Timing of Decompression and Fixation After Spinal Cord Injury – When is Surgery Optimal?

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ABSTRACT

Spinal cord injury affects a large number of young individuals with a significant cost to affected persons, families and societies both in terms of economic and non-economic costs. To date, our interventions have been limited to prevention, good initial resuscitation, modest pharmacotherapy and nursing care. This review examines the role of surgery in spinal cord injury. The pathophysiology of spinal cord injury is reviewed. The compelling animal data for early decompression is discussed as well as evidence for improved neurological outcome with early decompression in humans. Finally, the impact of early surgery on non-neurological outcome and overall complication rates is examined with the concept of "damage control" discussed with relevance to spinal cord injury. It appears that favourable outcomes are achieved with early surgery, with reduced morbidity/mortality, but definitive data is still pending. (**Critical Care and Resuscitation 2006; 8: 56-63**)

Key words: Spinal cord injury; timing; surgery; fixation; decompression

In Australia, new cases of spinal cord injury (SCI) occur with an incidence of approximately 12 per million population annually, added to an estimated prevalent population of 10 000 people living with SCI nationally.[1,2] SCI imparts a reduced life expectancy and a significant burden of disease to the injured, in proportion to the severity of injury.[3] The estimated annual cost of SCI is between \$80 000 and \$120 000 per case.[4]

Mounting evidence suggests that surgical decompression and fixation may improve neurological outcome with consequent increased functional status. Improved organisation of acute trauma systems and rehabilitation services has allowed evaluation of whether early fixation leads to improvement in the medical management of acute SCI. Furthermore, it has been proposed that surgery may help prevent the delayed complications of spinal trauma. Unlike head trauma, the emergent management of spinal injury remains a controversial management decision point. Yet with so few potential interventions available, early surgery may facilitate a better neurological recovery, with reduced complications.

Pathophysiology of spinal cord injury

Neural damage after SCI involves both primary and secondary mechanisms. The primary mechanism is the initial mechanical injury due to local deformation and energy transformation from acute compressive, lacerating, distracting or shear forces. Secondary mechanisms, as first proposed by Allen in 1911,[5] encompass a cascade of biochemical and cellular processes that are initiated by the primary process and may cause ongoing cellular damage and even cell death. These include vascular changes, ionic derangements, neurotransmitter accumulations, free radical production and lipid peroxidation, endogenous opioid effects, oedema, inflamm-

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ation, ATP depletion and apoptosis (see figures 1 and 2). Secondary injury can also conceivably arise from poorly immobilised unstable injuries which cause a further mechanical injury with further displacement.[6] Secondary injuries can in some cases cause more damage than the primary injury such that even with a potentially devastating initial injury, a considerable reduction of secondary injury mechanisms can lead to improved neurological function.

Post-mortem studies have calculated the degree of anatomic continuity in patients with both clinically complete and incomplete injuries.[7] There is greater continuity in some cases of complete spinal cord injury than in patients with preserved neurological function.

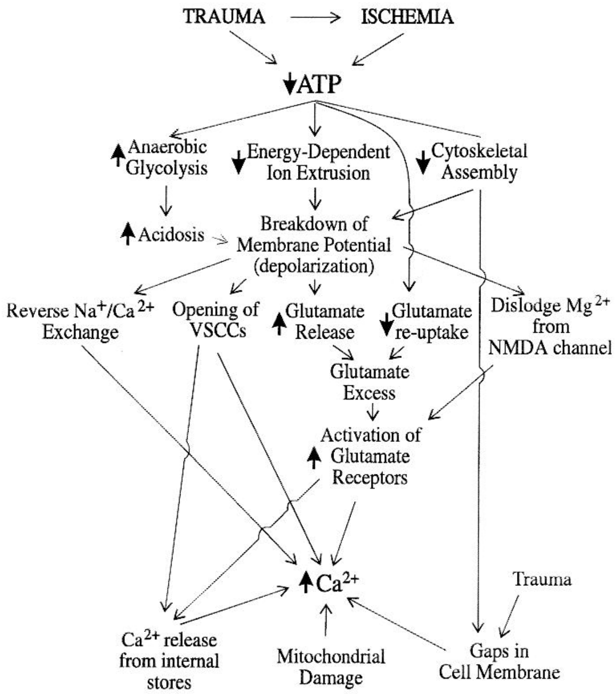

Figure 1. Mechanisms by which trauma and ischemia produce intracellular Ca^{2+} elevations. VSCC = voltage-sensitive Ca^{2+} channel (reprinted with permission).[45]

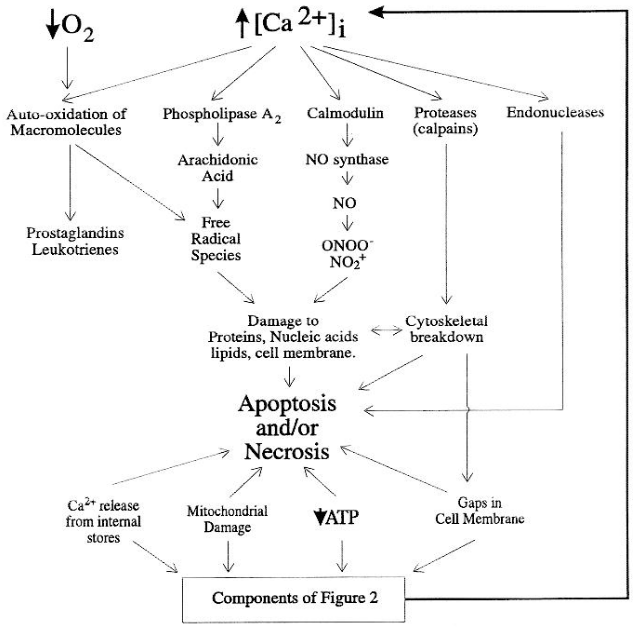

Figure 2. Mechanisms by which intracellular Ca^{2+} elevations trigger secondary Ca^{2+}-dependent phenomena, which result in neurotoxicity (reprinted with permission).[45]

The lack of correlation between preserved white matter and outcome suggests that other, potentially modifiable, factors may be involved that affect the quality of neural tissue.

Early trauma management protocols reinforce the importance of oxygenation, perfusion and immobilisation in management of spinal injuries. The emerging understanding of secondary mechanisms has spurred an interest in pharmacological adjuncts such as methylprednisolone.

The NASCIS II study demonstrated a modest beneficial effect of high-dose methylprednisolone if given within 8 hours of injury in patients with complete and incomplete spinal cord injuries.[8] The NASCIS III study suggested a trend to better outcomes if treatment commenced within 3 hours rather than 3 - 8 hours after trauma.[9] The trade off for this modest improvement was higher rates of infective and stress ulceration complications. Nevertheless, these findings suggest that a time window may exist for the prevention of secondary injury. Irrespective of possible pharmacological intervention, the mainstay of the traditional management of acute SCI has had as its cornerstone adequate resuscitation and good nursing/pulmonary care with surgery playing an important but delayed role.

Nonoperative management of spinal cord injury

Non-operative management of spinal injuries was championed by Sir Ludwig Guttman in the 1940s at the Stoke Mandeville Hospital in England. He advocated the use of postural techniques combined with bed rest to achieve reduction and spontaneous fusion of the spine.[10] At that time, surgical management consisted of laminectomy and surgical results were often worse than conservative management. It is now accepted that laminectomy is an ineffective management because it fails to adequately address the compression, may exacerbate injury and does not address potential instability. Using this framework, Frankel *et al*,[11] reported the results of conservative management of 612 patients with spinal injuries. While the details of the cohort's injuries and treatments are minimal, only 4 patients required surgical fusion for instability. Of the patients with complete motor and sensory injuries below the injury level, 29 % improved at least one grade.

Surgery for improving neurological outcome after spinal cord injury

1. Goals and rationale of surgery

Surgical intervention for SCI aims to decompress, realign and stabilise (see figure 3). The surgery is for the most part not on the actual spinal cord but rather the bony and ligamentous structures surrounding the cord. Cord compression is alleviated and potential cord injury is prevented. In addition to the immediate benefits of decompression and possible reduction in the magnitude and impact of secondary injury mechanisms, surgery may also prevent the morbidity associated with deformity and inadequate decompression, namely chronic pain, syringomyelia and spinal cord tethering.

2. Animal studies

Laboratory studies using a number of different animal models have provided persuasive evidence that decompression of the spinal cord is an effective method of limiting the extent of secondary injury. In a wide range of species, varying techniques have produced results that support the hypothesis that the severity of SCI is related to the force and duration of compression and that decompression of the spinal cord limits secondary injury,[12-26] Using a technique that combined a weight drop model to simulate an acute injury, followed by an epidural spacer to simulate ongoing compression, Dimar *et al*,[13] studied histological, electrophysiological and clinical outcome in rats. A worse outcome correlated with duration and degree of compression. When compression alone was compared to injury and compression, it was shown that an acutely injured cord demonstrated a reduced tolerance for spinal canal narrowing. Carlson *et al*,[14] reported similar results in a canine model, using histological, electrophysiological and clinical parameters to evaluate the effect of decompression after an injury that used a piston to create an injury followed by a varying length of compression. Early decompression led to better functional outcomes and smaller lesion volume. Despite the compelling animal data, the leap to effect similar gains in humans with SCI has been difficult

3. Controlled clinical studies

Review of the literature reveals nine prospective studies and one meta-analysis examining the effect of early surgical decompression on neurological outcome. The only randomised trial reported to date was described by Vaccarro *et al*.[27] Sixty four patients were randomised to undergo early surgery within 72 hours or late surgery after 5 days. Comparison of the two groups showed no significant difference in improvement of either American Spinal Injury Association (ASIA) grade or motor score. Several criticisms have been directed at these results including the large number of patients lost to follow-up and the liberal definition of early surgery up to 72 hours. The time window for prevention of secondary injury may be much shorter, as evidenced by the methylprednisolone trials.

In a secondary analysis of data from the NASCIS II database, Duh *et al*,[28] examined whether the timing of

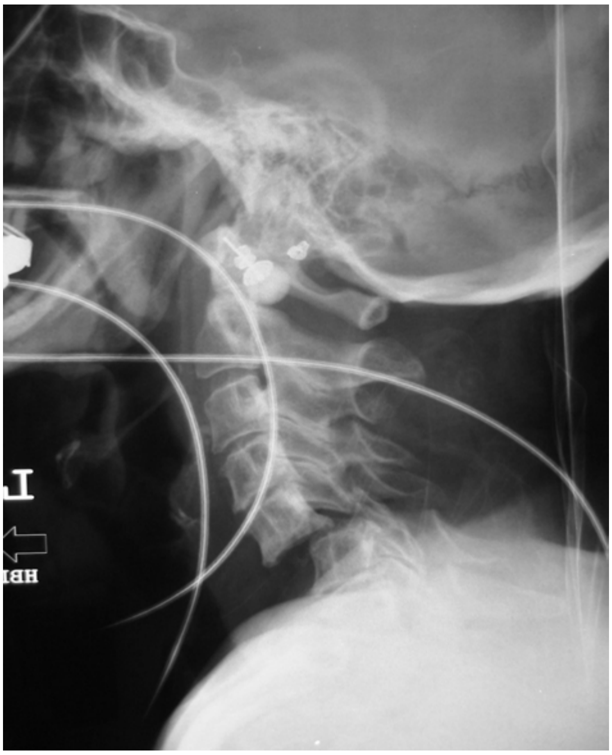

Figure 3 (a). A lateral neck x-ray of a 65 year old woman who had a fall and initially suffered a complete C7 quadriplegia. She was given intravenous methylprednisolone within 2 hours of the injury and haemodynamically resuscitated with immediate recovery of some lower limb function. Initial lateral c-spine x-ray showed bilateral jumped facets at the C5-6 level with approximately 60% subluxation. She was placed into skull traction and with fluoroscopic and neurological surveillance was almost completely reduced with 10 kg of weight.

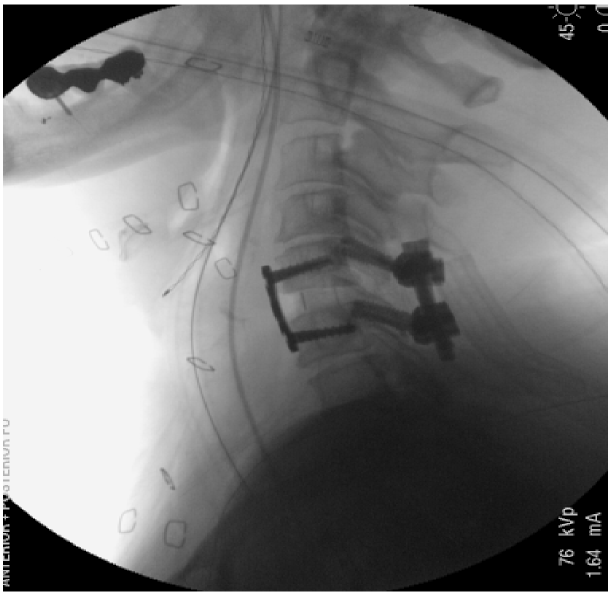

Figure 3 (b). Within 24 hours of admission she underwent a combined posterior/anterior decompression and stabilisation.

Figure 3 (c). The patient with MR scanning performed 72 hours after surgery confirming complete reduction and decompression of the spinal cord. Within 1 week of the injury the patient had completely recovered leg and sphincter function with only slight weakness in her hands and was transferred to rehabilitation. She is expected to make a near total recovery.

surgery affected outcome, independent of drug treatment. While the study was non-randomised and the analysis post-hoc, there was a non-significant trend towards better outcomes in patients operated earlier than 25 hours and more than 200 hours after injury compared with non-operative management.

Another secondary analysis of 600 patients from a GM-1 ganglioside trial who received surgical decompression was presented by Geisler *et al*.[29] Patients were divided into 5 categories by timing of surgery. There was a trend towards better outcomes in patients operated within 24 hours of injury. This finding reached statistical significance in cervical injuries. These results may be confounded by a significant correlation between ASIA grade and timing to operation, with Abbreviated Injury Scale-B (AIS-B) injuries more likely to be operated earlier.

Papadopoulos *et al*,[30] reported on a series of 66 patients managed with a protocol of early decompression by traction and surgery compared to 25 contemporaneous patients managed conservatively. Fifty percent of the protocol patients, compared with only 24% of reference patients, improved from their Frankel grade at admission. Eight protocol patients (12%), but no reference patients, improved from complete motor quadriplegia to independent ambulation.

Vale *et al*,[31] described one unit's experience in the management of 35 cervical and 29 thoracic spinal injuries, of which 58 underwent surgical management. When patients were stratified according to the timing of surgery, no correlation with neurological recovery was seen.

Chen *et al*,[32] evaluated the results of surgery in 16 of 37 patients with pre-existing cervical spondylosis of the spine, in whom an incomplete spinal cord syndrome developed after a minor neck injury. While improvement was seen in both groups, there was a statistically significant difference between the surgical and non-surgical patients at 1-month and 6-month follow-ups.

A recent meta-analysis has attempted to synthesise these data into a meaningful conclusion.[33] A literature search yielded 1687 cases and analysis of pooled data found that early decompression (< 24 hours) resulted in a statistically better outcome compared with both conservative and late management (> 24 hours). Analysis of heterogeneity suggested that only the patients with incomplete cord injuries were a homogenous group and that the validity of the analysis in other subgroups was unreliable. However, these findings provide further support for the notion that early decompression surgery may improve neurological outcome in patients with acute spinal cord injuries.

The Spine Trauma Study Group (STSG) is an international group of approximately 50 neurosurgical and orthopaedic spine surgeons from 13 different countries who are dedicated to advancing spine trauma care through multi-centre analysis and research related to spine trauma and SCI. Of particular interest is the STASCIS (Surgical Trial in Acute Spinal Cord Injury Study) project, an undertaking supported by the Joint Section of Neurotrauma and Critical Care and the Joint Section of Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons. STASCIS is an ongoing prospective observation study looking at the impact of timing on recovery of neurological recovery after SCI. Early results are showing trends towards improved outcomes with earlier intervention (unpublished data) but the study is not yet complete.

Surgery for improving non-neurological outcome after spinal cord injury

A body of information now supports the view that early spinal fixation in traumatic spinal injuries shortens the length of both intensive care and hospital admissions.[30,32,34-38] There is also evidence that the incidence of medical complications is lower, or at least no greater, with early surgical treatment.[34,36,37,39,40] Earlier mobilisation and better pulmonary care can be effected, along with a potential reduction in the psychological implications of prolonged recumbency. Earlier mobilisation may also translate to a lower incidence of thromboembolism as well as reducing the overall cost of the initial SCI with reduced intensive care time. Theoretical advantages in decreasing the delayed complications of spinal injury, such as delayed deformity and syringomyelia, have also been proposed by advocates of early surgery.

Resource utilisation, medical complications and delayed sequelae

In the study by Papadopoulos *et al*,[30] discussed previously, protocol patients who received early surgery spent a significantly shorter time in intensive care and had shorter overall admissions. The surgical group in Chen *et al*'s,[32] study of incomplete traumatic spinal cord injuries had shorter acute hospital and rehabilitation length of stay compared with those managed non-surgically.

A large series reported by Croce *et al*,[34] examined non-neurological parameters in 291 surgically managed spinal injury patients. It was found that early fixation was associated with a lower incidence of pneumonia, a shorter intensive care unit stay, fewer ventilator days, and lower hospital charges. A similar study by Kerwin *et al*,[35] found shorter overall hospital length of stay with early surgical treatment but no difference in the length of intensive care unit admissions, ventilator days or pneumonia incidence except in patients with thoracic injuries. Both these studies noted higher mortality in patients with higher injury severity scores (ISS > 25) and Kerwin *et al*,[35] warned against arbitrary universal time frames for surgery, advocating rather that timing decisions should be individualised to ensure that patients are appropriately resuscitated, and their medical condition is optimised.

A cohort of 26 patients with spinal injuries and an ISS greater than 26 were prospectively evaluated by McLain and Benson.[39] All patients were operated on within 72 hours and results were analysed based on whether patients received urgent (< 24 hours) or early (24-72 hours) surgical treatment. There were no differences in the rate of perioperative complications, morbidity, or mortality between the two groups.

Mirza *et al*,[36] compared patients with cervical spinal injuries treated at two different institutions. One centre had a policy of early (< 72 hours) surgery, whereas the other's protocol involved immediate closed reduction followed by observation before delayed surgery. Early surgery was not associated with a higher complication rate and involved a shorter duration of acute care stay.

This trend towards early surgical intervention in order to stabilise a patient's condition to facilitate recovery and rehabilitation has been incorporated into a 'damage control' concept. Kossmann *et al*,[41] advocates a post-resuscitation, simple stabilisation or external fixation procedure as an initial stage followed by a complex reconstruction and definitive stabilisation operation in a delayed fashion when the patient is physiological stable and experienced staff available. Such simple procedures would include anterior cervical decompression and stabilisation or possible posterior short-segment stabilisation with definitive decompression and ultimate stabilisation delayed 5 - 15 days. Again, further analysis is required to definitively state whether or not early surgery will translate to lower complications and reduced non-neurological morbidity.

Arachnoid scarring and non-anatomic fracture healing can lead to delayed complications after spinal injury. One of the common post-traumatic sequelae seen in spinal injuries is the development of an abnormal fluid filled cavity in the spinal cord, syringomyelia.[42] This may manifest some time after the initial injury as a progressive symptomatic deterioration. It is widely acknowledged that post-traumatic syringomyelia remains difficult to manage. It has been suggested that the development of syringes is related to the presence of uncorrected kyphosis or persistent spinal stenosis.[43,44] It has been proposed that early surgery may also prevent this serious delayed complication of spinal cord injury.[45] Delayed decompression of the spinal cord may lead to reduction in the size of a syrinx.

CONCLUSIONS

Spinal cord injury has devastating impacts on individuals affected, relatives and society at large. Aside from prevention, our management tools have been limited to good initial resuscitation, modest pharmacotherapy and good nursing care. It is emerging that surgical intervention may play an increasingly important role both in its presence and its timing with respect to improving the morbidity and mortality of spinal cord injury. Groups such as the STSG are striving to define the exact indications, rationale and timing of surgical intervention however, more and more it appears that earlier interventions will be associated with improved outcomes for patients. Time will tell.

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