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Early Management after Acute Traumatic Spinal Cord Injury

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INTRODUCTION

Trauma to the spine and spinal cord may result in neurological lesions. In mild cases the symptoms may be only transient, but severe trauma may reslut in permanent and complete disability, including tetra- or paraplegia, sensory deficits and autonomic dysfunction (1). Kraus (2) found that the reported incidence of spinal cord injury (SCI) ranged from 12.7 to 50 per million population per year. The incidence in Sweden is approximately 15 per million population per year. Young people are frequently afflicted. Eighty per cent of the injured patients are younger than 40 years of age and 50% are between 15 and 25 years old (2). The typical patient is a young male who has sustained the injury in a motor vehicle accident. During 1981, 50% of all deaths resulting from injury in the United States were caused by trauma to the central nervous system. Among these victims, 10%, or 3.3 per 100,000, died as a result of spinal cord injury (3).

The impression that the neurological deterioration after spinal cord trauma is primary and definitive has led to a conservative and nihilistic attitude towards the immediate treatment of these patients. However, there are clinical indications that the damage develops over time, and that part of the injured cord has the ability to recover. Among patients

with initial paraplegia and complete loss of motor and sensory function, 7% regained part of their lost function within a year, while among those presenting with a reduction of the distal motor power by 70-75%, 80±20% showed some recovery (3).

Following experimental SCI both primary and secondary events occur (4). The primary events, defined as changes appearing within 15 minutes, include loss of spinal cord conduction (5), damage to the blood-brain barrier (6) and extracellular ionic derangements (7). The mechanical damage initiates secondary pathophysiological processes mainly consisting of vascular changes leading to progressive ischemia (for review see 8). For instance, the neurophysiological recordings showed transient recovery after the injury, only to be lost concomitantly with the delayed reduction of spinal cord blood flow (SCBF) (5). These secondary events are well known in the pathophysiology of head injuries, but have previously been neglected after spinal cord trauma on account of the clinical difficulties in detecting changes in the neurological status. The extent to which the primary events are responsible for the total neurological deficit following trauma is still under debate.

During the last 10-15 years experimental and clinical pharmacological studies have emphasized the importance of secondary mechanisms as mediators of the final damage. In this survey the experimental and clinical literature is reviewed and the scientific basis supporting a policy of a more active attitude towards the acute treatment of spinal cord injuries is presented. An intensive care program focusing on the importance of avoiding the development of secondary posttraumatic insults to the spinal cord is also described. This program, which is used at our Spinal Cord Injury Unit in Uppsala, includes guidelines for adequate tissue oxygenation and perfusion and for pharmacological treatment and represents an active attitude towards early surgical intervention.

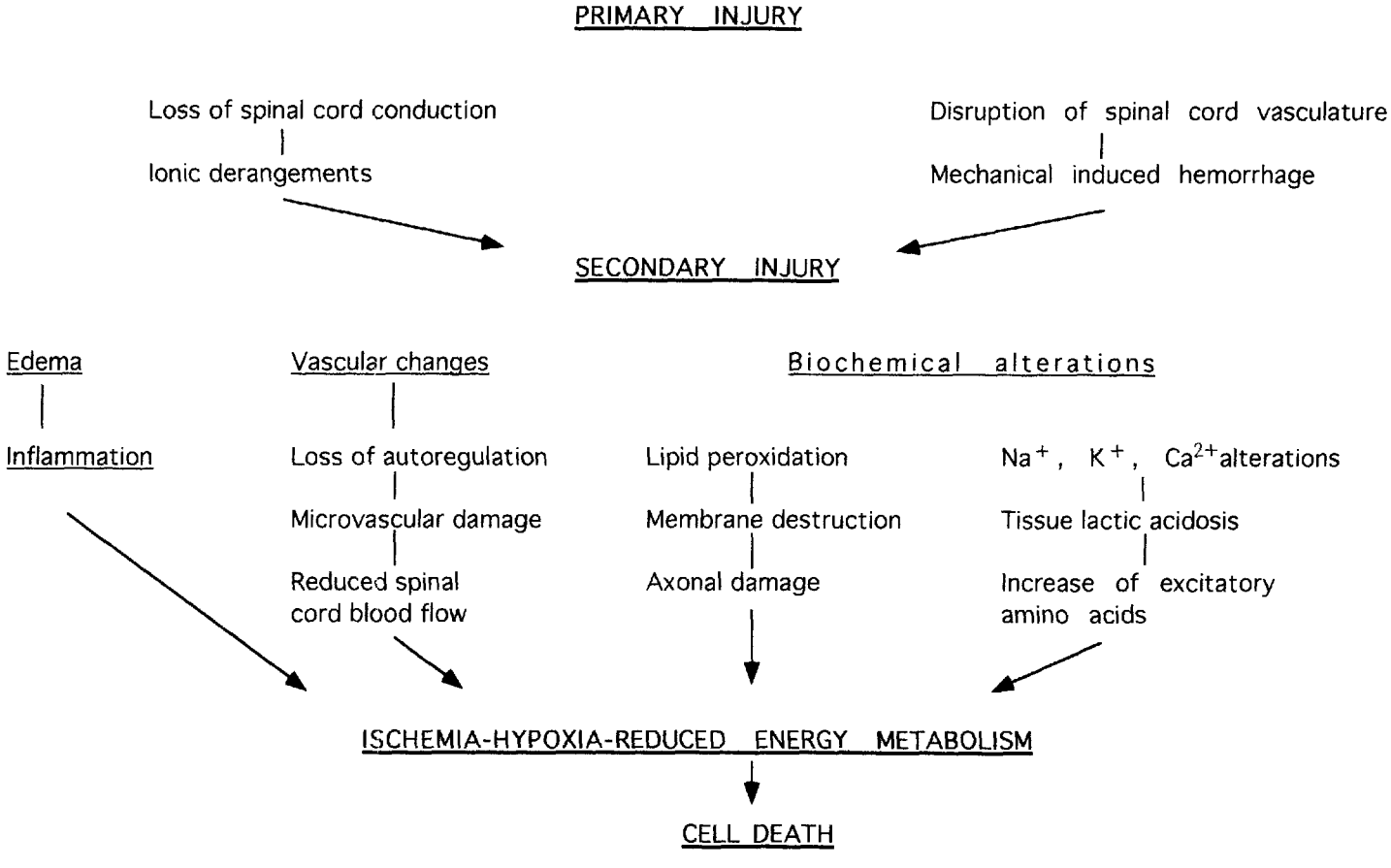

Fig 1: Schematic scheme of the primary and secondary pathways leading to cell death after spinal cord injury.

EXPERIMENTAL BACKGROUND

Spinal cord injury in man involves a number of different mechanical effects, and various experimental models have been claimed to represent some factor in the posttraumatic pathophysiology. The most common injury model is the weight-drop technique, which causes a contusion in the spinal cord, simulating the initial transient kinetic impact. Experimental models in which the spinal cord is compressed represent another pathomechanism and mimic the clinical situation in which permanent compression is caused, for example, by bony fragments, hematoma, or extruded disc material. However, the multifactorial nature of the trauma has made it difficult to establish an "ultimate spinal cord injury model" (9).

The cascade of events following an acute injury to the spinal cord is very complicated (Fig 1). As a result of trauma, ischemia develops, and the assumption that ischemia is involved in the destruction of nervous tissue is based on different experimental findings within various fields. It has been shown, for instance, that ischemia potentiates other secondary events such as accumulation of intracellular calcium, formation of edema, occurrence of lipid peroxidation, and release of energy metabolites and excitatory amino acids (8). The reverse reactions also occur. In addition to the trauma models, a variety of methods have been used for investigating the secondary events, such as behavioural analyses, neurophysiological recordings, measurements of SCBF, and studies of morphological changes (10, 11, 12).

Posttraumatic hypotension and ischemia

It is well known that the SCBF decreases after trauma to the cord (8). No causal relationship has been established, but it has been hypothesized that the hypoperfusion is the major cause of other secondary reactions.

Experimental studies of the immediate effects of SCI have revealed a posttraumatic hypotension. Simultaneously, other systemic effects such as decreased peripheral resistance, reduced cardiac output and bradycardia contribute to ischemia of the spinal cord (13).

The injury also causes immediate mechanical damage to the microvessels of the cord, followed by secondary vascular changes due to local micro-vascular obstruction caused by vasospasm and platelet aggregation (14). These alterations, together with an impairment of the autoregulation of the SCBF (25), i.e., the ability to maintain a constant blood flow over a wide range of systemic blood pressure, constitute the basis of the following progressive ischemia and finally the necrosis of the spinal cord.

Fehlings (19) proposes that injured axons are more vulnerable to ischemia than intact axons and also that ischemia becomes more severe during the first three hours if left untreated. The progressive ischemia which occurs during the first hours after the injury (16,17) has been found to be closely related to the degree of trauma and the subsequent neurological deterioration, i.e. axonal dysfunction (18,19,20). This ischemia could perhaps be prevented, at least to some extent, by early treatment.

As mentioned above, a spinal cord injury also affects the autoregulation of the SCBF. After injury the blood flow through the spinal cord is dependent on the systemic blood pressure. If the injury is severe enough, a systemic hypotension will develop, resulting in an inability to maintain adequate spinal cord perfusion. Experimentally, an increase in systemic blood pressure up to 160 mmHg was followed by a simultaneous increase in SCBF, but a further increase above this level only induced hyperemia in adjacent areas (21). Logically, the loss of autoregulation should be treated by counteracting the hypotension. Adequate ventilation is also of great importance, since the CO_2 reactivity in relation to SCBF is impaired. Following trauma, a PCO_2 reduction does

not result in vaso-constriction in the injured areas, and an increase in PCO_2 is not followed by vasodilatation.

Morphological changes

The SCI results in an immediate block of axonal conduction in the long tracts before any damage can be demonstrated by light or electron microscopy. Following injury, characteristic morphological changes are seen, and these are related to the degree of trauma (22,23). Within 15 minutes, as a result of mechanical injury to the microvessels, petechial hemorrhages and vasogenic edema are observed in gray and white matter, respectively. The mechanical injury is also responsible for an increase in gray matter hemorrhage during the first hours, but as early as four hours after injury this increase is followed by ischemic endothelial damage, progressive axonal destruction and accumulation of inflammatory mediators (22). The reduction of the microcirculation seems to follow the same pattern of distribution as the formation of edema. These ischemic areas are later visualized as necrosis and cavitation, and when these late changes appear an irreversible functional transection will have developed.

Tator (8) suggests that secondary damage to the microcirculation occurs as a result of thrombosis and vasospasm in arterioles traversing the gray matter to supply the white matter. Using a compression model, we found that necrosis appeared later in white than in gray matter and that this white matter necrosis was not preceded by confluent hemorrhage (23). After trauma causing reversible paraparesis, the SCBF was restored to 65% after 4 days and to 90% after 9 days (24). In the same model necrosis of the white matter developed within the same time interval (23). It therefore seems likely that insufficient circulation during the days prior to the development of necrosis is of major pathophysiological significance. The close link between the development

of irreversible morphological alterations and the spinal cord hypoperfusion indicates the importance of preventing the posttraumatic reduction in SCBF.

Biochemical changes

Numerous molecular changes are observed after trauma to the central nervous system (25). Of special interest in posttraumatic spinal cord degeneration is the oxygen free radical-induced lipid peroxidation, i.e., the formation of lipid peroxides within the cell membranes, which probably is a major culprit in this tissue injury (26). In this process Ca^{2+} ions appear to play a major role. An increase in the intracellular Ca^{2+} concentration facilitates the lipid peroxidation (27) and thus enhances the contractility of vascular smooth muscle cells, resulting in microvascular spasm (28).

The exact role of the lipid peroxidation is not clear. Nor is it clear to what extent this process is an independent phenomenon. However, there is strong support for involvement of microvascular lipid peroxidation in the development of spinal cord ischemia (28) and there is also evidence that the lipid peroxidation is a time-dependent reaction (29). Demediuk et al (29) have demonstrated that lipid peroxidation processes occur earlier in gray than in white matter. This might be explained by the higher vascular density and greater bleeding in the gray matter, offering better prerequisites for lipid peroxidation in this tissue. In another study progressive posttraumatic white matter ischemia could be prevented by calcium channel blockade, administration of antagonists to arachidonic acid metabolites, and attenuation of oxygen free radical-induced microvascular lipid peroxidation by vitamin E and selenium (28). In addition, compounds with a special capacity for inhibiting lipid peroxidation, i.e., methylprednisolone sodium succinate and the more potent nonglucocorticoid 21-aminosteroid tirilazad mesylate (U74006F)

have been shown to prevent the decrease in SCBF as well to improve the neurological recovery when administered 30 minutes after the injury (30,31).

Using graded compression and a microdialysis technique, a post-traumatic increase in energy metabolism was observed after severe compression leading to permanent paraplegia. An initial partial recovery was observed in the hypoxanthine and inosine metabolism, while the increased lactate level persisted. Lactate would thus seem to be an sensitive indicator of severe neurological deterioration (32). Using the same microdialysis technique and an impact trauma model, a toxic increase in excitatory amino acids was noted by Liu (33). The possibility that methylprednisolone and tirilazad may further improve posttraumatic energy metabolism and reduce toxic elevations of excitatory amino acids is currently being investigated.

Relationship between spinal cord blood flow and evoked potentials

The posttraumatic decrease in SCBF and its relationship to sensory evoked potentials (SEP) was first reported by Kobrin (34). Using a balloon compression technique at the midthoracic level in monkeys, he found that as long as a significant blood flow remained through the spinal cord, SEP persisted. A slow but progressive reduction of the SEP amplitudes occurred as the compression progressed, and the disappearance of SEP was followed or accompanied by absolute ischemia.

Previous studies in our laboratory showed a correlation between the degree of compression, the SCBF, SEP activity, and the following neurological deterioration (20). Compression of a degree causing reversible paraparesis, with only 10% of cord blood flow remaining during the compression, had a marked impact on the amplitude and conduction time of SEP, but these could still be evoked. With compression resulting in irreversible paraplegia, there was no blood flow through the

compressed area nor any evoked response. These findings are in accordance with the quantitaive evidence obtained by Fehlings et al (19) linking posttraumatic ischemia to axonal dysfunction. They found a linear relationship between SCI severity and decrease in SCBF, and a significant relationship both between motor and somatosensory evoked potentials and the degree of injury, and between ischemia and posttraumatic axonal dysfunction (19).

In addition, SEP has been found to recover transiently after an SCI, only to be lost again within hours or days (5,35). Using the same contusion trauma model as in the latter studies, a reduction in SCBF was not observed in the lateral column until 1-3 hours after the injury (5). This delayed reduction was followed by a short increase in blood flow and finally persistent hypoperfusion, which occurred simultaneously with the loss of SEP. The close relation between SCBF, SEP and the neurological deterioration strongly supports the theory of secondary injury mechanisms.

Pharmacological treatments

The concept of secondary autodestructive processes causing delayed tissue damage has been the guideline in different forms of pharmacological treatment after spinal cord injury. Although there are many pitfalls in interpreting the outcome of treatment, most of the successful results have been closely linked to the prevention of a reduction of SCBF and the subsequent ischemia. Attempts to improve the posttraumatic circulation with the aim of counteracting the development of tissue damage would therefore seem logical (for review see ref. 36). The following drugs have been the most frequently used in different experimental settings.

Among drugs affecting membrane stability, corticosteroids (methylprednisolone), have been most often used (for review see ref.

37). Their mode of action is not fully understood, but a direct membrane effect and sparing of the endothelium may play a major role. High doses of methylprednisolone have an antioxidant effect. This drug is very lipid-soluble and concentrates in membranes, leading to reduced free radical attacks on lipids.

In many studies methylprednisolone has improved both the SCBF and the neurological outcome after experimental trauma to the spinal cord inflicted in different ways (38,39). The need for high doses and the time interval before the start of the treatment are of great importance. Hall et al (38) found that methylprednisolone given 30 min after a contusion injury prevented a decrease in SCBF as observed after 3-4 hours, but with a longer delay before its administration the effect decreased. When administered 4 1/2 hours after injury, the drug had no impact on SCBF. On that basis the authors suggest that methylprednisolone is not able to reverse ischemia once it has occurred. This conclusion was not supported in our study in which this drug was given 1 hour after compression trauma. The drug increased the rate of normalization of SCBF and this effect persisted for at least 4 days after injury, and was accompanied by a concomitant beneficial effect on the neurological outcome (39).

It has been proposed that the 21-aminosteroid tirilazad mesylate (U74006F) may have a more potent neuroprotective effect than methyl-prednisolone, although both act as antioxidants and stabilizers of the membrane system (40). Tirilazad has been reported to improve the neurological recovery for up to four weeks posttraumatically if its administration is initiated 30 min to four hours after the injury (31, 41). In addition, tirilazad diminished the posttraumatic ischemia after both blunt and compression trauma, which might be explained by its preventive effect on the lipid peroxidation damage to the vascular bed (30).

Gangliosides are glycolipids located in the neuronal membrane which perhaps both influence the secondary injury mechanisms and promote neurite growth. Administration of gangliosides has been shown to reduce posttraumatic edema, limit the release of excitatory amino acids, and have a beneficial effect on the neurological recovery (42).

The possibility that posttraumatic release of endogenous opiates (endorphin) increases the tissue damage was first proposed by Faden et al (43). They suggested that the endorphins induced hypotension in animals that had lost autoregulation, leading to reduced SCBF and ischemia. In pharmacological studies, naloxone improved the mean arterial blood pressure (MABP), SCBF and neurological recovery even when first administered four hours after injury (43,44). Thyrotropin-releasing hormone improved the neurological outcome when its administration was started 60 minutes after injury in rats, but also when given as long as 24 hours after injury in cats (45).

Nimodipin, a calcium antagonist, has been found to increase SCBF and cerebral blood flow in uninjured animals, and also to increase SCBF when given 30 minutes after injury in rats (46). This drug, together with adrenalin (46) or dextran (16), maintained the posttraumatic MABP significantly better than saline, indicating that SCBF increased when MABP was maintained. Furthermore, the increase in blood flow was associated with improved function of injured axons as measured by evoked potentials (16). In summary, the above results indicate that experimental spinal cord injury can be influenced benificially to some extent if the treatment is directed toward prevention of a reduction in posttraumatic SCBF.

The duration of compression in relation to neurological impairment and spinal cord blood flow

It has been shown that both the degree and duration of compression are related to the subsequent neurological recovery and to the spinal cord blood flow (18, 20, 24, 47, 48). Using a graded compression model in rats, increased weights but with a similar duration of compression resulted in correspondingly increasing neurological deterioration ranging from minor deficits to irreversible paraplegia (47). After moderate compression for five minutes causing reversible paraparesis, 10% of the SCBF remained (20). When the duration of compression was increased to ten minutes, a more pronounced neurological deficit was observed (47). Sandler et al (18) also showed that an increased duration of cord compression was related to more pronounced ischemia involving a larger area. Both studies indicate that persistent ischemia as a result of continuous compression aggravates the neurological deficit. Early decompression results not only in an immediate increase in cord blood flow, but also in parallel recovery of this flow and the neurological deficit during a period of several days, which is similar to the recovery period in animals sustaining reversible paraparesis (24). These findings support the theory that early decompression, i.e., removal of external compression on small vessels inducing vasospasm, diminishes the neurological deficit by limiting the period of ischemia. It also facilitates the parallel recovery of SCBF and neurological function, which is in accordance with other reports (49). It should be noted that even preservation of a minor part of the white matter is beneficial, since, for example, only 10% of the ventromedial tract in cats is sufficient to permit useful hindlimb assistance to upward locomotion (50).

CLINICAL ASPECTS

These experimental findings, and also the Second National Acute Spinal Cord Injury Study (NASCIS II), have shown that posttraumatic neuroprotection is possible (51). In the latter study, for the first time administration of a pharmacological agent, methylprednisolone, improved neurological function in humans up to 1 year after a spinal cord injury (52). This achievement has altered the medical management in favor of a more active attitude in the early stage, since the beneficial effect of methylprednisolone ceases if it is administered more than 8 hours after the injury. These results constitute the strongest argument for the secondary injury theory. As a result of this possibility of neuroprotection, a schedule of medical, pharmacological and surgical treatments has been introduced. These guidelines are based on one decade of experience in the field of neurotrauma intensive care at our hospital and are applied in cooperation with the "first admission hospital". The aim is to initiate the treatment as soon as possible and not later than within a few hours after injury.

Overall management

The acute management starts in the prehospital situation with respiratory and cardiovascular stabilization and proper immobilization. According to Rogers (53), 5-10% of the neurological injury occurs after the patient has come under medical care. Every patient admitted with an acute spinal cord injury, irrespective of the degree of neurological deterioration, should be regarded as having sustained a reversible injury, and the aim must be to reduce the consequences of the secondary

pathophysiological events. It should be kept in mind that trauma to the spinal cord very rarely results in a spinal cord transection.

The spinal shock that occurs with lesions above Th6 is caused by the interrupted thoracolumbar sympathetic outflow to the heart and peripheral vessels. Characteristic signs of spinal shock are cessation of the axonal conduction and signs of sympathetic dysfunction such as bradycardia, hypotension and hypothermia. In patients with spinal shock the possibilities during the first hours or days of performing a reliable neurological examination and of predicting the final neurological outcome are diminished. By the time this evaluation is possible the benefits of an intensive care program are lost. Spinal cord injured patients should be regarded as a group sustaining high-energy trauma and considered equivalent to patients with multiple injuries, since up to 43% of the patients with spinal cord injuries also sustain injuries to other parts of the body (54). Besides repeated neurological assessment, the physical examination must therefore include a search for other injuries such as multiple fractures, chest and abdominal injuries, and damage to the genito-urinary system. Diagnostic measures such as physical examination, and radiological and other investigations should be performed concomitantly with the medical management. The medical treatment and the surgical decompression and stabilization should not be delayed unnecessarily by prolonged clinical diagnostic procedures (for reviews see 55, 56, 57, 58).

Medical treatment

Presuming that the secondary pathophysiological events occurring after a spinal cord injury resemble the changes seen after experimental injuries, some therapeutic principles could be applied in the treatment of

patients with an injured spinal cord. The therapeutic guidelines, i.e., the intensive care program, should not only concern the spine but also other organ systems contributing to the recovery of the spinal cord. It should also be emphasized that the therapeutic guidelines in most respects are similar to those applicable for other CNS damage.

Respiratory system

Adequate respiration must be secured in order to avoid hypoxia and hypercapnia. Early attention to the respiratory system is important, as other associated injuries such as chest trauma with hemato- and pneumothorax are common. Rib fractures occur in about 25% of the patients with thoracic fractures, and in addition to the muscular fatigue or pareses following the SCI they can result in abrupt cessation of breathing. Arterial blood gas monitoring should be started as early as possible. If the patient is unable to maintain adequate ventilation, endotracheal intubation and artificial ventilation should be performed even if the patient is awake, not only in order to secure adequate oxygenation to the spinal cord but also to prevent impairment of all body organs. Direct laryngoscopy should be avoided (59). We recommend mild hyperventilation with a PCO_2 of 4.0±0.5 kPa and a minimum oxygen tension of 12.0 kPa. The assisted ventilation is continued at least for 48 hours, and longer if necessary. The use of a Stryker bed facilitates treatment such as assisted coughing, which may be given both pre- and postoperatively in order to avoid atelectasis and pneumonia.

Circulatory system

An adequate systemic blood pressure must be established and maintained to guarantee perfusion of the spinal cord. A systolic blood pressure below 115 mmHg has been found to be associated with a increased mortality and morbidity in patients after a spinal cord injury

(60). There appear to have been no studies dealing with the consequences of impaired autoregulation in the injured human spinal cord, but experimental data clearly demonstrate the importance of maintaining an adequate blood pressure in order to compensate for the loss of autoregulation and to obtain an adequate blood flow in the injured spinal cord (15).

The symptoms of spinal shock must by differentiated from those of hemorrhagic shock. Both cause hypotension, but in the former case it is accompanied by bradycardia and in the latter case by tachycardia. The hypotension in spinal shock is a consequence of reduced peripheral resistance rather than of hypovolemia.

Central venous catheters should be used routinely to assess the central circulation. After excluding other reasons for hypotension than spinal shock, fluid administration should be restricted to a minimum in order to avoid spinal cord and pulmonary edema. An MABP of 80 mmHg or a systolic blood pressure of 130 mmHg may be recommended in order to maintain satisfactory perfusion of the spinal cord, and plasma expanders are used initially to achieve this goal; if necessary pressor agents are given to obtain a normo- to mildly hypertensive level.

General treatment

One of the symptoms of spinal shock is total muscle flaccidity, including that of the bladder and bowel. It is convenient to have an open catheter in situ in the acute period in order to avoid overdistension of the bladder. The gastrointestinal function is monitored by daily palpation and auscultation of the abdomen (61). The abdominal circumference is measured daily. A nasogastric tube is inserted for initial drainage, since paralytic ileus is a feared complication and there is a risk of aspiration. The start of intermittent bladder catheterization is usually coincidental with the beginning of oral or nasogastric feeding, i.e., when the bowel

sounds have returned. In order to diminish the risk of deep venous thrombosis and pulmonary embolism, administration of low molecular heparin is started 48-72 hours after injury or surgery. Calf measurements are performed daily in order to detect any venous thrombosis as soon as possible. Pressure sores are prevented by use of the Stryker bed and the patient is turned over every second hour. An antispasticity program is initiated as soon as possible.

Pharmacological treatment

As previously mentioned, two drugs have been found to have a significant clinical effect on the neurological outcome. Early administration of methylprednisolone (51) and GM-1 ganglioside (62) improved the neurological function after acute injury to the spinal cord. The methylprednisolone was given as an initial bolus dose of 30 mg/kg (51) followed after an interval of 15 minutes by a 23-hour infusion at a rate of 5.4 mg/kg/h. This improvement persisted for one year after the injury in both plegic and paretic patients, but only if the treatment was given within eight hours posttraumatically (52). Some authors even consider that there are contraindications to administering methylprednisolone later than eight hours after the injury (63).

A significant improvement in neurological function was also observed one year postinjury after administration of GM-1 ganglioside when this was given continuously for a mean of 26 days starting within a mean of 48 hours after trauma (62). This study comprised 52 patients, 18 of whom served as controls. The recovery was better in paralyzed muscles, which regained useful motor strength, than in initially paretic muscles.

Radiographic diagnosis

The aim of the radiological investigation is to detect the mechanism underlying any fracture, and also the cause and site of compression, in order to facilitate the surgical approach for decompression and stabilization. As detailed as possible, an analysis of the neurological and skeletal structures is required (64). Of utmost importance for the surgical approach is to find out whether the encroachment of the spinal canal is caused by vertebral bony fragments, disc material, hematoma or stretching of the spinal cord due to instability. The cervical spine, including the first thoracic vertebrae, should be investigated first with lateral x-ray views, supplemented with anteroposterior and open mouth views. The entire spinal column must be X-rayed, since multiple injury sites occur in up to 15-20 percent (65). If the detailed nature of the fracture is uncertain, computed tomography (CT) should be performed. We prefer magnetic resonance imaging (MRI) to CT, because of its superiority in detecting the non-bony anatomical structures responsible for the compression, and its ability to reveal parenchymal changes in the spinal cord (66).

Surgical management

The indications and timing of surgery after an SCI are still controversial, except in patients with ongoing neurological deterioration. There are two principal opinions regarding surgery. First, there is a conservative management view represented by Gutman, who recommends nonsurgical immobilization to achieve the "surgical goal" of reduction and fusion (67). By contrast, Ducker in various reports advocates early surgical intervention, sometimes within three hours, on the basis of a postulated

dependence of the prognosis on the duration of neuronal tissue compression (68,69).

Early spinal surgery is performed for three reasons, (i) to improve the neurological restitution, (ii) to prevent or alleviate secondary complications (such as pneumonia and embolus), and (iii) to facilitate rehabilitation. There appears to have been no prospective randomized study that has demonstrated a beneficial effect of surgical intervention alone on neurological recovery. Most of these studies are retrospective, surgery has not been performed in the acute period, and unequal numbers of patients, sometimes from different institutions, have been compared (70, 71, 72, 73). Only one study has shown that addition of surgical treatment to the medical management statistically improved the motor recovery (74). This was found in patients with cervical central cord syndrome, characterized by greater motor loss in the upper than in the lower extremities (74). Concerning the postoperative remaining stenosis, i.e. the result of an operative decompression, this has been found to be correlated to recovery in some studies but not in others (55, 66, 75).

Regarding the mortality and morbidity after SCI, one prospective randomized study has been presented. Here Wilberger et al (76) found that in patients with SCI at the cercical level the rate of complications after early surgery (within 24 hours) was lower than after surgery performed 24 hours to 3 weeks after the injury. Complications such as pneunomia, pressure sores, and deep venous thrombosis occurred 50% more frequently in the group submitted to late surgery. The length of hospital stay was also reduced to half of that required in the late-surgical group. The latter finding conforms with reports by some authors (77, 78) but not by others (79, 80). In one study even a shorter hospitalization was noted in nonoperated paraplegic patients (81). In a comparison between operated and nonoperated patients, Tator found a

lower mortality rate in the operated group but an increased rate of complications (78), the latter in agreement with Ahn (77).

The aim of surgery is to achieve adequate decompression, reduce any deformity, and to stabilize any spinal instability. Whether to use an anterior or posterior approach depends on the mode of compression and the fracture type. Tator et al (78) and Wilberger (75) report that the surgical methods now available can be safely used without risk of increasing neurological deterioration. On the basis of the experimental results presented above, the development of new operative techniques, (82) and the improvement of the overall medical management, our attitude towards early decompression and stabilization of spinal instability has become more positive. Despite the controversy concerning indications for immediate surgery, it seems logical to believe that early decompression of the spinal cord is of utmost importance if optimal tissue recovery is to be achieved. Immediate decompression and fusion are performed as soon as the patient is stable with respect to any associated injuries and to cardiovascular and pulmonary factors.

Short guidelines

The guidelines given in Table 1 are based on literature reports and on the experience gained at our unit during more than a decade of acute management of patients with spinal cord injuries.

Table I. Short therapeutic guidelines

Prehospital care

- Respiratory and cardiovascular stabilization.
- Adequate immobilization.

At the "first admission hospital"

- Secure adequate ventilation (PO_2 > 12 kPa). If necessary, endotracheal intubation should be performed and artificial ventilation instituted (PO_2 > 12kPa; PCO_2 4.0±0.5).
- Perform and repeat physical examination in order to detect any other injuries as a cause of systemic hypotension.
- Establish adequate perfusion of the spinal cord (MABP ≥ 80 mmHg or systemic blood pressure ≥ 130 mmHg); use plasma expanders initially and if necessary pressor agents.
- Initiate high-dose steroid treatment with methylprednisolone as soon as possible and not later than 8 hours after trauma.
- Perform an adequte radiological investigation.
- Admit the patient as soon as possible, and before surgical intervention, to a spinal cord injury unit.

At the spinal cord injury unit

- Continue the treatment steps referred to above.
- Perform decompression and stabilization of the spinal deformity as soon as possible.

CONCLUSION

This survey presents guidelines for the clinical treatment of patients with spinal cord injury, based on experimental and clinical pharmacological studies. The concept of secondary injury mechanisms is strongly supported and an early active attitude in the management of patients with spinal cord injury is advocated. The overall goal in the prevention of these secondary mechanisms is to preserve as much as possible of the nervous tissue at the injury site. The number of reports suggesting the combined treatment described in this paper is small, but the results of the clinical pharmacological study with methylprednisolone offer new hope for the future. As the knowledge of the pathophysiological mechanisms underlying spinal cord injury expands, new combined pharmacological treatments are being tested, the imaging modalities are improving, and our experience in the clinical treatment accumulates new broader approaches to save CNS tissue are becomin feasible. Possibly in the future new treatment modalities such as transplantation of myelin-forming cells, use of nerve cell grafts, and stimulative measures to promote regeneration of the spinal cord long tracts will be introduced (83). It is hoped that, by combining the advantages of all therapeutic approaches, the functional prognosis in patients sustaining a spinal cord injury will become more favorable.

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