnecessary. Only limited clinical evaluation of cervical spinal trauma by MRI has been done although it is now being recognised as a useful investigation, within the first week of injury, providing the patient is stable enough to be scanned without any ferromagnetic material (ventilators, neck traction calipers etc.) attached(10,31).

5.1.3.1 Indications and Limitations of M.R.I.

Although Bohn and co-workers did not use MRI in their study of cervical spine injuries in children, they stated "there is good reason to believe that the true extent of these injuries could be better demonstrated by this technology"(11). In the light of this, MRI scans were used to assess the efficacy of this scanning method in acute CSI.

The limitations of MRI include:(32,27,37)

i) its high cost;
ii) any patient with a ferromagnetic prosthesis may not undergo this investigation;
iii) scans may not be undertaken on patients with pacemakers;
iv) slice thickness is relatively wide compared to a CT scan;

v) scan time is relatively long (up to 40 minutes);

vi) characterisation of a detected lesion is often not possible;

vii) paramagnetic enhancers may be needed to outline lesions;

viii) few MRI scanners are presently available in the Western Cape and hence time available on these scanners, especially for research projects, is extremely limited.

5.1.3.2 Technique.

A brief summary of the mechanism of MRI follows. This is, however not intended as a comprehensive discussion of the subject and the following texts can provide greater detail(27,32,33).

Images generated by an MRI scanner are displayed in a format similar to those of computerised tomography since the signals are products of similar electronic processes. These signals though are generated by a principle very different from the radiographically-based Computer Assisted Tomography.

5.1.3.3 Magnetic Resonance Imaging in Trauma.

There is limited experience with magnetic resonance imaging of the acute trauma victim(14). Although MRI produces superb images of soft tissue, images of bone are generally poorly visualised due to the low proton content.

MRI is useful for contusions, compressions and oedema. Haemorrhage may also be recognised using MRI but, in the first three days after the haemorrhage has occurred, it shows as a hypo-intense area where little signal is produced(29). Lotz described haematomas in cerebral tissue and divided them into hyperacute (those less than 24 hours old); acute (between 1 and 3 days old); subacute (between 3 and 14 days old) and chronic (greater than 14 days). In his study he showed that oxyhaemoglobin produced little paramagnetic activity and, therefore in the hyperacute stage haemorrhages showed up as a hypo-intense area. In the acute phase, haemoglobin becomes de-oxygenated and begins to show paramagnetic activity. Because the T-1 weighted effect does not occur, the haematomas remain hypo-intense on T-1 weighted images. The T-2 values are markedly shortened and on T-2 weighted images, the acute haematomas appear markedly hypo-intense. In the subacute phase, deoxyhaemoglobin has begun to be converted to methaemoglobin, especially in the periphery of the haematoma, which leads to spatial arrangements with protons moving to within three angstrom units of the active ferric sites in the haem group. This results in a paramagnetic effect with T-1 shortening and the resulting hyperintense areas on the T-1 weighted scans. As the haematoma ages throughout the subacute phase, hyperintensity on T-1 scans also increases. In the chronic phase, the haematoma continues to appear hyperintense but a hypo-intense area, immediately

surrounding it on T-2 weight images, is noted and this is thought to correspond with the haemosiderin in peripheral macrophages.
Since all cases in this study were dead on arrival at hospital or died shortly after admission it is unlikely, in the light of this information, that any hyperintense areas due to haemorrhage would be seen on any MRI scans. In addition, since the preparation of the specimens requires removal from the body, the spinal canal will be filled with air which, for obvious reasons, contains no protons and is also a hypo-intense area on MRI. Even in a live patient it is unlikely that in the acute phase (less than three days post injury) magnetic resonance scanning would show haemorrhage. Magnetic resonance scanning will also not show great detail in bony abnormalities and plain radiographs, therefore, are a better modality for this type of investigation. These features were confirmed when 12 of the total of 33 cases (36%) were MRI scanned and are reported in chapter 4.2.2.

Should the patient survive the initial trauma, for longer than three days, the increased signal intensity on both T-1 and T-2 weighted images will provide useful information. In the acute phase, MRI will be useful to show oedema and the soft tissue injury surrounding the spinal column. In the long term haemorrhages, swelling, and eventually demyelination of the damaged spinal cord, can be seen (14,31).

Due to the high cost of MRI, the difficulty in obtaining time on the machine, and the fact that the preparation of the specimens had removed a large quantity of the peripheral soft tissue where MRI shows great promise in revealing associated soft tissue injuries(27), it was decided to discontinue the scans. These findings do not decrease the value of MRI studies in clinical research or where patients survive.

5.1.4 COMPUTER ASSISTED TOMOGRAPHY(27)

As this investigative technique was not used in this study, only a brief discussion is presented.

Computer Assisted Tomography (CT) is a radiological procedure which uses a computer to organise the tomographs in axial, coronal or sagittal planes. The resolution of CT scanners varies. The newer model scanners have relatively high resolution and are extremely useful in a large number of clinical situations. Limitations of CT scans of the spine include relatively poor coronal and sagittal images, as compared to the high resolution axial images; as well as limited ability to show lesions of the spinal cord and dura without the introduction of contrast agents.

CT is performed by using conventional x-rays fired towards a sensor, rather than an x-ray plate, and the penetration of the x-rays is sorted using a computer to build up a picture of the relative radiolucency of the intervening substances, in various planes.

As it is a radiological procedure, some parts of the spinal scan will deliver relatively large amounts of radiation to sensitive organs, such as a lumbar scan which gives relatively large doses of radiation to the gonads. This is not a major consideration in the cervical area, however.

As a CT scan uses radiological principles it provides excellent information regarding bony structures and their relative positions. It is because of this that CT scan is now considered of major value in the assessment of spinal injuries. Before computer assisted tomography was available, conventional tomography was used. This, unfortunately necessitated frequent turning of the patient which obviously placed a spinal injured patient at great risk.

Unlike magnetic resonance scanning which does not provide good images of bone, which contains small numbers of protons, the CT scan is ideal for the exact documentation of fractures. It will show great detail, including the exact site of the fracture, the position of the vertebral anatomy, the size and/or stenosis of the vertebral canal, fragment positions as well as provide a large amount of information for evaluation of the stability of the spinal column.

CT can also show non-osseus injuries, including haematomas, in the para-vertebral areas. Traumatic disc herniation may also be seen as well as spinal cord oedema, nerve root avulsion and dural tears. Many of these features can be enhanced by the use of a contrast medium. Extradural and subdural haemorrhage may also be seen but, due to a density similar to that of the spinal cord, small quantities are difficult to diagnose. The use of contrast media, however, should delineate the extradural and subdural haematomas accurately.

Since it has major value in the acute and sub-acute period following a cervical injury, CT scan is likely to continue, with plain x-rays, as one of the major investigative procedures undertaken during this time. As the quantity of paramagnetic substances increases at the injury sites three days after trauma, CT may be displaced by MRI, in the patient who requires additional investigations.

5.2 <u>THE PATHOLOGY OF SPINAL INJURY</u>(17,18,28)

As all the cases in this study died acutely after injury, this review is limited to changes observed in this phase.

5.2.1 MACROSCOPIC CHANGES.

5.2.1.1 Haemorrhage.

This haemorrhage, into the muscle surrounding the spinal column, is indicative of rupture of vessels within the muscle due to stress and/or shear forces applied to the muscles. Muscles have greater elasticity than the surrounding vessels and hence remain intact macroscopically while the small blood vessels rupture. Retropharyngeal haematomas may be large enough to cause respiratory distress(17).

5.2.1.2 Fractures.

These were discussed previously (section 5.1.1), however macroscopic examination of the fractures can also be undertaken. As indicated by Davis *et al*, soft tissue disruption and haemorrhage frequently occurs at the site or arise from the site of a bone fracture and/or ligamentous tear(17).

5.2.1.3 Ligamentous injuries.

Lacerations of the ligamentous structures may occur with or without associated fractures. Davis et al found that 18, in a series of 36, cases with cervical injury had ligamentous lesions. These consisted of tears and ruptures of the ligaments surrounding the vertebrae or facet joints. The most common isolated lesion found was a tear of the capsular facets exposing the joint space(17). The majority of the injuries showed evidence of combined ligamentous rupture in various situations. This suggests that the forces applied to the neck are not simple forces in one direction, but are often a combination of extension, flexion and rotation forces which rupture multiple ligaments(17,28). Their study also found the numbers of ligamentous injury almost equal in each of the following: the interspinous ligaments, the anterior longitudinal ligament, the ligamentum flavum and the posterior longitudinal ligament. The articular capsule was also commonly involved, but not as frequently as the sites mentioned previously, and only one transverse ligament of the dens was found ruptured. The majority of the observed injuries occurred in the atlanto-occipital area(17).

Of the 33 children examined in this study six (18,2%) had ligamentous injuries at the axio-atlanto-occipital area, and one at C5 (3,0%).

5.2.1.4 Disc lesions.

No disc lesions were seen in this study, but in their study Davis et al found damage to the intervertebral discs to be a frequent event occurring most commonly in the lower cervical region, especially the C6-C7 level. These lesions were also often associated with tears of the anterior vertebral ligaments(17). In this study, there was only one severe injury in the lower cervical segments with rupture of the posterior ligament and no disc injury was seen. This is possibly due to the fact that as the mean age of the study population was six years, the greatest risk in these children is to the upper cervical column(36).

5.2.1.5 Other soft tissue injuries.

Other associated soft tissue injuries surrounding the spinal cord include haemorrhages, such as retropharyngeal haemorrhage and distant lacerations and haemorrhages in the skin, subcutaneous tissues and other structures. Again, these are often associated with ligamentous or bony injury and, in the case of the posterior pharyngeal haemorrhage, can become a potentially dangerous space-occupying lesion.

On examination of the dissected cervical spines, 22 (66,7%) showed paravertebral haemorrhage, of varying degrees, none of which was large enough to be life threatening. It was not possible to determine accurately the origin of these haemorrhages but no fractures were seen at these sites and it is likely that they represent minor trauma to the muscles and ligaments.

5.2.1.6 Spinal cord.

i) Concussion. This is a reversible functional disorder of the spinal cord which by definition, according to some authors, must recover fully within 48 hrs(23). If a concussive injury takes place in the first four cervical segments the respiratory function may be inhibited, or cease, and in this specific instance the recoverable primary injury would give rise to a secondary fatal event. It is not possible to speculate accurately on the number of deaths that may arise from respiratory embarrassment of this type but it may be appropriate for mechanical ventilation to be instituted at the roadside, as soon as possible, after a motor vehicle collision.

ii) Haemorrhages. These can be of the following types: epidural, subdural, subarachnoid, and into the substance of the spinal cord itself. In their study Davis *et al* found that only three of the thirty-six cases (8%) had epidural haemorrhage and this was confined to the thoracic, middle and lower cervical regions. Section of the spinal cord by Davis et al showed diffuse petechial haemorrhage in 22 of the 36 cases (61%) especially at the sites of macroscopic injury(17). These features were confirmed in this study, with petechial haemorrhage being seen in 23 cases (69,7%). The high incidence of other haemorrhages surrounding the cord, observed in this study, was not seen in their study, and of the 3 cases (8,3%) which showed epidural haemorrhage, two were in the cervical area. The age of these cases is not noted in their results. It is possible that the high incidence of haemorrhage seen in this study is a feature of childhood cervical spine injury. Table 4.1 details the different haemorrhages noted in the 33 children autopsied at Salt River Mortuary.

iii) Contusions. The cord can show evidence of contusions and haemorrhage into the substance of the cord itself.

iv) Lacerations and/or complete transections of the cord are also associated with ligamentous or bony injuries. Six complete transections were found in the atlanto-occipital area.

5.2.1.7 Vascular injuries.

In all series up to now, these injuries are rarely reported. For example, in their series, Davis et al found only two cases of tearing of the vertebral artery(17). The vertebral artery seems to survive despite severe osseous damage. Davis et al found, however, that in cases of atlanto-occipital injury there was almost always rupture of the surrounding small radicular branches given off by the vertebral arteries which pass along the nerve roots to anastamose with the anterior spinal artery. (section 3.2.6) Davis et al found that these were almost always torn shortly before they entered the subarachnoid space(17). Angiography was used, as part of their study methodology, to determine the site of injury.

In this study, no ruptures of the vertebral arteries were seen, although, in 17 of the children (51,5%), haemorrhage was seen surrounding the vertebral arteries. It is probable that this represents damage to the thinner, weaker, radicular branches of the vertebral artery.

Ischaemic lesions of the cord may also develop which in the acute phase may be difficult to recognise. These lesions are caused by a combination of interruption to the arterial supply or venous drainage(40). Spasm of the injured arteries may lead to ischaemic damage which would complicate any other damage present.

5.2.2 MICROSCOPIC CHANGES.

Microscopic injury can be divided into those changes which will be seen acutely and those that require some time after the injury to develop.

5.2.2.1 Acute Changes

Acute changes are seen microscopically and are limited to haemorrhages into the substance of the spinal cord (normally petechial in nature) which occur within seconds of the traumatic impact(18). These early haemorrhages are seen in the grey matter, the pia and arachnoid mater. If the person survives for more than ten minutes, additional haemorrhages are seen in the white matter of the cord(18). In this study the observed petechial haemorrhages were of both types, and only in the complete transections were the haemorrhages of the very early type.

In the AIS '85 manual, diffuse axonal injury (DAI) is rated as a Grade 5 (critical) injury. It could be argued that these similar haemorrhages into the cervical cord are early manifestations of DAI. If this argument were proven valid and acceptable, then these haemorrhages should score five, if below C4, and possibly even six (maximum injury) if above C4. This is based on the premise that even if these haemorrhages indicate, at best, a temporary cessation of function if present above C4, this would result in the secondary fatal event of respiratory arrest.

5.2.2.2 Subacute and chronic changes.

Oedema may only be recognised microscopically after four hours and, in concussive injuries, may only be recognised after 24 hours. Electron microscopy is required to document early changes to neurones and axons. Any injury to these will be seen under the light microscope only if survival has been prolonged for a minimum of 12-18 hours which would allow axonal spheroids to develop. From 24-48 hours an inflammatory reaction will take place and fibrocytic cells begin to be seen(18).

The long-term implications of chronic changes, including demyelination will not be discussed.

5.3 INJURY SCORING

The Injury Severity Score (ISS) was first published in 1974$^{(8)}$. This injury scoring system used the AIS ratings for each injury, combining them to produce a score, which correlated better with mortality than the worst AIS rating for any one area$^{(9)}$. The ISS is calculated by taking the highest AIS rating from each of the three most severely injured regions. These scores are then squared and summed to give the ISS. Once a score for a patient has been calculated, it may be used to indicate the seriousness of the injuries.

In this study the mean ISS was 41, although with a range of 10 to 75 the standard deviation was large (21). This suggests, of course, that the group is heterogeneous but the data set is too small for further analysis. The pathology study of the Child head Injury Research team may elucidate this.

It appears that the AIS '85, and therefore ISS do not permit adequate scoring for cervical spine injuries. One of the children in this study had an ISS of 10. The injuries in this case were minor external abrasions, mild cerebral swelling, a subarachnoid film (cranial) haemorrhage, and petechial haemorrhage into the cord at C3 and C5. All of these injuries rate as three on the AIS (if the spinal haemorrhage is rated as a "contusion"). If the rating for petechial haemorrhage in the cervical spine was increased as suggested in chapter 5.2.2.1, it would produce an ISS score, in this injury, of 25 which is recognised as severe and more likely to result in a poor or fatal outcome.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 FURTHER WORK ON PAEDIATRIC CERVICAL SPINE INJURY

This study investigated paediatric cervical spine injuries from a pathological perspective, utilising the available material at Salt River Police Mortuary. It became apparent that the functional effect of the petechial haemorrhages seen on microscopic examination are difficult, if not impossible, to interpret without clinical information. The full implication of these haemorrhages can only be assessed if a combined clinical and pathological study is undertaken.

The limitations placed on the study by the available radiological equipment is unfortunate, and it would be useful to be able to compare the clinical information and *in vivo* plain x-rays, CAT and MRI scans, with the final information gained from the pathological investigation. Without more information, the authors of the AIS will be unable to assess the need to include pathological changes in the section on cervical spine injury.

A study of this nature will not be free of problems, as these results and those of other authors, show that intracranial injuries are often associated with trauma to the cervical spine (11,17).

6.2 ASSESSMENT OF CERVICAL SPINE INJURIES

Fractures are not a feature of paediatric cervical spine injury and therefore x-rays should not be used to exclude injury to this area. SCIWORA is seen in over 50% of cases(36). Magnetic Resonance Imaging is a useful medium but is limited as a diagnostic tool in the acute phase of injury. Pang and Wilberger found that, with SCIWORA, that there may be a delay of onset of the physical symptoms(36). These features make the diagnosis of this important injury difficult for the Trauma Surgeon and all paediatric motor vehicle collision victims must be suspected of having a cervical injury until proven otherwise. The absence of injury is difficult to prove, and the delayed onset of some of the signs must be remembered. Certainly at the roadside, emergency service personnel should stabilise the neck prior to transport in all paediatric cases. Any child who presents with hypotension or apnoea, must have cervical spine injury considered high on the list of differential diagnosis(11).

The pathologist, and especially the trauma pathologist, can make an important contribution in this field. Prevention programmes have the greatest chance of success if there is adequate information to motivate their support. The forensic pathologist can provide much of the information needed in the case of motor vehicle collisions. There is, therefore, a place for similar dissections of the cervical spine in all paediatric cases, even if other clear fatal injuries exist. If severe injuries to the spine are masked by other injuries and this is not discovered before death, it is important that the forensic pathologist increase his clinical colleagues' awareness of the potential devastating damage that is hidden within the spinal column. As discussed in Chapter 5.1.2 the full implication of these hidden injuries will only become apparent if a combined clinico-pathological study is undertaken.

6.3 INJURY PREVENTION

Injuries to the cervical spine in children are not uncommon. Although this study has not considered surviving paediatric motor vehicle collision victims, those that die at the site of the collision, or shortly thereafter, show a high incidence of cervical spine injury. These injuries vary from small haemorrhages in the paravertebral tissues to multiple petechial haemorrhages into the cord. Damage to the first four cervical segments is a potentially life threatening injury because of the potential for secondary respiratory paralysis. If this paralysis occurs either due to a permanent injury or to spinal shock, without respiratory support, the child will almost certainly die. The only hope of survival in these cases is that a passerby with adequate knowledge of resuscitation techniques may offer assistance. It is extremely unlikely that the emergency services will arrive within four minutes and before hypoxic brain damage occurs.

All the injuries seen in this study are almost certainly primary, and most are potentially lethal. Only preventative programs have any real hope in reducing the mortality and morbidity from craniocervical injuries.

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