6. TREATMENT OF HEAD INJURIES

6.1 INTRODUCTION

Treatment of an injured car occupant begins at the accident site, with extrication and first aid. Maintenance of unobstructed breathing and treatment of shock are the first essentials. Serious head injuries, and especially those in coma, should then be taken as quickly as possible to a hospital with facilities for definitive neurosurgical treatment and intensive care. Treatment is planned to ensure that the injured brain is given optimal conditions for recovery from the primary effects of the injury, in so far as recovery is possible, and to protect the brain from secondary complications such as intracranial haemorrhage, brain swelling or infection (see 2.1). When the acute phase is past, consideration can be given to rehabilitation. Recovery from serious brain injury is often incomplete and always slow, and the rehabilitation process may extend over several years. Minor head injuries (see 2.2.1) do not require specialist care, but do need reassurance and supervision by a medical practitioner alert to the possibility of delayed complications and distressing symptoms. Facial injuries require expert surgical treatment to prevent or minimise facial disfigurement.

6.2 REVIEW OF LITERATURE

All aspects of head injury management have received much attention in recent years. Professor Bryan Jennett and his colleagues in Glasgow have been pioneers in evaluating management strategies, using quantitative measures of conscious level (Teasdale and Jennett, 1974) and outcome (Jennett and Bond, 1975, Jennett et al. 1981). The importance of cost-benefit assessments of methods of treatment, and the difficulties inherent in these assessments, have been ably reviewed by Miller and Teasdale (1985).

In Australia, as most developed countries, some 70 per cent of deaths of head injured car occupants occur before hospital is reached (Selecki et al., 1981). It is widely believed that better first aid and earlier primary medical treatment might prevent some of these deaths, or might minimise disabilities in the survivors (Hoffman, 1976; Gilroy, 1985); Hossack (1972) reported that in a series of 500 car occupants killed in road crashes, 14 drivers and 21 passengers had apparently died from inhaling blood or vomit, after head and/or facial injuries that appeared to be survivable (see 2.2.2). Simpson et al. (1984) in a prospective study of primary medical treatment of 153 head and spinal injuries in South Australian rural areas, found evidence of unsatisfactory initial management in 11 (7.2 per cent) cases.

Improved roadside treatment could be given by better trained members of the lay public, by more efficient ambulance services, or by medical retrieval teams. The case for more competent first aid practice in selected sections of the lay public, e.g. in car licensees, has not to our knowledge been fully explored, though there are countries in which endeavours have been made to achieve this. The Federal Republic of Germany has imposed first-aid training on driving licensees since 1969, but the licensees' level of self-assessed competence does not appear to be very high (Unfallverhutungsbericht Strassenverkehr, 1983).

In the U.S.A. and in Canada, it has been found that the most cost-efficient means of delivering roadside care for severe injuries is by purpose-trained ambulance staff (paramedics) with special skills, often brought to the accident site by helicopter.

Compton and Little (1983) studied the role of paramedic ambulances in Sydney N.S.W., and concluded that these were of considerable value. In the Federal Republic of Germany, the preferred system of bringing primary medical care to the roadside is by helicopter ambulance: medical specialists in intensive care (Notaerzte) and paramedics are flown in, or driven when weather is adverse (Unfallverhutungsbericht Strassenverkehr, 1983). The cost of this service has been criticised. We believe that the relative merits of these systems under Australian conditions need further study (Simpson et al., 1986).

There is now broad agreement on the principles of hospital management of severe head injuries in persisting coma. In most cases, the trachea (windpipe) is intubated and the patient is mechanically ventilated to maintain an adequate supply of oxygen to the brain and to ensure that blood carbon dioxide is kept low (25-30 mmHg) (Gildenberg and Frost, 1985). Maintenance of a normal (< 20 mmHg) intracranial pressure has also been given much attention. Many (Smith et al., 1986) though not all (Stuart et al., 1983) neurosurgeons routinely monitor the intracranial pressure continuously by a recording device inserted into the head. Elevated pressure may be due to clot formation, which demands urgent relief by operation, or to swelling of the injured brain: various means of controlling brain swelling are in use, but none is completely satisfactory and there is a need for continued laboratory research and clinical trials (Cooper, 1985).

Maintenance of adequate cerebral blood flow is critically important, and this can be imperilled by high intracranial pressure. It can also be impaired by a low arterial blood pressure. The importance of correcting this was stressed some years ago in an influential paper from Richmond, U.S.A. (Miller et al., 1978). Arterial hypotension (shock) is likely to occur in car occupants who have suffered multiple injuries; Selecki et al. (1986) concluded that failure to correct shock was an important and preventable cause of death in cases with traumatic intracranial haemorrhage.

The principles of neurosurgical treatment of traumatic intracranial haemorrhage are generally accepted; Bakay and Glasauer (1980) and Jennett and Teasdale (1981) give good textbook accounts. Car occupants are not exceptionally at risk of intracranial haemorrhage, but the large number of car crashes makes these haemorrhages an important part of neurosurgical practice; the recent N.S.W. study (Neurotrauma in Australia, 1986) reported on 14 extradural haemorrhages (mortality 64 per cent), 67 acute subdural haemorrhages (mortality 85 per cent) 25 multiple intracranial haemorrhages (mortality 100 per cent) and only 7 chronic subdural haemorrhages (mortality 14 per cent), all in car drivers or passengers. The nature of this study makes it likely that these 113 cases represent some 90 per cent of all surface intracranial haemorrhages suffered by car occupants in N.S.W. (pop. 5,000,000) over a two year period; the larger figure for fatal intracranial haemorrhage given by Selecki et al. (1981) may express the inclusion of intracerebral (deep) haemorrhages. The dreadful mortality figures from surface intracranial haemorrhages cause special concern, since these are generally regarded as favourable conditions. The figures for car occupants with intracranial haemorrhages are uniformly worse than those sustained in other incidents. There are many reasons for this: the high incidence of multiple injuries in car occupants is certainly one, and it is also likely (though unproven) that many of these car occupants sustained serious diffuse brain injuries (see 2.2.1). Delay in making the diagnosis is also certainly a factor.

There is now general agreement that computerised tomography (CT scanning) is the most sensitive diagnostic investigation in head injured patients (see 2.2.1), and it is no longer necessary to argue with administrators that hospitals which care for head injuries must have these devices; the case was conclusively established in Scotland by Teasdale et al. (1982) and in Italy by Bricolo and Pasut (1984). Early diagnosis now depends not only on good clinical observation, but also on the availability of CT scanners. The CT scanner must of course be used with discrimination: there are cases in which a correct clinical diagnosis can be made without the scanner, thus saving critically important minutes when the case is deteriorating rapidly (Andrews et al, 1986).

The importance of early diagnosis in securing good outcome in extradural haemorrhage is well recognised (Jamieson and Yelland, 1968), though occasionally hyperacute extradural bleeding may be beyond surgical remedy even at an early stage (Greenberg et al., 1985). The importance of early diagnosis in acute subdural haematomas was first clearly shown by Seelig et al. (1981), and was recently endorsed by Stening et al. (1986).

This awareness of the occasional urgency of neurosurgical intervention, and the much more frequent need for urgent intensive care, have directed attention to the logistics of head injury management: to the systems that bring the injured person to the right hospital as quickly as possible in the best possible condition. In large urban communities, there is much to be said for direct admission to a hospital with full neurosurgical services: in U.S. terminology, a level I Trauma Service or Area Emergence (Detmer et al., 1977). This logistic strategy has long been favoured in the U.S.A., Canada, and the Federal Republic of Germany; the chief argument against it has been a supposed benefit from interim emergency resuscitation at the nearest hospital, but Miller et al. (1978) found that in Virginia, USA this alleged benefit was not in fact being achieved: patients who had received such interim resuscitation did not arrive in better shape than those admitted directly. However, in large countries like Australia, it is impossible to manage all head injuries in this way. Great distance may demand intervention on the spot by the nearest medical practitioner. Stuart et al. (1983) in Queensland favour immediate treatment, including craniotomy where necessary, by properly trained country medical practitioners. Simpson et al. (1984) in South Australia see this as a correct solution in some cases, but favour where possible air retrieval by a medical team comprising a specialist in intensive care and where necessary a neurosurgeon, who may be needed to complete a livesaving craniotomy begun by a local doctor.

In recent years, there has been increasing interest and concern over the rehabilitation of victims of head injury. Even minor head injuries can be disabling; Wrightson and Gronwall (1981) stress the importance of careful follow-up, reassurance, and advice on return to work. Head injuries with prolonged coma have been given much attention. Attempts have been made to promote recovery while patients are still unconscious, by various forms of sensory stimulation: Todorow (1975) presented paediatric cases in which this approach seemed to be logical, and Le Winn and Dimancescu (1978) have presented a program for so called environmental enrichment which has attracted much lay interest in Australia. The utility and indeed the feasibility of environmental enrichment remain unconfirmed, but environmental deprivation is generally agreed to be detrimental and many centres endeavour to promote recovery by ensuring that the sensory input is as nearly normal as possible during the period of unconsciousness. (Simpson and Yeo, 1982).

Chronic disability after head injury can express impairment of any aspect of brain function, in virtually any combination; the head injuries of car occupants are usually diffuse or multifocal, unlike the localized brain wounds so numerous in war time. Memory impairment, loss of cognitive skills, and speech disorders are often seen, and motor disorders (spasticity, weakness, and tremor) are particularly common after diffuse axonal injury (see 2.2.1.). But disorders of behaviour and changes in personality are by far the most disabling and distressing sequelae of closed head injury (Jennett et al., 1981; Klonoff et al., 1986). The recent literature on intellectual and behavioural effects of brain injury is well reviewed by Levin (1985). The need for detailed assessment of these disabilities has stimulated the development of the subspecialty of neuropsychology, and various qualitative and quantitative tests are widely used for clinical and medico-legal purposes (Walsh, 1978, 1985).

Neuropsychologists are also becoming engaged in designing specific programs for rehabilitation of the victims of brain injury; Miller (1984) has published a monograph on the neuropsychologist's role in rehabilitation, which brings out with saddening clarity how few neuropsychological programs have been scientifically tested. This criticism can also be made of the physical aspects of rehabilitation. Nevertheless, throughout the world, multidisciplinary teams are being formed for rehabilitation of the head injured; Evans (1981) presents a good general account of the work of two British teams, one in a centre for airforce personnel, and one from a civilian hospital. The victims of head injury are often hard to accommodate in a general rehabilitation hospital, especially those given to aggressive or disruptive behaviour; some segregation is often needed. Eames and Wood (1985) have reported on the use of behaviour modification by token rewards and punishments in a selected group of such cases, treated in the well-known Kemsley Unit, St. Andrew's Hospital, UK.

It is a general impediment in head injury rehabilitation, that the processes of recovery are poorly understood. It is common experience that the victims of head injuries show objective improvement over many weeks or months. It is unclear to what extent this expresses the recovery of nerve cells or nerve fibres which have suffered reversible damage, or the substitution of function by uninjured nerve cells (Wall, 1975). There is even uncertainty on the time base of recovery: efforts to determine when recovery reaches a plateau have been made, and suggest that different neurological systems recover at different rates. Controlled animal experiments (Black et al., 1975) have shown some benefit from early physical retraining after brain injuries, but such experiments have obvious limitations in assessing human retraining programs.

With the best possible rehabilitation, there will be a residue of survivors with permanent disabilities, some of whom will require institutional or domiciliary care and some of whom will be unemployable and in need of diversionary activities. Selecki et al. (1981) found that in 1977, 2 per cent of all NSW head injuries were hospitalised for more than one month and 0.4 per cent for more than 3 months; 1 per cent were transferred to nursing homes. They projected from these data an annual minimum number of 750 patients with permanent damage to the brain. This would be an incidence of 15 per 100,000 population, and must evidently include a substantial number of victims with only moderate disability in the outcome scale of Jennett and Bond (1975). Johnson and Gleave (1987) in a careful study of a much smaller sample of head injuries found that 1.13 per 100,000 of the UK population under 65 would annually require care (0.38/100,000) or be unemployable (0.75/100,000). Broe et al. (1981) found in NSW a very similar annual incidence: 0.4/100,000 in need of institutional care, 1/100,000 dependent on others in daily living, and 3/100,000 with psychosocial disabilities such as personality changes and temper outbursts. The burden of these disabilities falls very largely on the victims' wives and parents (Brooks and McKinlay, 1983), and the burden must be carried a long time, since the expectation of life after survival of a severe head injury is not greatly reduced (Caveness 1976).

The treatment of facial injuries has also received much attention recently. Schultz and Oldham (1977) of Chicago gave a good overview of the management of these injuries. They stressed the importance of emergency treatment; as has been brought out earlier (2.2.2) some patients with facial injuries die from obstructed breathing and/or inhalation of blood or vomit, and it is possible that some lives may be saved by better first aid and primary medical care. The definitive management of the soft tissue and skeletal injuries of the face is less urgent. Meticulous repair of facial lacerations is needed to give the best possible cosmetic appearance, and this is often undertaken by plastic surgeons. Schultz and Oldham (1977) detail the treatment of the various patterns of facial fractures: this is also usually undertaken by plastic surgeons, in collaboration with oral surgeons when the jaws and teeth are involved. World wide development of the interdisciplinary specialty of craniofacial surgery facilitates the formation of teams to bring together the appropriate skills. In recent years, there has been an increasing tendency to replace and fix shattered bones by open operation rather than by manipulation and external splinting: fixation may be done with wires, with small metal plates, or with bone grafts. Buetow and Eggert (1984) of Erlangen discuss this, and describe in a single injured car occupant some extraordinarily complicated fracture patterns, fixation of which required splinting of the teeth, three plates, a bone graft, and the insertion of grafts of preserved human dura matter. These very complex yet rewarding operations are often performed a few days after injury, by multidisciplinary craniofacial teams. This is especially important when there is a combination of cerebral and facial injury, with shattering of the roof of the nose and escape of cerebrospinal fluid (Raveh et al., 1984). In Australia, David (1984), has reported on the value of combining plastic surgical and neurosurgical repair of these injuries in a single stage: this has given better results, and has significantly reduced hospital stay.

6.3 CONCLUSIONS

Review of the recent literature on the treatment of head injuries shows a widespread belief that better first aid and primary care after car crashes may save lives. Although the evidence is circumstantial, it is nevertheless strongly supported by the surveys reviewed here. Our review has not shown any dramatic advances in the management of primary brain injuries (see 2.2) and the limited capacity of the brain to recover from injury makes it unlikely that the outlook will improve greatly in the future: the nation must therefore expect a substantial prevalence of young adults with crippling brain injuries causing mental and behavioural disabilities. Advances have been made in the diagnosis and management of the secondary effects of brain injury and in the treatment of facial injuries. These advances have been achieved by surgical teams with highly specialised skills and experience, using expensive diagnostic apparatus (especially CT scanning), and working with the support of intensive care and laboratory services available 24 hours a day. High costs and the need for concentrating clinical experience have sited these teams in a small number of metropolitan hospitals. However, in Australia car crashes often occur in rural areas, at great distances from the nearest metropolitan hospital (Simpson et al., 1984). These considerations have given great importance to the logistics of trauma management. Modern communication systems and air transport should overcome the tyranny of Australian distances, but this can only be achieved if they are integrated in well organized regional trauma services.

7. TREATMENT OF CERVICAL (NECK) INJURIES

7.1 INTRODUCTION

Neck injuries resulting from vehicle accidents are common and range in severity from mild sprains to tetraplegia and even death. There is also a comparable range of treatment indicated, from no treatment to major surgical intervention. Treatment protocols also vary considerably from centre to centre in relation to the surgical or conservative tendencies of those in charge of the unit where treatment is carried out.

7.2 REVIEW OF LITERATURE

The aim of treatment is to achieve optimal survival, prevention of cord damage or its progression, stabilisation of any vertebral injury evident, and maximal post injury independence, hopefully enabling return to the workforce or community as a productive member.

The management of the individual at the site of injury and during transfer to hospital may have more bearing on the outcome of the injury than later treatment in hospital. Those first to the injured individual must ascertain the presence or possibility of a significant neck injury. This is done by determining if the injured person can move all limbs and feel them being touched, which requires the cooperation of the injured person. If the victim is unconscious it must be assumed that he or she has a neck injury and they must be managed accordingly. A conscious person reporting neck pain should also be managed as if they have a significant neck injury. Evidence of trauma to the head should immediately raise the suspicion of associated neck injury.

Cloward (1980) reports figures from a large study of spinal injuries treated at the Edinburgh Royal Infirmary indicating that 25 per cent of fatal complications occurred during the period from the time of the injury to arrival in the emergency room. He also noted that non-medical personnel are often the first to attend to a road crash victim, and if untrained, poorly trained or careless, they may disregard correct methods of handling spinal injured people and so risk the victims entire future. This is due to the fact that in an unstable cervical spinal injury a small amount of movement may result in irreparable spinal cord compression, rendering the patient tetraplegic. Kiesel (1969) also states that cervical spine injuries occurring without neurological involvement may be transformed into a crippling lesion by the well meaning but inexperienced rescuer.

Selecki et al. (1986) point out the detrimental effect of delays in getting spinally injured accident victims to a centre equipped to deal with the injury and its possible complications. From a retrospective study of medical case records it was found that in 27 of a total of 202 traumatic spinal injuries the late onset of neurological deficit appeared to result from aggrevation of the initial injury due to a preventable failure to immobilise the vertebral injury adequately. At least 16 of 69 deaths due to spinal injury were thought to have been avoidable.

It is also important to recognise that other life threatening injuries may exist in association with a significant neck injury and must be dealt with prior to moving the patient. Swain et al. (1985) reported the frequency of other severe injuries requiring attention as:

1) head injuries (coma > 6 hours or skull fracture) 19 per cent
2) chest injuries (requiring treatment or rib fracture) 15 per cent
3) abdominal injuries (requiring laparotomy) 2 per cent
4) multiple injuries (including skeletal fractures not mentioned above) 22 per cent

Burke (1973) reported the incidence of associated injuries as 33 per cent head, 31.2 per cent thoracic, 24.3 per cent fracture to long bones or pelvis and 14.2 per cent other injuries, but fails to indicate the severity of the associated injury.

Farrington (1968) reports well accepted methods of extraction of the injured victim from the vehicle and incident site. Initial application of a cervical collar is recommended by all authors reviewed, including Kiesel (1969), White (1978), Cloward (1980) and Swain (1985). All point out that this may give a false sense of security as a cervical collar alone fails to fully immobilise the neck, and recommend the use of a cervical stabilisation board which fixes the trunk, shoulders, head and neck prior to any attempt to move the injured person. If this type of board or similar device is not available, Swain (1985) recommends the use of four people to move the patient once a collar has been applied. One controls the legs, one the hips and abdomen, another the chest and the fourth, who directs movement, the head and neck. The patient is then belted to a stretcher and sand bags placed or either side of the head to prevent rotary movement.

White (1978), Selecki (1979), Swain (1985) and Cloward (1980) all recommend a similar sequence of events once the patient reaches the hospital emergency room.

(1) The head and neck must be immobilised immediately if not already secured.

(2) Assessment of all injuries must be made and priorities for treatment established. This includes a neurological examination to identify the presence, completeness and level of any spinal cord injury.

(3) Use of steroids to reduce swelling of the spinal cord has been recommended although White indicates there is no statistical

verification of its benefits. Bohlman (1979) concluded steroids provided no benefit in 37 patients with traumatic partial paralysis and reported an increase in some complications of spinal injury which he felt were related to its use.

(4) Assessment and maintenance of respiratory function, which may be impaired through damage to the upper cervical cord or associated thoracic injuries, is imperative.

(5) Following the initial assessment and stabilisation, X-rays of the cervical spine are performed while the head and neck are still immobilised.

Where paralysis is evident without X-ray evidence of compression or distortion of the spinal cord, or the nature of the injury is not fully evident on plain X-ray films further radiological tests are required. Today the use of CT examination provides a non-invasive and accurate method of identifying both bony and soft tissue injuries (Brant-Zawadzki et al., 1981; Gerlock et al., 1983). If CT also fails to provide necessary information, myelography (injection of contrast dye into the cerebrospinal fluid which surrounds the spinal cord and repetition of cervical X-rays) may be performed to indicate the level of the lesion and the relationship of neural to bony and soft tissue structures.

Cloward (1980) reports the injury classification used below to discuss the treatment of various cervical injuries.

1) Whiplash or hyperextension injury. Damage is usually confined to ligaments and muscles although sometimes intervertebral discs are injured. The injury does not involve the nervous system.

Treatment of this group is symptomatic. Both Kiesel (1969) and Cloward (1980) report the use of supportive cervical collar for 1-6 weeks depending on the severity of the injury, and concurrent anti-inflamatory medication. Cloward, drawing on experience gained over a marathon 40 years of dealing with this type of injury finds approximately 1/3 of patients managed in this way have symptoms subside in 2-4 weeks.

Lander (1985) reported from his study that 40 per cent had significant pain for one month or longer and 8 per cent for greater than 6 months. Juhl (1981) reported that the majority from his series were back at work and normal activity within 4 weeks but in one-third return was delayed up to 2 months.

All authors recognise a small group that will continue to have pain for several months despite settlement of any litigation. A few in this group are found to have a significant disc lesion evident from discography (X-ray picture of an intervertebral disc following injection of dye) or clinically with plain X-ray evidence of disc narrowing greater than expected for age and appearance of adjacent intervertebral discs. This group may benefit from anterior interbody fusion (Cloward, 1980).

2) <u>Paralysis without injury or dislocation of vertebrae.</u>

Transient subluxation of vertebrae occurring at the moment of the injury may damage the spinal cord resulting in complete or partial impairment of spinal cord function. With this type of lesion there may be no radiographic clue as to the nature of the soft tissue injury and the use of CT scanning and myelography are indicated to help identify the nature of the lesion. Management of the injury will depend on the nature and level of the neurological defect, its progress or regression, and the general condition of the patient. Cord injury without X-ray evidence of vertebral fracture is especially common in children, presumably because the spine is more flexible (Burke, 1974).

If a surgically decompressible or correctable lesion is evident surgery is recommended early via either an anterior or posterior approach with a good prognosis for recovery in incomplete lesions. A disc injury with herniation of disc material resulting in nerve root or spinal cord compression is readily accessible by an anterior approach as described by Cloward (1980).

3) Injury to the spinal column without injury to nerve roots or spinal cord

Selecki (1979), Bohlman (1979), White (1978) and Cloward (1980) recommend the use of skeletal traction applied at the time of diagnosis to reduce any deformity and realign the spinal canal. Reduction should be complete in 15-20 minutes and the position checked at least hourly with reduction of traction weight to the minimum required to maintain the realigned position without distraction of intervertebral discs. (The undesirable effect of distraction on recovery has been reported by Selecki and Williams, 1970).

The length of time traction is maintained will depend on the injury, its stability, and evidence of bony fusion. Traction is followed, again for a variable period, by the use of a cervical brace or collar until healing of supportive structures in the neck is complete.

Selecki (1979) states that surgery to fracture/dislocations of the cervical spine without evidence of spinal block has never been indicated in the acute stages, even when they are unstable. However, many authors advocate early operative stabilisation in selected cases.

4) Injuries to the vertebral column associated with paralysis.

As already discussed in the chapter relating to characteristics of cervical injuries, damage to the spinal cord may occur in several ways resulting in complete or partial loss of cord function below the level of the injury. Some of these mechanisms are remediable if acted upon early by traction and realignment of the spinal cord. The role of steroids has already been mentioned, but their place remains uncertain, as does the use of hyperbaric oxygen.

A lesion complete from the outset has a poor prognosis for recovery of function regardless of whatever treatment is instituted.

Instability of vertebral components can be managed with either anterior or posterior cervical fusion once the patient's condition is stable. Debris within the spinal cord is removed using an approach most suited to the location of the debris. The indications and contra-indications for surgery as reported by Selecki (1979) are as follows:

Indications for surgery:

(1) Progressive deterioration of neurological state,

(2) Presence of a complete block of the canal on myelography,

(3) Compound fracture of the spinal cord,

(4) Presence of bone fragments within the spinal cord,

(5) Failure of reduction of a fracture/dislocation with evidence of cord compression.

Contraindications for surgery:

(1) Evidence of improved neurological state,

(2) Complete transection syndrome evident immediately following the injury, without evidence of a spinal canal block,

(3) Medical contraindication to surgery e.g., severe chest injury.

During the acute stages of the injury, specialised nursing is required to prevent pressure sores and maintain spinal alignment whilst fulfilling the patient's bodily needs. Hachen (1977) in a Swiss study reports that in no other field of medicine has the effect of technology on patient care had greater benefit than in the management of acute traumatic tetraplegia. From annual statistics of the Swiss National Paraplegic Centre the mortality rate in 1966 of these injuries was 32.5 per cent for complete lesions and 9.9 per cent for incomplete lesions. In 1976, mortality had fallen to 6.8 per cent for complete and 1.4 per cent for incomplete lesions. He related this improvement to two factors. Firstly, the rapid transport of patients (using helicopters) under close medical supervision directly from the site of injury to the Spinal Injuries Centre (Hachen, 1974). Secondly, the immediate admission of all tetraplegic patients to highly specialised subunits for intensive care (Feuer, 1976). These principles have been accepted and are being implemented to varying degrees around the world.

Once the immediate problems have been overcome there remains a protracted and too often unrewarding course of rehabilitation, again requiring specialised nursing and physical therapy staff in specialised centres. The aim is to achieve the highest possible level of independence in the community. Some, however, will remain totally dependent on others for the duration of their lives.

7.3 CONCLUSION

Minor cervical injuries are common but still result in considerable disability, often lasting several months, but few have long term disability or discomfort. Conservative treatment with skull traction, nursing and general care has long been and still is the treatment of choice for fracture/dislocations with or without spinal cord involvement (Cloward, 1980). Few patients with a serious injury to their spinal cord, regardless of presenting disability, undergo surgery as an emergency: usually several hours and more often a few days supervene, before surgical intervention is initiated (White, 1978).

The need to handle injured persons as if they have a significant neck injury cannot be overemphasised and rapid transport with medical supervision to specialised centres has been shown to produce the best possible outcome. It seems evident that there is little room for improvement in terms of treatment of established cord damage once the patient arrives in the emergency room, but there is considerable scope to improve the logistic management of road crash spinal cord injuries, to ensure that expert treatment is available as soon as possible, to prevent aggravation of the initial injury.

8. PREVENTION OF HEAD AND NECK INJURY

8.1 INTRODUCTION

The preceding Chapters have indicated the nature and importance of the head and neck injuries sustained by vehicle occupants. The need for preventing these injuries, or at least minimizing the severity of those which do occur, is emphasised by the limited opportunity which exists for effective treatment. The review of the biomechanics of injury to the head and neck provides some indication of the types of countermeasures which may be successful, apart from the obvious one of preventing the head from hitting anything. In this Chapter we review the literature on the prevention of head impacts, and on the control of the severity of injury to the head and neck resulting from impact loading, either direct or induced. As before, we have chosen not to review measures which are intended to prevent injury by preventing accidents.

8.2 PREVENTION OF HEAD INJURY

8.2.1 Preventing Impacts to the Head

Occupant restraint systems may, in some crash circumstances, prevent impacts to the head and face. This can be brought about by limiting the motion of the head so as to prevent contact with the interior of the passenger compartment, including specific objects such as the steering wheel. Occupant restraints can also play a valuable role by preventing the occupant from being ejected, either partially or completely, from the car. As indicated earlier, the risk of serious and fatal injury is greatly increased if an occupant is ejected from the car in the crash. However, occupant restraints can offer only limited protection from objects which intrude into the passenger compartment, whether they be parts of the vehicle itself or some other object. Furthermore, occupant restraint systems are most likely to be effective in frontal crashes, for reasons which are generally obvious but which will be elaborated on later in this section.

In the present context, that of preventing impacts to the head or face, the term "occupant restraint" refers primarily to seat belt systems. The air bag form of restraint acts by converting a potentially injurious impact into one which is less likely to result in any significant injury but it does not, strictly speaking, prevent head contact.

It should be noted that the effectiveness of a seat belt restraint system is dependent to a very large degree on the properties and the integrity of the seat assembly itself (Adomeit, 1979; McLean et al., 1981). Indeed in a rear-end collision the seat back and head restraint can act as a very satisfactory occupant restraint system.

Herbert et al. (1975, 1976) has noted that, in a frontal crash, the forward displacement of the head of a restrained occupant is considerably greater with an inertia reel belt system than it is with a well-adjusted static belt, largely because of the webbing stored around the inertia reel. In practice, of course, static belts were often not correctly adjusted (McLean et al., 1981) and so, overall, the inertia reel belt probably offers a superior level of protection. However, head or face contact with the steering wheel is common among drivers restrained by both static and inertia reel belts (Gloyns et al., 1981). This is reflected in the results of the study by Rutherford et al. (1985) of the effects of the introduction of the mandatory belt wearing law in the United Kingdom. As noted in Chapter 4, the incidence of major brain injuries and some facial fractures increased among drivers following the introduction of the law.

Various measures have been developed to reduce the slack in an inertia reel belt system when a load is applied, as in a crash (Dejeammes et al., 1984). The webbing of the belt can be automatically clamped immediately above the inertia reel mechanism or near the upper mounting point (the "D-ring") as soon as the load is applied, the clamp being actuated by the load in the webbing. This effectively removes the webbing stored around the inertia reel from the load bearing path.

A second, more complex, measure applies a load to the webbing early in the crash sequence. A crash sensor ignites a pyrotechnic charge which then actuates a mechanism which either rapidly rotates the inertia reel or by other means takes up slack in the belt outside the inertia reel mechanism. Tests conducted by Dejeammes et al. (1984), Mitzkus et al. (1984) and Rosenau et al. (1984), among others, have demonstrated a reduced likelihood of head contact, a lower value of Head Injury Criterion (HIC), and a lower chest loading with both the webbing clamp and the preloading device (also referred to as a belt pretensioner). The pretensioner has the advantage of removing slack in the belt resulting from bulky clothing being worn by the occupant. Unlike the air bag restraint system, which will be discussed later, the pretensioner is fail-safe. In the event of a failure in the actuating system the conventional seat belt system still operates normally.

The increase in cost of these devices compared to a standard inertia reel belt system has been estimated at a factor of 1.5 for the webbing clamp and a factor of 2 for the belt pretensioner without a crash sensor. A belt pretensioner was fitted to an experimental safety vehicle by Mercedes-Benz in the early 1970s (Reidelbach, 1977) and a similar device is now available on current production models in Australia, together with a steering wheel mounted air bag (see Section 8.2.2).

It is apparent that the greater the space around the head of a restrained occupant the less likely it is that the head will strike the interior of the passenger compartment in the event of a crash. Herbert et al. (1975, 1976) plotted the envelopes of head trajectories of a restrained 50th percentile male anthropometric dummy subjected to moderate to low decelerations in three different cars. While the 3-point belt system prevented head contacts in the forward direction it did not do so for lateral decelerations, except in certain circumstances (side window open and side door supporting the upper torso). It should be noted that a device such as a belt pretensioner or a webbing clamp, by reducing the movement of the head in a crash, reduces the required head space.

The Economic Commission for Europe has specified the "head-impact zone" for passenger cars in Regulation No. 21 in terms of a radius about the H-point (which is approximately the hip joint of a normally seated occupant). This head impact zone extends across the front of the passenger compartment, excluding the steering assembly, and the nearest inner side wall. Any part of the "head-impact zone" which can be "contacted" by a sphere of given radius located at the defined distance from the H-point must have specified energy absorbing properties.

The specification of the head impact zone in ECE Regulation No. 21 implies that the occupant is restrained, at least by a lap belt. However, many crash-involved occupants are not restrained (McLean et al., 1981) and so an attempt should be made to minimize the severity of the head impacts that occur with the interior of the passenger compartment regardless of restraint usage.

The effectiveness of the belt systems described above depends on the occupant actively choosing to wear the belt. For this reason, "passive" belt systems have been developed in an attempt to deal with this problem. In most cases the passive belt system comprises a diagonal belt (similar to the diagonal section of a three point belt) which is arranged in such a way that it moves out of the way to enable an occupant to be seated and, when the door is closed, the belt automatically moves into position. The lower torso is restrained, in the event of a frontal collision, by the knees contacting an energy-absorbing rearward extension of the instrument panel.

A passive belt system was available on the Volkswagen "Rabbit" ("Golf" in Australia) from the 1975 model year in the United States. Reinfurt et al. (1981) compared the injury severities of three groups of crash-involved occupants of these cars: no belt used, "active" belt used, "passive" belt used. Passive belts, which could be disconnected, were used by half to three-quarters of these occupants. The authors concluded that the two systems, when used, were equally effective in reducing serious injuries. However, the much higher usage rate of the "passive" belts (about double that of the "active" belts) meant that there was an overall reduction of some 20 to 30% in serious injuries in the cars equipped with "passive" belts. Despite this result, the "passive" belt system has been withdrawn by Volkswagen from the United States market for a variety of reasons, including the legislative environment (Rosenau et al., 1984).

8.2.2 Reducing the Severity of Head Impacts with the Vehicle Interior

Occupant restraint systems

As indicated in the preceding section, improvements to seat belt systems have the potential to reduce both the frequency of head impacts and the severity of those impacts which do occur. The air bag restraint system was developed initially to replace seat belts entirely, with the obvious attraction that it is a "passive" system which does not rely on any action on the part of the occupant, unlike the "active" seat belt which must be worn to be effective.

Comparisons of "pure" air bag systems (as compared to air bags which are supplementary to seat belts) with three-point belt systems in similar crash conditions have indicated that the air bag provides a similar level of protection to that of the three-point belt.

Dejeammes et al. (1975) compared the results obtained from instrumented anthropometric test devices (ATDs) in Renault 12 cars which were involved in off-set head-on collisions and barrier crash tests at 50 km/h. The ATDs restrained by belts exhibited greater head movement as a consequence of less effective restraint of the torso compared to that provided by the air bag. In the barrier crash test the rear of the car was projected upwards to a greater degree than was observed in the off-set head-on collisions. This caused the head of the ATD representing a 95 percentile male to contact the header area above the windscreen when restrained by an air bag. No such contact was observed when the restraint was provided by a three-point belt system. The authors noted that the 50 km/h barrier crash appeared to be the limit of crash severity for adequate protection for these two restraint systems in a sub-compact vehicle.

Walsh and Kelleher (1978) evaluated the performance of the original General Motors air bag systems, which were fitted to 1,000 Chevrolet Impala passenger cars in the 1973 model years, and a conventional three-point belt system. Full-scale crash tests were conducted; head-on collisions between 1973 Chevrolet Impalas at a closing speed of 100 km/h with full and partial overlap between the fronts of the cars. The performance of the two restraint systems was measured using instrumental ATDs and cadavers. The investigators concluded that "satisfactory levels of protection were provided for the full range of adult occupant size" by both restraint systems.

The concept of the air bag restraint is that the bag is fully inflated before the occupant makes significant contact with it. Horsch and Culver (1979) studied driver interactions with a steering wheel mounted bag when the driver was (1) initially positioned away from the steering wheel and (2) in contact with the wheel at the moment of deployment of the air bag. The tests were conducted using either a SAE J944 body block or a GM Hybrid III anthropometric dummy set up for both static deployment and for deployment on an impact sled. Tests were also conducted with no deployment of the air bag. The results indicated that the highest chest loading occurred when the torso was in contact with the steering wheel at the moment of deployment, followed by contact with the steering wheel when the air bag was not activated. The lowest loading was when the torso was located well away from the steering wheel when the air bag was triggered. While this study concentrated on chest loading, it is reasonable to assume that the severity of neck loading would mirror the above results for the three test conditions.

At present, the optimal restraint system for the driver of a passenger car appears to be the combination of a three-point seat belt with a pretensioning device and a steering column mounted air bag. As noted earlier in this Chapter, this system is available as optional equipment on Mercedes-Benz passenger cars in Australia. Most of the major automobile manufacturers in the United States now offer at least one model line equipped with driver's side air bags.

Changes to the steering wheel

Existing safety standards applicable to the steering assembly (wheel and column) such as Australian Design Rule (ADR) 10B are intended to minimize the severity of injury to the upper torso of a driver in the event of a frontal crash. Consideration is now being given to the development of a repeatable test of the potential of the steering assembly to injure the head or face, with a view to the amendment of these standards (Petty et al., 1985).

Padding of surfaces inside the passenger compartment

The first surface to be padded for safety reasons in passenger cars was the instrument panel. B.J. Campbell (1963) examined Automobile Crash Injury Research (ACIR) data files to study the role of padding on instrument panels in reducing the frequency the severity of head injury. He concluded that padding did indeed operate to prevent some head injuries and to reduce the severity of other head injuries. The strongest beneficial effect of padding was seen in the lower part of the injury scale, influencing injuries that were not so severe as to be dangerous to life. No effect of padding was detected in the range of injuries severe enough to threaten the occupant's life. The author cautioned that it was not reasonable to expect large and obvious changes in the risk of injury due to the padding when viewed in the context of all injuries sustained in car crashes. This was because the "appreciable" effect of padding in the highly restricted crash situations studied in this investigation was diluted by the introduction of many crash situations in which instrument panel padding may have been irrelevant because other objects were struck instead.

In 1972 an Australian Design Rule for Motor Vehicle Safety was introduced with the intention of reducing the injury potential of internal sun visors and the adjacent vehicle structure. (ADR 11; Internal Sun Visors). The Rule requires that a head form, when impacting an internal sun visor at a velocity of 3.5 m/s (12.6 km/h), should be stopped with a deceleration not exceeding 80 g for more than 3 milliseconds. More recently (1984) ADR 11 has been amended to permit compliance with ECE

Regulation 21 as an alternative to the above test. The ECE 21 energy absorption requirement is more stringent than that specified in ADR 11 in that the maximum permissible deceleration is the same but the impact velocity is 24.1 km/h. However, as noted in Section 8.2.1, ECE 21 appears to define a head impact zone, within which the energy-absorption requirement takes effect, on the assumption that the occupants pivot about the H-point.

ADR 21; Instrument Panels, specifies energy absorption requirements for the upper section of the instrument panel which are similar to those of ECE 21. The test procedure for ADR 21 is described in the Society of Automotive Engineers Recommended Practice J921, June 1965.

We were unable to find an evaluation of the effectiveness of either ADR 11 or 21 or ECE 21 in the literature.

Monk et al. (1986) described the selection of energy absorption material for use in padding the A-pillar (the pillar adjacent to the windscreen) to reduce the severity of a head impact. They concluded that a one inch thick pad of Dytherm 3 padding material had the potential to reduce by 80 per cent the probability of death from a head impact with the A-pillar at an impact velocity of 25 mph. The probability of death was deduced from measurement of the deceleration of the head form and calculation of the Head Injury Criterion. The authors noted that the small thickness of the Dytherm padding material, compared to materials such as rigid foams, reduced the risk of the head pocketting into it and thereby decreased the risk of injury to the neck.

Helmet wearing by the occupants of passenger cars

Apart from seat belt wearing, the only immediately-available means of reducing the severity of a head impact with the interior of the passenger compartment is, as Herbert (1976) has noted, to wear a protective helmet. Neither the motorcyclist's crash helmet nor the protective helmet designed for use by pedal cyclists would appear to be entirely suitable for use by car occupants, particularly because of the restricted head space in some cars. For practical reasons such as this, and to encourage public acceptability of helmet wearing, there is a need to develop a specification for a suitable helmet for this purpose.

8.3 PREVENTION OF NECK INJURY

The prevention of injury to the neck of a car occupant is unusually complex because of the difficulty of objective diagnosis of so-called "whiplash" injury and because of the inadequate understanding of the mechanism of this injury.

The provision of head restraints in cars was required first in the United States (Federal Motor Vehicle Safety Standard No. 202) in 1968. This Standard was evaluated by McLean (1973) using data on the collision circumstances which was collected by the police and information on neck injury obtained from telephone interviews conducted with the drivers about one week after the crash. No meaningful reduction in the incidence or severity of neck injury was found for adjustable head restraints but there was some indication that high seat backs, or fixed head restraints, did provide some benefit.

This Standard has recently been evaluated by Kahane (1982) of the US National Highway Traffic Safety Administration using data from the Texas accident files, the National Crash Severity Study (NCSS), the National Accident Sampling System (NASS) and the Fatal Accident Reporting System (FARS). He concluded that head restraints, both integral and adjustable, had significantly reduced the number of injuries in rear impact crashes.

Of integral seatbacks, 85 per cent were found to exceed the minimum height requirement of Standard 202, whereas, 75 percent of adjustable head restraints were not in fact adjusted by the driver to the correct position but were left fully down. It is not surprising, then, that Kahane found that integral seats nearly twice as effective as adjustable restraints in reducing whiplash injury. Paradoxically, integral seats while supplying greater protection, were found in only 28 per cent of cars sold between 1969-1981. The higher sales of adjustable restraints appeared to be due to market preference based on aspects of comfort and styling.

An Australian Design Rule, modelled on FMVSS 202 was introduced in 1972 (ADR 22). This Rule differs from the American Standard in that the height of the head restraint is greater. ADR 22 was evaluated by Cameron & Wessels (1979) who found only weak evidence that ADR22 was effective in reducing whiplash injuries in rear end impacts. The only beneficial effect being found for female occupants of front left passenger seats. Drivers in front end impacts, however, were found to be more likely to sustain whiplash and major intracranial injuries in ADR22 cars when compared to those in pre-ADR22 cars. The inability of the authors to control for crash severity or seat belt wearing will of course place a caveat on these conclusions.

ADR22 was upgraded to ADR 22A with which all new vehicles in Australia had to comply from 1975 onwards. This was evaluated by Cameron (1980) who found that ADR22A was effective in reducing the risk of whiplash injuries to female drivers and front left seat passengers. No conclusive benefit for males was found. The previously reported (Cameron & Wessels, 1979) increase in risk of whiplash injury to drivers in front end impacts in cars equipped with ADR22 head restraints was confirmed - the increased risk of major intracranial injury was not. Once again the author was not able to control for crash severity on seat belt wearing in this analysis.

A detailed investigation of claims for compensation for whiplash injury is currently being conducted for the Victorian Motor Accidents Board (Wilson, personal communication).

Whereas neck injury is usually a consequence of a rear end collision, it is nevertheless important to recognize that non-contact neck injuries are reported in both front and side collisions. Rutherford et al. (1985) reported an increase in neck injury with the introduction of the mandatory seat belt wearing law in the UK. This finding is worthy of further investigation, particularly with regard to the possible wider use of pretensioning devices for seat belts.

8.4 CONCLUSION

It is clear that, overall, the use of seat belts decreases the incidence and severity of head injury. However, it is also clear that current inertia reel belt systems do not adequately protect the driver from head and/or face impacts with the steering wheel. Devices such as belt pretensioners and air bags, both of which are now available on production vehicles, can greatly reduce the magnitude of this problem. Design of the steering wheel to minimize contact loading in the event of an impact by the face is also at a stage at which such wheels could be required as original equipment.

Padding materials that can greatly reduce the severity of an impact between the head and the interior of the passenger compartment are now available in a form suitable for use in production vehicles. Ways to ensure the early adoption of such materials in passenger cars should be considered by the Vehicle Standards Advisory Committee (VSAC) of the Australian Transport Advisory Council (ATAC).

Even if ATAC were to act as rapidly as possible to require a higher standard of head impact protection in the passenger compartment it would be almost ten years before half of the passenger cars in Australia were so equipped. Therefore, the use of protective headwear, possibly in the form of a protective hat rather than a helmet, should be encouraged. This would be facilitated by the introduction of headwear more suitable for this purpose than most of the helmets currently available.

There is a need to improve the level of protection against neck injury in rear impacts which is provided by existing head restraints.

9. RECOMMENDATIONS

9.1 INTRODUCTION

The subject of this review has been the head and neck injuries sustained by the occupants of passenger cars in crashes. As noted earlier, the prevention of crashes has not been covered. The following recommendations are therefore directed to the prevention of head and neck injury in a crash and to the reduction of the severity of the injuries that do occur to those body regions.

9.2 THE NEED FOR ACTION

It is clear that head and neck injury to car occupants account for a large part of the loss of life attributable to road crashes. There is also good reason to conclude that non-fatal injuries to the head and neck are the cause of far more long-term disability, both physical and social, than is commonly recognized.

It is therefore recommended that:

> The risk of sustaining an injury to the head or neck in a car crash be publicized widely, together with the fact that the personal and social consequences can be extremely severe, to encourage the adoption of appropriate countermeasures by both the users and the makers of passenger cars.

9.3 ACTION BY CAR OCCUPANTS

The effectiveness of the three-point seat belt in preventing injury to the head or neck is well established, with the exception of the injuries caused by the driver striking the steering wheel. Although lap belts do not provide the same level of protection against head or face impacts inside the car they do reduce the risk of ejection and hence the overall risk of severe injury.

It is therefore recommended that:

> Every opportunity be taken to ensure that all car occupants comply with existing belt wearing laws.

Head contact with either the interior of the car or an intruding object is likely in a crash even for a belted occupant particularly in side impacts. The severity of the injury resulting from such a contact could be reduced in many cases by a suitably-designed protective hat.

It is therefore recommended that:

> The wearing of protective hats by car occupants be encouraged.

9.4 ACTION BY ORGANIZATIONS

Several opportunities exist for the adoption of new countermeasures for the prevention of head injury.

It is recommended that:

> The Vehicle Standards Advisory Committee be asked to consider the further development of the Australian Design Rules for Motor Vehicle Safety with regard to
>
> (1) air bag restraint systems for car drivers as a supplement to seat belt restraint;
>
> (2) seat belt pretensioning or webbing locking devices;
>
> (3) steering wheel characteristics to minimize the severity of injuries to the head and face, and;
>
> (4) the provision of padding of the A-pillars, header rail and side roof rails.

It is also recommended that:

The Federal Office of Road Safety arrange for the development of specifications for a protective hat for use by the occupants of passenger cars.

9.5 ACTIONS TO MINIMIZE THE DELETERIOUS OUTCOMES OF HEAD AND SPINAL INJURIES

It is evident from the review that there is scope to minimize the social and personal costs of head and spinal injuries through the provision of emergency and continuing medical treatment centres, including rehabilitation.

It is therefore recommended that:

(1) Adequate and efficient emergency medical services should be available in all populated areas.

(2) All major population centres should have ready access to a specialized spinal and head injury treatment unit.

(3) Rehabilitation services for those injured in road crashes should be made available in all major centres. .

(4) There should be provision for the evaluation of the above services.

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