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CHAPTER 3

Recent developments in the management of injuries of the cervical spine

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The past 2 decades have witnessed a number of new developments in the management of the injuries of the cervical spine. The advent of computerised tomography (CT) now widely available has made imaging of the spinal canal possible. Magnetic resonance imaging (MRI) has revolutionised the clinicians' ability to assess impingement on the cord and the longitudinal extent of cord pathology. This, together with an improvement of understanding of the correlation between signal intensity patterns and potentials for neurological recovery, is likely to prove very valuable in the re-evaluation of different management procedures for different patterns of injuries. MRI has been particularly valuable in the management of post-traumatic syringomyelia. Advances in surgical techniques with the introduction of anterior and anterolateral surgical approaches to the cervical spine together with spinal cord monitoring during surgery, and a wider choice of instruments have improved surgical targeting and reduced surgical complications.

The recognised role of spinal injuries centres (Frankel 1987) in the early management of patients with spinal injuries (Donovan et al. 1984; Heineman et al. 1986; Devivo et al. 1990) and lifelong follow-up (Brown et al. 1987) and the worldwide establishment of these centres have made possible clinical trials to evaluate various procedures of management and pharmacological agents. A specialist training in spinal injuries approved by the Royal Colleges has been established in the United Kingdom since the early 1980s. A wider choice of well-designed cervical orthoses and cervical spine splinting devices (Yeo et al. 1986; Meyer 1989) are now available. The general awareness about initial management at the roadside, better cervical splinting devices, and safer transport is suggested to have increased the number of tetraplegic patients surviving and reaching hospital and has resulted in the decrease in incidence of complete cervical cord lesions (Meyer 1989).

The diagnosis and management procedures of cervical spine injuries will be discussed in the light of available information on pathogenesis, review of the literature, and personal experience.

DIAGNOSIS

Despite these favourable developments, missed spinal injuries still occur (Rinaldi et al. 1975; Ravichandran and Silver 1982; Reid et al. 1987). The incidence of missed injuries in 1 series was as high as 30% (Bohlman 1979). Delay in diagnosis of a cervical spinal injury can result in an increase of the neurological deficit (Rogers 1957; Reid et al. 1987). A conscious alert patient who is able to communicate and has no symptoms of neck pain, rigidity, or tenderness in the

cervical spine is unlikely to have a cervical spine injury (Fischer 1984). Extreme pain from other injuries may, however, lead to missed cervical spine injuries (Nichols et al. 1987). Elderly patients with primary ligamentous injuries of the cervical spine may not have significant symptoms to draw the attention to a cervical injury even though they may be alert. We have seen 2 patients in the last 3 years with bilateral dislocation in the lower cervical spine. One of these patients did not have symptoms until a week after the injury when he first complained to a doctor. The other patient had minimum symptoms, a hidden injury on the lateral cervical spine X-ray, and when he was recalled 2 weeks later, his symptoms had improved in spite of the progression of the lesion to bilateral facet dislocation. Neither patient had neurological signs until reduction was attempted when they became tetraplegic.

Associated life-threatening conditions which take precedence over a cervical spine injury can result in delay of the diagnosis. The diagnosis of a secondary cervical injury is in our experience often delayed following the diagnosis of a primary injury in the spinal axis. Multilevel spinal injuries (Bentley and McSweeney 1968; Kewalramani and Taylor 1976; Calenoff et al. 1978) have been reported with an incidence as high as 16.7% (Tearse et al. 1987). The lower cervical spine and cervicodorsal junction was the most frequently involved, followed by the upper cervical spine in our series (Gupta and El Masri 1989) of 91 patients with contiguous and noncontiguous multilevel spinal injuries. Impairment of sensation, motor power, and monosynaptic reflexes in the conscious patient are usually reliable signs in the diagnosis of the level and the density of the cord lesion. We have, however, recently been asked to exclude functional paralysis in a patient who presented with symptoms of hyperaesthesia in 1 arm and subjective motor weakness in the upper and lower limbs. Neurological examination revealed normal appreciation of all sensory modalities and normal tendon reflex responses with weakness in the 4 limbs. Radiography including CT scanning of the cervical spine was negative. An MRI scan revealed a cord lesion at the level of C5.

The plantar reflexes are unreliable (El Masri et al., personal observation) and in our experience none of the multisynaptic reflexes should be relied upon for the diagnosis or the prognosis of a spinal cord injury in the first 72 h following injury. The supraclavicular nerve distribution (C4) is often mistakenly documented as D2 or D3. Another not infrequent cause of misdiagnosis of the level of injury, and delay in diagnosis of the injury altogether, is the misinterpretation of the passive movements in the hands, wrists, and elbows which occur due to the combined effect of gravity and active movement of the elbow flexors and/or deltoid.

Discrepancies between the neurological and radiological findings (Hardy 1977; Ravichandran 1978; Reale et al. 1983; Bachulis et al. 1987) can also result in the delay of the diagnosis. The unconscious, semiconscious, and intoxicated patients present particular problems to the clinicians resulting in delay of the diagnosis (Bachulis et al. 1987; Nichols et al. 1987). In patients with dense cervical cord injuries, the absence of chest expansion during inspiration with an increase in the abdominal girth (diaphragmatic breathing) is in our experience the most reliable clinical sign of a cord injury below the level of C3. Generalised retraction of the intercostal muscles can also be seen in thin patients. The combination of a number of the following clinical signs can also contribute to making a diagnosis. (a) Facial or scalp lacerations and neck swelling or bruising can be suggestive of the mechanism of injury. (b) Miosis of 1 or both pupils is sometimes seen. (c) The difference in pattern of spontaneous movement and the difference in tone between the proximal and the distal muscles in the upper limbs, and between the upper and lower limbs, the position of the upper limbs and the response to painful stimuli by pressure over the bony prominences along the segmental distribution of the cord throughout the body can be suggestive of the level of the injury. (d) The combination of hypotension and bradycardia and the presence of priapism usually indicate a cord injury. (e) Unlike a patient with head injury who is likely to be incontinent to urine, a patient with combined head and spinal injury is likely to be dry in the accident department.

Obvious radiological signs can be absent in the presence of a cervical injury (Bachulis et al. 1987). An enlarged prevertebral cervical shadow (Gopalakrishnan and El Masri 1986) is a good indicator of a cervical injury and lack of cervical lordosis is another helpful radiological sign.

The difficulties with visualisation of the lower cervical and cervico-thoracic areas can be overcome by the application of a soft cervical collar about 15 minutes prior to the radiological examination and by the application of a gentle but firm push over the shoulders with a simultaneous pull on both arms for a period of 15 seconds. The hands over the shoulders will obviously have to be removed just prior to the taking of lateral cervical spine X-ray during which the pull over the arms should be maintained. Failure to demonstrate this area should be followed by a swimmers view, linear tomography or CT with reconstruction usually in this sequence. Dynamic views should be restricted to conscious patients who are able to communicate and who are suspected to have a cervical spine injury despite the absence of obvious radiological signs. A negative yield from dynamic views of the cervical spine should be expected in the presence of neck pain and rigidity which usually lasts for a period of about 5 days following the injury. Spinal care and a cervical collar should be provided to all unconscious, semiconscious, or intoxicated patients with head injury and/or multiple injuries until a spinal injury can be excluded clinically and radiologically. Once a spinal injury has been diagnosed, the whole of the spinal axis should be X-rayed.

BASIS AND RATIONALE OF MANAGEMENT

Whilst the definitive management of the cervical spinal injury is controversial there is no argument about the goals that need to be achieved. All agree about the necessity though not the means of the containment of the biomechanical instability to preserve spared neural tissue until healing occurs. The importance of the maintenance of the flexibility of the cervical spine, prevention of late pain, myelopathy, and instability, and the provision of a cost-effective programme of rehabilitation at the end of which the patient could lead a reasonable quality life is appreciated by all clinicians in this field. Different groups of clinicians, however, have differing views on the importance of canal encroachment. To a large extent, the choice of definitive management depends on the background, instinct, and the experience of the clinician and his knowledge of the pathology (Hughes 1978; Kakulas 1988) and the pathogenesis (Ducker 1976; De la Torre 1981; Means and Anderson 1987; Janssen and Hansebout 1989). The different interpretations of the pathogenesis may help explain the diverse approaches to management.

Opinion is divided as to the contribution of the initial impact to the final neurological outcome. Frankel et al. (1973a,b), Dall (1972), White et al. (1976), Bedbrook and Sakae (1982), and Kakulas and Bedbrook (1976) believe that the fate of the neurological injury is largely determined at the time of the accident. The suggestion by Freeman and Wright (1953) that permanent cord damage could result from the sequelae of the cord injury rather than from the initial impact itself has stimulated scientists and clinicians to direct treatment during the critical period prior to or in the early stages of the development of the secondary changes (vascular, cellular, electrophysiological, enzymatic, electrolytic, and metabolic) in order to prevent further neurological deterioration and/or improve the neurological outcome.

In general, opinion is divided as to the mechanism and the clinical significance of these secondary changes. The triggering stimuli for and the exact temporal sequence of these changes remain obscure (Means and Anderson 1987).

It is generally agreed that progressive ischaemia plays an important role in the development of secondary injury. Increased circulation time (Wagner et al. 1969), alteration of the vasomotor reactivity of the injured segment (Ducker and Kindt 1971) accumulation of lactate (Locke et al. 1971), platelet aggregation related to endothelial changes (Goodman et al. 1979), and impairment of autoregulation (Griffiths 1976; Smith et al. 1978; Senter and Venes 1979) are well-documented. Ischaemia alone does not, however, seem to satisfy all scientists to be solely responsible for the electrophysiological and neuropatho-

logical changes (Tarlov 1972; Bingham et al. 1975a,b; Kobrine 1975; Kobrine et al. 1978).

The literature on the experimental work strongly suggests that beyond a certain magnitude of initial impact, the secondary changes in the spinal cord of the experimental animal cannot be manipulated successfully and neurological improvement cannot be achieved. In the laboratory attempts at manipulating the secondary changes following subthreshold impact within a window of opportunity seems to be successful. It is possible that the difficulties encountered in the determination of these factors in humans, as well as the realistic restrictions of the clinical situation, have at least contributed to the much less spectacular outcome of the different surgical procedures and pharmacological agents which seem to give better results in the laboratory.

The relationship between pathogenesis and neurological progress (deterioration or improvement) is another concern to the clinician. In general, spontaneous substantial neurological deterioration is rare. In a series of 112 consecutive patients with cervical injuries, only 2 patients deteriorated. One patient deteriorated from Frankel grade C to A and recovered to Frankel grade B within 6 months. There were no radiological findings on CT and plain X-rays, including dynamic views of the cervical spine. The other deteriorated from Frankel grade E to D.

About 5% of tetraplegic patients are likely to exhibit spontaneous transient ascent of their level by 1–2 segments, usually within the first 3 days following injury, with recovery occurring usually within the following 6 weeks to 6 months. This occurs with conservative as well as surgical management and a cause is rarely found (Stauffer 1989). The pathogenesis of this seemingly unprovoked transient deterioration is not known.

The vulnerability of the injured cord to further trauma was recognised in the early fifties: 'The spinal cord has more protective structures and circumstances than the brain but when these devices are overcome, they exist probably to a lesser degree of resistance to injury' (Freeman and Wright 1953). This further cord injury may not necessarily be from a mechanical cause; in our experience it can occur in the absence of cord compression and mechanical instability.

In the non-traumatised cord, hypoxia, hypotension, and sepsis are unlikely to result in paralysis.

Physiological instability of the injured cord (El Masri et al., personal observation) would account for the neurological deterioration or delay in expected improvement associated with hypoxia, hypotension, sepsis, and other undetermined causes, especially in the absence of biomechanical instability or cord compression.

This nonmechanically provoked neurological deterioration is, in our opinion, under-reported. We have witnessed patients with biomechanically stable cervical and upper dorsal injuries and no cord compression developing postural hypotension resulting in neurological deterioration, both prevented by the administration of ephedrine prior to remobilisation (El Masri et al., pers. commun.). This has prompted us to perform tilt-table studies on all our patients with incomplete cervical cord injuries, measuring blood pressure and repeating neurological examinations during different degrees of tilting prior to mobilisation. Neurological deterioration associated with intraoperative hypotension during cervical decompression has been reported by Bohlman (1979).

The profound effect of sepsis and hypoxia on the reflex activity of the injured cord is documented by Guttman (1973b). Unexplained progressive cord lesions without deformation of the canal have also been reported (Braakman and Penning 1976). The effects of various anaesthetic agents on the autoregulation of the uninjured spinal cord of experimental animals is unknown and might have an adverse effect on the cord (Hickey et al. 1986). What is certain is that the cardiorespiratory and autonomic system status as well as the potential multiple sources of infection in these patients are at least as great a threat to the injured and physiologically unstable cord as the biomechanical instability and neural tissue compression by the spinal axis.

Significance of canal encroachment

Compression of neural tissue in the cervical spine is an ongoing concern to clinicians as well as scientists. Whether canal encroachment by spongy cancellous bone from the vertebral bodies transmits and sustains the same forces on the

spinal cord as ruptured disc material does in man is not known.

Improvement following cervical spinal surgical decompression is currently advocated on the basis of various experimental studies. Bohlman et al. (1979) were of the opinion that mechanical compression to remaining tissue prevents optimal recovery of spinal cord functions. They studied the effect of anterior compression on the cervical cord of dogs using remote control transducers inserted between the 5th and 6th cervical vertebra. Different degrees of paralysis occurred within 24 h of compression in all 8 dogs who survived. Three dogs recovered to normal at 10 days, 12 days, and 9 weeks post injury and without removing the transducer. Another 2 dogs deteriorated. One became completely paralysed and the transducer was removed at 7 days. Recovery to normality was attained a week later. The other dog had its transducer removed 4 days later and recovered immediately. Interestingly, in this series similar forces did not always result in a similar initial neurological deficit. The initial neurological deficit was, however, similar in 2 dogs following similar force applications. One recovered with removal of the transducer. The other recovered without removing the transducer 4 weeks later. These results suggest that, at best, decompression may have helped the dogs exhibiting neurological deterioration recover earlier, although this cannot be proven from such a small number of animals.

Dolan et al. (1980) used a clip compression model to study the value of decompression for defined forces of various magnitudes and duration in rats. The results showed that increasing the force or the duration of compression caused a reduction in functional recovery. They also found that the earlier the persisting compression is removed, the better the functional recovery. They stated, however, that in many injuries the force of compression is likely to be so great that it is impossible to achieve decompression early enough to yield any recovery. Guha et al. (1987) used the same model with lower compressive forces over periods ranging between 15 and 240 minutes (to simulate a clinically relevant period between injury and decompression). They concluded that the ultimate neurological deficit after experimental spinal cord trauma is determined by both the severity of the initial impact force and the duration of persisting compression, with the magnitude of the initial impact force being the dominant factor. They suggested that decompression of the spinal cord within up to 4 h (simulating circumstances encountered in clinical practice) may enhance neurological recovery, provided the severity of the initial impact is below the impact force beyond which no recovery would occur.

The detrimental neurological effect of a combination of compression and ischaemia in the dog has been documented by Gooding et al. (1975).

Our experience in man, however, suggests that, provided both the biomechanical and the physiological instability of the spinal cord are well-contained, canal encroachment in the cervical spine following injury does not delay nor prevent recovery in patients with incomplete lesions.

The following 4 examples demonstrate the clinical significance of cervical spinal canal encroachment in patients with incomplete lesions.

Case 1 (NP) (Fig. 1). A 23-year-old male was admitted 11 days post injury with compound fractures of the left femur, fractures of the right and left ankles, a fracture of the distal third of the tibia, and a fracture of C6 with 20% canal encroachment. His only neurological deficit was weakness in the right triceps (power 3) which recovered completely within the following 4 weeks.

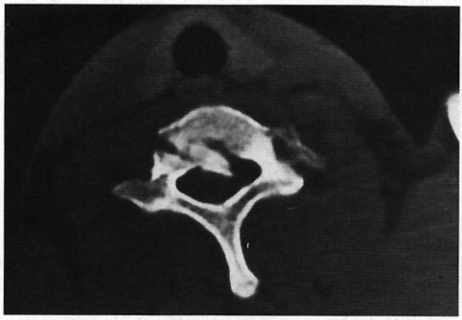


Fig. 1. C.T. of C6 showing 20% canal encroachment. Case 1 (NP).

Case 2 (HB) (Fig. 2). A 19-year-old girl was admitted 2 weeks following her injury in a road-traffic accident in India. She sustained a C7 fracture with 30% canal encroachment. Initially she had complete somatosensory loss which lasted 2 h. She improved to Frankel grade D and was discharged home 52 days after her injury. She is able to walk without orthoses.

Case 3 (NB) (Fig. 3). A 17-year-old girl was admitted the day of her injury, having been involved in a road-traffic accident in which she sustained a C3/C4 fracture with left-sided canal encroachment resulting in a Brown-Séquard syndrome. There was complete left-sided hemiplegia. Deep touch was preserved on the right and pinprick sensation was preserved in S3/S4/S5 bilaterally. She started improving 2 weeks from injury and was discharged from hospital walking without orthosis and with only 1 stick for security 21 weeks post injury. She had some residual weakness in the left upper limb (Frankel D) which is improving.

Case 4 (WB) (Fig. 4). A 41-year-old woman was admitted the day of her injury following a road-traffic accident with a C5/C6 fracture subluxation, about 50% canal encroachment, and minimal somatosensory sparing. She improved to Frankel D/E on discharge, 81 days following her injury. She has some residual weakness in the left hand.

Post-mortem examination sometimes reveals a cord lesion extending proximally and distally for a variable number of segments beyond the cord lesion (Guttman 1973a; Kakulas and Bedbrook 1976). The value of localised decompression at the site of the canal encroachment in these patients remains to be determined.

Significance of the biomechanical instability of the cervical spine

The cervical spine is the most mobile and least stable of all spinal vertebral elements. The containment of this instability until healing occurs is unarguably essential for the preservation of neural tissue and the exploitation of the best potentials for recovery. The definition of biomechanical instability is under much debate however (Yashon 1986). We define instability as any potential movement at the site of the injury

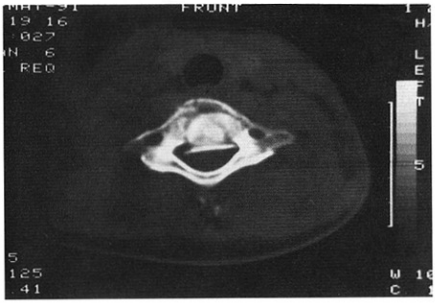


Fig. 2. C.T. of C7 showing 30% canal encroachment. Case 2 (HB).

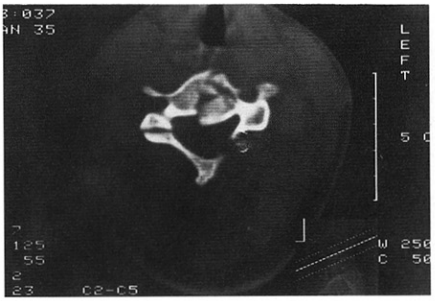


Fig. 3. C.T. of C4 showing left hemicanal encroachment with Brown-Séquard paralysis on the left. Case 3 (NB).

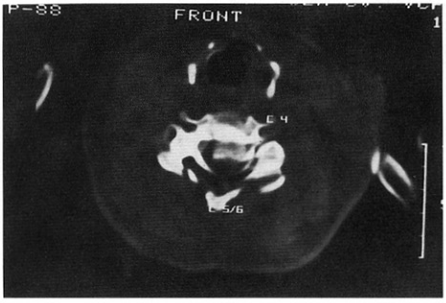


Fig. 4. C.T. of C5/C6 showing 50% canal encroachment. Case 4 (WB).

that could traumatise an intact cord or result in further cord damage, late pain, late myelopathy, or late functionally restricting deformity.

Accordingly, most injuries of the cervical spine are biomechanically unstable. This instability is time-related as most osseous injuries of the cervical spine will become stable at between 8 and 12 weeks following injury (Bedbrook 1971). Bone morphogenic protein (Urist et al. 1969) and other inducers of osteoblast activity may in the future shorten the time to osseous union (Mohan and Baylink 1991).

MANAGEMENT

In general the management of cervical spine injuries is usually undertaken in 3 stages. Following resuscitation the cervical spine is externally stabilised by the insertion of skull calipers and the application of 2–10 lbs of traction, according to the level of injury. Realignment is usually attempted once the patient's general condition becomes stable. A definitive treatment is then considered, planned, and executed. This consists of containment of the instability until healing occurs, with or without decompression.

Resuscitation

Impaired cardio-respiratory functions due to the loss of sympathetic reflexes and loss of motor power in the intercostal and abdominal muscles requires expert attention. Routine ventilation and intubation should be avoided and the procedures restricted to life-saving. In our experience with good chest physiotherapy, the majority of patients with intact C4 segments and above do not require intubation or ventilation. If necessary a minitracheotomy (Gupta et al. 1989) helps reduce the dead space and facilitates suction of bronchial secretions. Good oxygenation must be ensured. Intravenous fluid overload with which the patient is unable to cope due to the sympathetic areflexia should be avoided. Atropine may be necessary for the treatment of bradycardia and cardiac arrest. Dopamine should be used sparingly in view of its possible contributory effect on the pathogenesis of experimental cord injuries. Dopamine was found to be present in the injured cord and its role in pathogenesis was thought to be important (Hedeman et al. 1974; Naftchi et al. 1974; Bunegin et al. 1976; Salzman et al. 1987). This has, however, been disputed (De la Torre et al. 1974; Bingham et al. 1975b; Zivin et al. 1976).

High-dose methylprednisolone administered within 8 h of injury and continued for 24 h (Bracken et al. 1990) was found in a multicentre clinical trial to result in a statistically significant improvement in neurological outcome compared with opiate antagonists (naloxone) and placebo. GM-1 ganglioside in a placebo-controlled trial (Geisler et al. 1991) was considered efficacious and safe in treating spinal cord injury patients when administered within 48 h of injury and for a period of about 26 days. Harris et al. (1980) did not find diuretics beneficial. The efficacy of manipulation with these pharmacological agents and many others is still widely debated.

External stabilisation

The different types of skull calipers and their advantages and disadvantages are beyond the scope of this Chapter and we refer the reader to Grundy (1983). We prefer to use the cone calipers for their ease of insertion, their effectiveness during reduction of dislocation, their safety, and their ease of nursing management throughout the period of conservative management in recumbency (6 ± 2 weeks).

The halo ring is preferred by some when early mobilisation is planned with conservative management. Extension of the neck in recumbancy can only be achieved by the placement of pillows under the shoulders during the first few days of bed rest as the distance between the occiput and the ring would tend to otherwise result in cervical spine flexion. Extra care to avoid all unwarranted movement of the halo ring is necessary since any movement is likely to be transmitted to the cervical spine.

Realignment of the cervical spine

An angulatory deformity of the cervical spine frequently occurs with or without displacement, usually at the involved unit of motion. Flexion

deformities are by far the commonest and occur with flexion, rotation, compression, and distraction injuries. Hyperextension injuries rarely result in a marked angulatory deformity. Postural reduction at an early stage following injury will achieve realignment with 6–15 lbs of traction in angulatory deformities including facet subluxation (without over-riding of the facets). Unilateral and bilateral facet dislocations (with over-riding of the facets) are unlikely to realign without extra traction. Although unilateral and bilateral facet subluxations and dislocations are relatively uncommon, they present in about 25% of patients with cervical spine injuries admitted to our centre. Reduction of cervical subluxations and dislocations is advocated (Evans 1961; Yashon et al. 1975; Shrosbree 1979; Cotler et al. 1987; Star et al. 1990) in order to release cord and root compression and improve the neurological outcome. Frankel et al. (1969) found no correlation between the various degrees of reduction and the neurological outcome. This was confirmed by Dall (1972), Heiden et al. (1975), White et al. (1976), Maynard et al. (1979), and Harris et al. (1980).

Like all dislocations, reduction is desirable if it can be effected without further trauma to the spinal cord. In our experience it results in rapid pain relief which could otherwise take 5–7 days. Recovery of cord and root function at the level of the injury and in 1 or 2 segments below, in our experience, frequently occurs with or without reduction of cervical subluxation and dislocation. The various methods and techniques of reduction have been described by Hardy and Rossier (1975). There is still a great deal of controversy as to the best or most acceptable method. Closed reduction with incremental skull traction only remains the preferred initial treatment in many centres (Cotler et al. 1987; Rorabeck et al. 1987; Star et al. 1990).

Manipulative reduction under general anaesthesia is condemned as dangerous by some (Rogers 1942; Ellis 1946; Durbin 1957; Bailey 1961) while others have found it to be a safe and effective means of reduction in the acute stage (Evans 1961; Burke and Berryman 1971; Kleyn 1984; Osti et al. 1989). Evans (1983) highlighted the difficulties of closed reduction in the cervicothoracic junction. He advised against attempting the procedure in patients with complete lesions and suggested open reduction by an experienced surgeon for patients with incomplete lesions; it is better to leave the dislocation unreduced if the expertise of the surgeon and the circumstances are not ideal.

In our institution we undertake closed reduction without initial sedation or anaesthesia using cone calipers, with the cervical spine in 15° flexion supported by head pillows. The patient is placed in the supine position with a pillow under the shoulders to facilitate extension of the neck towards the final stage of the procedure.

Extension of the neck prior to distraction is likely to hinder reduction and may be hazardous because pivoting of the superior (dislocated) facet on the inferior one could further encroach on the canal. Neurological examination is carried out before and throughout the procedure. An initial loading of 6 lbs is followed by 2-lb increments every 4 minutes with serial lateral radiographs of the cervical spine with every 6–12-lb increment, depending on the degree of distraction achieved.

If reduction is not achieved with 30 lbs, 10–20 mg of intravenous diazepam are administered and the increments are continued for up to 45 lbs. If still unsuccessful, a gentle pull is applied on the calipers to bend the neck 30° laterally, away from the dislocated facet at which point the head is rotated towards the dislocated facet. A click is often heard and felt and the patient admits to sudden relief of pain. The neck is then maintained in slight extension by removal of the 2 head pillows and their replacement by a Sorbo pad. Reduction will be achieved in the majority of patients with this method (Popoola et al. 1991).

Closed reduction under general anaesthesia is attempted in patients with incomplete cord lesions if slow reduction fails, and is followed by surgical reduction and fusion if still unsuccessful, provided less than 48 h have elapsed since injury. In our experience, the longer the delay from injury, the more difficult and dangerous the procedure becomes. In 1 series 3 failures occurred when the reduction was attempted at 1–2 weeks from injury (Cotler et al. 1987). It is conceivable that

soft tissue inflammatory changes occur in the course of time in the vicinity of the injury and between and around the facets.

Difficulties are also encountered in the reduction and in its maintenance when the facets are fractured. The time interval between injury and the procedure, the age of the patient, and the presence of degenerative changes are in our experience factors relevant to the safety of cervical spine reduction.

It is interesting to note that in 1 series of 53 sequential cervical spine reductions (Star et al. 1990), only 2 patients had transient segmental deterioration at the zone of the injury when the median time interval from injury was 8 h for unilateral facet dislocations and 11 h for bilateral facet dislocations. In our opinion, the procedure should be performed by an experienced clinician as early as possible following injury and should not be attempted in elderly patients or in patients with degenerative changes of their cervical spine or when 48 h or more have elapsed from the time of the injury.

Management of the instability of the cervical spine

The rationale of management consists of the containment of the biomechanical instability until healing occurs. This can be achieved by conservative or surgical means. The conservative method consists of 6–12 weeks of bed rest with 2–6 lbs of skull traction during which the rehabilitation of the multisystem deficit, the psychosocial rehabilitation of the patient and his relatives, and plans for resettlement are provided simultaneously. For the types of skull calipers and their complications see Grundy (1983). An alternative method of conservative treatment is by early mobilisation of the patient in a cervical orthosis. For guide to their selection and use see Johnson et al. (1977, 1981). The advocates of the halo-thoracic brace suggest that with care they have relatively few problems (Chan et al. 1983; Tator et al. 1982; Parry et al. 1988). Cooper et al. (1979) suggested that the halo-thoracic brace is contraindicated in patients with complete lesions. Complications with redisplacement are reported in all series. Complications with pin-site infections and loosening as well as scarring have been recorded by Garfin et al. (1986).

The success of the halo-thoracic vest depends on its ability to maintain distraction against gravity and impact compressive loads (Levine and Edwards 1986b). With careful application and maintenance in the neurologically intact or slightly impaired patient with vertebral body compression or comminution, the halo vest may be as good in maintaining stability as traction in recumbency. Distraction injuries and rotational injuries with facet fractures can, however, be accentuated by axial (halo) traction (Levine and Edwards 1986b). This has also been our experience.

We have compared the halo-thoracic vest with the Minerva POP (Pringle 1990) and found that the halo vest appears more effective in immobilising injuries above the level of C2, but that the Minerva is safer and more comfortable, more free of complications, and more reliable for injuries below that level (Pringle 1990). In another comparative study, Benzel et al. (1989) found that 'snaking', a serpentine movement of the cervical spine whereby a simple movement such as flexion or extension is accompanied by an unexpected combination of flexion and extension movements at each intervertebral level (Johnson et al. 1981), occurs more often in the halo-thoracic vest than in the thermal plastic Minerva body jacket.

Spinal fusion should be considered as a procedure that ultimately leads to stability but that does not complete immediate post-operative stability (Green and Magana 1987).

In our institute most injuries at all levels in the cervical spine are treated with 6 weeks of bed rest and skull traction followed by 6 weeks in a cervical orthosis. A Minerva will be used for neurologically intact patients and a Philadelphia collar for neurologically impaired patients.

MANAGEMENT OF SPECIFIC INJURIES OF THE CERVICAL SPINE

Odontoid fractures

These fractures are managed successfully by a variety of conservative techniques (Amyes and

Anderson 1956; Nachemson 1960). They are still managed conservatively in our institute. Alternatively, a posterior gallie fusion procedure is successful, though rarely in the acute stage (Clark and White 1985). The most dramatic recent changes have been with anterior screw fixation and with posterior plate fixation. Some surgeons advocate internal fixation of type 2 odontoid fractures. This is a very controversial approach but on occasions it has to be entertained. Anterior screw fixation is associated with a steep learning curve and should be entertained by few surgeons (Aebi et al. 1989; Jeanneret et al. 1991b). The procedure will be made easier as plain image intensification improves and the resolution of the image is clarified. The fracture line is not seen as the guide wires cross it. Two guide wires should be used if possible to prevent rotation. Cannulated screws that are inserted over the guide wires must be a good idea. Two screws are better than 1 and, just as in screw fixation elsewhere, the threaded portion of the screw must not occupy the fractures but only the distal fragment to allow compression.

An alternative preferred by Magrel and Seeman (1987) is posterior plating of C1/C2. The screws are inserted in the lateral masses but the surgeon has to be aware of the difference in screw placement in C1 compared to the other vertebra.

Non-unions can be treated by compressive screw fixation (Böhler 1982). Another recent approach to non-unions and malunions with cervical myelopathy is transoral resection of the odontoid together with a simultaneous posterior fusion.

In our experience, odontoid fractures cause unnecessary anxiety. The most recent advances are technically demanding and controversial. They should be entertained only by experienced surgeons and with appropriate indication. The surgeon who is isolated can find comfort that conservative techniques will keep his patient alive.

C1 fractures

These fractures should still be treated conservatively despite the discovery with modern scanning that they are often more complex than first thought (Levine and Edwards 1986a,b). Their comminution defies direct repair so that fixation must include the skull, should fracture demand stabilisation. Plating of the skull to below C2 is an option which demands constant practise of plating into the lateral masses. An easier option involves closed loops with sublaminar fixation. Fixation to the skull is best reserved for C1 lesions caused by e.g. rheumatoid arthritis (Crockard et al. 1986; Grob et al. 1991).

Hangman's fracture

This is a fracture through the junction of the pedicles with the vertebral body of C2. On its own, this fracture is innocent and is very easily managed by conservative techniques (Fielding et al. 1989). Internal fixation may be indicated in patients who are difficult to control.

There are 2 approaches and methods to consider: (a) Anterior plating of C2/C3 is an effective treatment. Access is made easier through a high retrophalangeal approach. (b) Posterior plating of C2/C3 is also an option (Roy-Camille). Wiring the posterior elements is even simpler and biomechanically it is just as effective as plating, with none of the associated technical risks (Levine and Edwards 1985).

Lower cervical injuries

The majority of these fractures become stable in the course of 8–12 weeks. Surgical stabilisation should, however, be considered in patients who are not compliant with conservative management. Late instability (a term we do not readily agree with) is seen in many, though by no means all, primary ligamentous injuries usually with bilateral facet subluxation or dislocation with or without anterior wedging. Conservative management is unlikely to result in permanent containment of this instability, hence, we would prefer the term 'conservatively uncontainable instability', since the late deformity that occurs is related to an instability present from the time of injury. This instability can usually be predicted from the distance between the interspinous processes and from the abnormal or lesser degree of overlap between the facets at the level of the injury. The

Oswestry or Sheffield oblique views of the cervical spine indicate the degree and the site of the subluxation or the dislocation (Lodge and Higginbottom 1966; McCall et al. 1973; Higginbottom 1982). Traditionally unstable injuries of the cervical spine have been managed with great success by simple wiring. The results of such techniques will be hard to beat. Montesano et al. (1991) and Sutterlin et al. (1988) suggested that wiring is almost as good as plating but with a fraction of the technical difficulty or risk.

An alternative is the use of posterior plates; if the surgeon is comfortable with this approach then it is a satisfactory method of treatment. Hookplates are another means of securing a strong fixation posteriorly. They are stronger than wiring but technically more demanding (Jeanneret et al. 1991a). In the presence of laminar fractures, posterior plating offers the opportunity of adequate internal fixation, bypassing the fractures if necessary (Nazarian and Louis 1991; Anderson et al. 1991). Laminar hooks are a fiddle but may have a role in facet dislocations. Sublaminar wiring is an option to obtain biomechanical stability. There is an associated risk, however, of neurological deterioration (Sutterlin et al. 1988). Posterior plating using screws in the lateral masses (Roy-Camille et al. 1989) can be used in these cases as an alternative.

Anterior decompression is seldom required in distraction injuries and posterior ligamentous disruption. Anterior decompression alone in these injuries is likely to result in further destabilisation of the cervical spine and should be accompanied by either an anterior or posterior stabilising procedure. Should decompression be deemed necessary because of an uncontainable associated instability in a noncompliant patient with a burst fracture or rarely because of gradual neurological deterioration in an incomplete tetraplegic patient, the anterior approach provides not only a satisfactory means of decompression for the majority of patients, but also a chance to surgically stabilise the cervical spine.

Biomechanical studies have suggested that on occasion both approaches may be used (Ulrich et al. 1991). There is little to choose between the various devices but the Caspar device is well-designed and offers the chance of distraction before plating (Caspar 1984). In all the plating devices, the strength of fixation is enormously enhanced by engagement of the posterior cortex of the vertebral body. A clear image intensifier picture is therefore mandatory. To improve the fixation by additional posterior fixation is rarely justified (Aebi et al. 1991).

Decompression by laminectomy is unlikely to be of benefit when the compressive elements are from the vertebral bodies. Reduction of the spinal cord blood flow during the procedure has been reported in the experimental animal (Anderson and Means 1985). Neurological deterioration is known to occur following the procedure in man (Morgan et al. 1971; Bohlman 1979). Further biomechanical destabilisation of the cervical spine is likely to occur and a stabilising procedure should be considered following laminectomy.

MOBILISATION AND REHABILITATION

Often the terms mobilisation and rehabilitation are confused. Early mobilisation is likely to be an advantage to a neurologically intact patient with a cervical spinal injury and no cord involvement. To a neurologically impaired patient early mobilisation is a passive process. Rehabilitation, however, is an active process that requires energy, inner motivation, ability to balance, flexibility of the spine, and a psychological readiness to attend to personal care, hygiene, and activities of daily living within the limitations of the neurological disability. During the stage of sympathetic areflexia, the patient is at a higher risk of developing postural hypotension. This can occur despite the use of abdominal binders and elastic stockings. The vital capacity of tetraplegic patients is known to be further reduced in the sitting position (Cameron et al. 1955; Morgan et al. 1986), probably due to diminished excursion of the diaphragm. This is likely to improve with the use of abdominal binders and elastic stockings until the return of tone in the abdominal muscles. The combination of postural hypotension and reduced vital capacity are likely to negate the theoretical advantages of early mobilisation and the early commencement of rehabilitation.

In our institute, prior to mobilisation of the patient (at 6 weeks), we have found it necessary to conduct tilt-table studies with simultaneous neurological examination and measurement of blood pressure during different degrees of 'head-up' tilting. This is particularly important in patients with incomplete cord injury, some of whom develop further neurological loss associated with a drop in blood pressure during tilting and recover immediately with return to the horizontal position.

A critical review of the literature would suggest that the total hospitalisation time is unrelated to the timing of mobilisation, the commencement of rehabilitation, or the method of management of the cervical spine injury (conservative or surgical), when the patient is treated by an expert multidisciplinary team. In 1 retrospective series of 106 consecutive patients with cervical cord injuries, 49% of the patients were operated (Wilmot and Hall 1986). No difference was found in the total length of hospitalisation time between the surgical and nonsurgical groups. There was, however, a significantly longer hospitalisation time in patients who were operated prior to admission to the centre. In a prospective study of 208 patients of whom 127 patients had cervical injuries between C1 and D1 (Tator et al. 1987) with surgical procedures performed on approximately 45% of patients, the only parameter found to be significant to the length of stay was the severity of the cord injury. In a third, retrospective, series of 102 consecutive patients with cervical cord injury (Murphy et al. 1990), a comparison was made between the outcome of conservative management, surgical fusion within 2 weeks of injury, and surgical fusion after 2 weeks of injury in patients with unstable cervical injuries using the criteria of White et al. (1976). The mean hospital stay was 21 days less in the group of patients surgically stabilised within 2 weeks of injury (168.6 days) when compared with those treated conservatively (189.4 days). Late fusion resulted in longer hospitalisation than the latter group (mean 197.1 days). There were, however, 12 patients who were respiratory-dependent on admission whose management is not described.

We calculated the total hospitalisation time (between injury and discharge) in 91 patients with cervical spinal injuries out of a series of 112 consecutive admissions. We excluded 21 patients, 9 died (7 were over 60 years of age), 6 were referred to spinal injuries units closer to home following stabilisation of their general condition, 3 were admitted over 120 days following treatment elsewhere, 2 had double injuries and no neurological deficit to the cervical cord or roots, and 1 was neurologically intact and wished to be treated closer to home. Eight patients underwent posterior fusion and 1 patient anterior decompression and fusion. The other 82 patients were treated conservatively.

All patients were discharged following completion of the rehabilitation (74 to their own home following completion of house adaptations, 15 to a halfway house, 2 to the referring hospital, and 1 to a nursing home). The mean total hospitalisation time for all 91 patients was 122 days. By excluding the hospitalisation time of the 27 patients who were admitted with intact neurology, the mean total hospitalisation time of patients admitted with cervical cord injuries in our institution was 159 days. The mean total hospitalisation time of patients presenting in the different Frankel groups is shown in Table 1.

The actual time between injury and completion of rehabilitation is, if anything, even shorter than the total hospitalisation time which would have been further reduced if difficulties were not encountered in resettling the patients in the community. We agree with Bedbrook and Sakae (1982) that the time in hospital reflects multiple and individual factors in each patient and cannot be related to such a single factor as the method of care of the spinal injury. In our experience the density of the cord lesion, the rehabilitation of the multisystem deficit, and the resettlement process of the patient in the community are the main determinants of the total hospitalisation time and are not affected by any particular method of management to the cervical spinal injury.

NEUROLOGICAL OUTCOME

The complexity in the evaluation of the neurological outcome with whatever method of manage-

TABLE I
Total hospitalization time.

	Mean (days)	Range	S.D.	S.E.
Frankel A	205	(97–268)	42.38	9.48
Frankel B	198.91	(125–256)	40.75	12.29
Frankel C	137.957	(41–347)	66.62	13.89
Frankel D	63.78	(3–117)	33.96	11.32
Frankel E	35.04	(3–84)	17.60	3.86

'Complete' (A). This means that the lesion was found to be complete, both motor and sensory.
'Sensory only' (B). This implies that there was some sensation present below the level of the lesion, but that the motor paralysis was complete below that level.
'Motor useless' (C). This implies that there was some motor power present below the lesion, but it was of no practical use to the patient.
'Motor useful' (D). This implies that there was useful motor power below the level of the lesion. Patients in this group could move the lower limbs and many could walk, with or without aids.
'Recovery' (E). This implies that the patient was free of neurological symptoms, i.e. no weakness, no sensory loss, no sphincter disturbance. Abnormal reflexes may have been present.

ment of the injury cannot be underestimated. Collins (1983) highlighted some of these difficulties. Comparison is often made between centres with different admission policies, different methods of management, different infrastructure of rehabilitation services, and possibly different expectations from their patients. Most studies comparing medical versus surgical neurological outcome are done retrospectively. Despite these difficulties a critical review of the literature (Frankel et al. 1973a,b; Paeslack et al. 1973; Heiden et al. 1975; Young and Dexter 1978; Maynard et al. 1979; Philippi et al. 1980; Bedbrook and Sakae 1982) including the review of our material would confirm the findings by Frankel et al. (1969) that neurological improvement does occur in all groups of patients with different densities of cord lesion and that the better the initial degree of sparing the better the neurological outcome is likely to be. Table 2 shows this trend in 6 studies. The arguments about the interpretation of degree and distribution of recovery in patients presenting with complete lesions (Maynard et al. 1979) will only be solved when a uniform timing of and method of assessment are adopted. Furthermore, despite many attempts at fine tuning the prognostic indicators (Folman and El Masri 1989; Crozier et al. 1991), the temporal course of the recovery is not documented and the final outcome cannot be predicted with great certainty. The very dynamic nature of the neurological progress without this information being available makes comparison between various methods of treatment rather difficult.

Retrospective evaluation of the effect of different surgical procedures and comparison of neurological outcome with conservative management within centres (Harris et al. 1980; Wilmot and Hall 1986; Murphy et al. 1990) and between centres (Philippi et al. 1980) did not suggest better neurological outcome with surgical fusion or laminectomy over the natural history. The only prospective study we could find comparing surgical and conservative management in a relatively large number of patients with cervical injuries (127) and including anterior decompression, though in an undetermined number in this region of the spine, was that of Tator et al. (1987). They concluded that there was no difference between the operated and the non-operated groups of patients with regard to neurological recovery.

Heiden et al. (1975) compared the outcome of fusion and decompression (anterior and laminectomy) with conservative management of 356 patients with all degrees of cervical cord lesions. They also compared early surgery (less than 48 h from injury) with late surgery (more than 48 h from injury). They found no difference in neurological outcome. They concluded, however, that surgery within the first week of injury in patients with complete cervical cord lesions was associated with unacceptable morbidity. In another study

TABLE 2
Various studies confirming the natural history of neurological improvement and the rarity of significant spontaneous neurological deterioration.

	A	B	C	D	E
A	81	21	10	11	0
B	3	9	2	14	15
C	0	1	4	11	5
D	0	0	0	30	11
E	0	0	0	0	0

Stoke Mandeville (1969)
(n = 218)
No surgery.

	A	B	C	D	E
A	25	10	3	1	0
B	0	0	4	7	0
C	0	1	2	15	5
D	0	1	0	7	48
E	0	0	0	0	8

Royal Perth (1982)
(Rehabilitation Hospital)
(n = 144)
10% decompression and fusion.

	A	B	C	D	E
A	41	6	1	1	0
B	0	4	2	10	0
C	0	0	2	3	0
D	1	0	0	14	6
E	1	0	0	3	0

South West Region (1978)
(n = 95)
10% laminectomy; 27% fusion.

	A	B	C	D	E
A	50	4	3	4	1
B	0	3	2	13	0
C	0	0	2	17	4
D	0	0	0	4	7
E	0	0	0	0	0

Santa Clara Centre,
California (1979)
(n = 114/123)
51 patients early surgery (during first 4 weeks post injury) both laminectomy and anterior fusion; 10 patients late surgery (longer than 4 weeks post injury); 57 patients conservative.

	A	B	C	D	E
A	26	14	4	3	1
B	0	1	4	11	4
C	0	0	1	24	4
D	0	0	0	2	9
E	0	0	0	0	0

Colmar-Mulhouse
and Basle (1980)
(n = 108)
9% surgical treatment.

	A	B	C	D	E
A	14	4	1	1	0
B	0	1	6	4	0
C	0	1	5	17	0
D	*1	0	0	4	5
E	0	0	0	1	26

Midland Centre for Spinal
Injuries (Oswestry, personal
communication)
(n = 91)
8 patients posterior fusion; 1 patient anterior decompression and fusion.
* Deteriorated following reduction of bilateral dislocation.

(Wagner and Chehrazi 1982) no significant difference in the percent of recovery was noted when decompression was carried out early (up to 8 h) or late (9–48 h after injury).

The value of early surgical decompression in patients with cervical cord injuries is yet to be established. The value of late decompression (Bohlman and Freehafer 1975; Anderson et al. 1986) in patients with incomplete cervical cord injuries who usually continue to improve up to 18 months and sometimes longer following injury requires further prospective study.

Remodelling of the spinal canal is known to occur in the thoracolumbar spine (Fidler 1988). Remodelling in the cervical spinal canal has not yet been reported.

It would be wise during the decision-making in the choice of management to remember the 8 maxims of White (1989).

Maxim 1. Do the least amount of surgery that is necessary to solve the patient's problem(s).

Maxim 2. Each additional risk to the patient must be justified by substantial evidence of incremental benefit for the patient.

Maxim 3. As much as possible, measure intraoperative treatment forces, distances, and results.

Maxim 4. Beware the 'human' inclination to choose an operation because it is 'fashionable'

Maxim 5. Beware the 'macho' propensity to choose an operation because it is difficult.

Maxim 6. With the use of excessive force in surgery, the surgeon is having, about to have, or at risk of having a complication or complications.

Maxim 7. The best surgeons carefully plan their operations and frequently review the anatomy.

Maxim 8. Stick to your preoperative plans and contingencies; improvision is generally best saved for the anatomy laboratory.

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