Acute Management of Traumatic Cervical Spinal Cord Injuries

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Abstract

Successful outcome from a traumatic cervical spinal cord injury (SCI) depends heavily upon the quality of the acute care rendered to the affected individual. In recent years, there have been significant advances in the acute management of SCI. We discuss current management strategies in the areas of prehospital care and transport, emergency room management, surgical considerations and pharmacotherapy. **Key Words:** Tetraplegia, stabilization, decompression, methylprednisolone.

SPINAL CORD INJURY (SCI) is a catastrophic event and one of the most common causes of severe disability and death following trauma (1). Approximately 10,000 acute spinal cord injuries occur in the United States each year. Tetraplegia, defined as loss of sensorimotor function as a result of an injury to the cervical spinal cord, accounts for approximately 55% of all SCIs (2 – 4). The Edwin Smith Surgical Papyrus of Egypt described SCI five thousand years ago as "ailments not to be treated" due to the poor prognosis (5). Fortunately, this has changed and a recent study of patients with traumatic SCI resulting in tetraplegia showed that 85% of these patients were alive 5 years after their injury (6). Though much has changed over the last five thousand years, to date no one has discovered a regenerative process to repair the traumatically injured spinal cord in humans. As a result, the outcome of the injured individual is often determined by the acute management of the SCI. Over the past two decades, great improvements have been made in the area of prehospital emergency care and the initial medical, surgical, and pharmacological management of the spinal-cord-injured person (7).

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Prehospital Management

Early management of the cervical-spinal-cord-injured patient begins at the scene of the accident. It has been estimated that 3 – 25% of spinal cord injuries occur after the initial insult, either during transit or early in the course of treatment (8). Over the last 20 years, there has been a dramatic improvement in the neurologic status of SCI victims arriving in the emergency room. During the 1970s, the majority of patients arrived with complete neurological lesions. During the 1980s, however, the majority of spinal-cord-injured individuals arrived in the emergency room with incomplete lesions (9). This change in neurological status is extremely important, in that patients with incomplete injuries have a far better prognosis for neurological recovery than those with complete injuries. This drastic improvement in neurological status seen in the emergency room has been attributed to the development of the Emergency Medical Services (EMS) system.

An EMS system is an integrated and organized emergency response system. It consists of many components, including trained responders (i.e., paramedics) who utilize appropriate extrication techniques, and who are trained in basic and advanced trauma life support. It also includes emergency transportation with communication linkages between a central coordinating center and a trauma center (10). Therefore, it is clear that the management of acute cervical SCI begins with prehospital care by EMS at the scene of the accident.

Prehospital care consists of five phases: evaluation, resuscitation, immobilization, extrication and transportation (11). The evaluation is made up of two parts: the primary and secondary surveys. The primary survey consists of evaluation of the airways, breathing and the circulation (the "ABCs"). The secondary survey consists of a more thorough evaluation, from head to toe, of the injured person. During the evaluation it is important to consider the possibility of an SCI. Any victim who is unconscious is considered to have an SCI until proven otherwise. A conscious accident victim may complain of neck or back pain, or palpable tenderness in those areas. There may be signs of muscle weakness, paralysis, or altered sensation in the trunk or extremities. If these signs are not present, it is important to ask the patient if they ever were noted, even if only temporarily. Deep tendon reflexes may be lost. There may be signs of incontinence or urinary retention due to loss of bowel and bladder function. Priapism may be present, or there may be a loss of anal sphincter tone. Signs may be subtle, such as increased skin warmth and flushing due to loss of sympathetic vascular tone below the level of the injury. There may be superficial signs such as abrasions, lacerations or deformities of the spine, neck, or head regions. Injuries to other areas such as the head may mask an SCI. In addition, altered states of consciousness due to alcohol or drug use may also mask an SCI.

Resuscitation begins during the evaluation and primary survey. The neck should never be moved out of a neutral position in order to establish an airway in any patient suspected of having a spinal injury. Any patient with a suspected SCI should be given supplemental oxygen during transport to the hospital. In the alert patient with a C5 lesion or lower, oxygen can be given by nasal cannula or face mask. In the obtunded patient, oxygenation may be facilitated with a chin lift maneuver and insertion of an oropharyngeal airway. However, if adequate oxygenation cannot be maintained or established due to respiratory arrest, the victim must be intubated. The esophageal obturator airway (EOA) (12) or blind nasotracheal intubation are methods of choice, because either can be accomplished without hyperextending the neck. Although endotracheal intubation provides better oxygenation, the EOA will provide adequate ventilation during transport. If endotracheal intubation is necessary, an assistant should stabilize the neck during the procedure.

It is of critical importance to reestablish circulation to neural structures if there is to be any recovery of neurological function. External cardiac massage must be started if necessary. Any active bleeding should be attended to. Bleeding from the neck or spinal area should be controlled by direct localized pressure. Circumferential pressure dressings should not be used. There is some controversy surrounding the establishment of intravenous lines at the scene of the accident. Standard procedure consists of the insertion of a large-bore intravenous line with infusion of Ringer's lactate in all SCI patients. Others, however, believe that if rapid evacuation to a trauma center is possible, delaying transport to start intravenous lines at the scene of the accident is not beneficial.

The cervical SCI patient may present with either neurogenic or hemorrhagic shock. Neurogenic shock is the result of a spinal cord injury at or above the fourth thoracic vertebra. Such injuries result in the loss of sympathetic nervous system control of peripheral vascular tone. This leads to the pooling of blood in the extremities and reduced central venous return, resulting in compromised cardiovascular function. There is an associated bradycardia due to the loss of sympathetic innervation to the heart and unopposed parasympathetic tone. Both hemorrhagic and neurogenic shock present with systolic blood pressure of approximately 70 mm Hg or lower. However, neurogenic shock presents with bradycardia and a slow, regular pulse, while hemorrhagic shock presents with tachycardia and a rapid, irregular pulse. The situation may be complicated by a combination of both types of shock. The quickest and easiest treatment for either type of shock is placement of the patient in the Trendelenburg position. This will help decrease the lower extremity pooling of blood and increase central return. The specific treatment for neurogenic bradycardia is the administration of 0.4 mg of IV atropine, or IV dopamine hydrochloride via low dose infusion. However, this is only a temporary measure. Caution should be used in delivering fluids to patients in neurogenic shock. In these patients, the problem lies not in the volume of blood loss, as is the case in hemorrhagic shock, but in its distribution. Large increases in volume may cause these patients to develop heart failure. While the use of MAST pants (Military Anti-Shock Trousers) has been shown to benefit patients in hemorrhagic shock by collapsing lower extremity and abdominal vasculature, their role in neurogenic shock has not been established. Special care should be observed when using MAST pants in instances of suspected lumbar or thoracolumbar fractures, as they can aggravate the neurologic injury.

Immobilization of the spinal column and the patient is critical in SCI. Regardless of the posture in which the spinal-cord-injured individual is found following the accident, all patients should be placed in a neutral supine position. The following recommendations for moving a victim with suspected cervical spinal cord injury have been made.

With very gentle traction, with hands locked under the jaw and neck, the patient's head and neck should be placed in alignment with the axis of the body. As long as the neutral position is not surpassed, no further damage to the spinal cord will occur with this maneuver. Traction with weights should never be applied at the accident field because of the danger of over-distraction in cases of severe spinal column disruption, which could result in secondary injury with aggravation of neurological deficit (9).

It has been estimated that as many as 20% of spinal cord injuries involve multiple skeletal levels. As a result, the entire spinal column must be immobilized and splinted from the top of the head to the bottom of the buttocks. The best method of splinting the patient is by using a rigid, straight board. The neck is best immobilized by securing it with a hard collar and sandbags on each side and with tape or Velcro straps tightly over the forehead. The chest should be strapped in lightly so as not to impede breathing. Soft collars should not be used, since they do not sufficiently immobilize the neck to protect against further injury. Philadelphia Collars, while providing better support, also do not provide enough support for some of the more rigorous motion that may be experienced during extrication and transportation. These devices can also give victims a false sense of security. If stressed, they will allow mobility of the neck.

Common sense is the most important factor in extrication and transportation of a patient. No two situations will be the same. With respect to extrication, the status of the patient, accessibility, and any environmental hazards will determine how the situation should be handled. The ultimate goal is to safely remove the patient from the accident scene for transportation to the hospital. A patient's status, injuries and location with respect to a suitable trauma facility will determine the method of transportation (i.e., by land or air). Although speed is important, the most important factor is getting a patient safely to the emergency room with all systems stabilized, in order to enhance the potential for maximum neurological recovery.

There is some controversy surrounding the type of trauma center best suited for initial treatment of the SCI patient. There are three levels of trauma centers as defined by the Committee on Trauma of the American College of Surgeons (13). Level I centers offer tertiary specialized care for major trauma such as SCI. These centers have 24-hour physician coverage in all specialties and 24-hour operating rooms, laboratories, and intensive care units. Level II centers have similar resources but on a 30-minute response time basis. They are not equipped to handle certain major problems such as SCI. Level III centers are responsible for stabilization, preliminary diagnosis, and preparation for transport of severely injured patients to level I or II centers for better care. The controversy lies in the question of whether the acute-spinal-cord-injured patient should be taken to the nearest hospital, or be transported to the more specialized level I trauma center, even if the distance is greater and it would take more time. Many believe that the acute-spinal-cord-injured person who is stable with regard to vital signs, should be transported past the local hospital to the nearest level I center if the transport time is reasonable (i.e., less than one hour). If the patient is not stable, or the distance is too great, then the patient should be taken to the nearest trauma center for stabilization. Once stable, the patient should then be transported as quickly as possible to a level I tertiary care center.

Emergency Room Management

Upon arrival in the emergency room, the first priority in the management of the traumatic SCI patient is reestablishment of "physiologic homeostasis." It is important to normalize vital signs and blood oxygen levels, and to reestablish as normal a spinal alignment as possible. Much of what is done in the initial stages of emergency room management is a repetition of the EMS management. However, this repetition is critical, since reviews indicate that injuries have been exacerbated and lives lost because of basic errors in emergency room treatment of trauma victims. In addition, it is important to remember that lifethreatening wounds, if present, take priority over the SCI.

As with the evaluation at the scene of the injury, the “ABCs” of resuscitation are the first step. It is critical to safely and carefully establish a stable airway and respiratory status in order to maintain optimal oxygenation, and to restore circulation to prevent shock. Cervical SCI often compromises the respiratory status of the patient. This typically results in the loss of thoracic and abdominal musculature, which assists in breathing. As a result, ventilation becomes dependent solely on the diaphragm. Signs of diaphragmatic breathing include minimal or absent chest wall movement, with passive outward and inward movement of the flaccid abdominal wall. A normally functioning diaphragm requires an intact phrenic nerve, which originates from the third, fourth and fifth cervical roots. In high-level cervical injuries, the functioning of the diaphragm is affected to a degree depending on the level of the cervical injury.

Patients exhibiting diaphragmatic compromise require nasotracheal intubation and ventilatory support. Many practitioners advocate prophylactic intubation in higher level tetraplegics even if they are adequately ventilating initially, as they may soon fatigue and require ventilatory assistance as time progresses. There may also be ascending cord swelling, which could compromise respiratory function. If intubation is required, nasotracheal intubation is preferred over orotracheal intubation or tracheostomy. A tracheostomy could limit surgical access to the spine and should only be performed if there is direct injury to the trachea, or if nasotracheal intubation is technically impossible. As stated previously, great care should be taken not to move the neck out of neutral position. In all severely injured trauma patients, a nasogastric tube should be inserted to decompress the stomach and protect the airway from aspirated vomit.

Blood gases should be obtained, to assure that the patient is ventilating well. Optimal oxygenation is a PaO_2 of at least 100 mm Hg and a $PaCO_2$ of less than 45 mm Hg. A PaO_2 less than 70 mm Hg on room air, or a $PaCO_2$ greater than or equal to 45 mm Hg indicates the need for intubation. According to Soderstrom and Brumback (11), aside from removing or preventing mechanical impingement on the cord (bone fragments, foreign bodies, edema), optimal oxygenation is the most important therapy for injured neurological tissue. Ischemia with resultant hypoxia is a major contributing factor to poor outcome in cord injury.

Circulatory support is the next step. Hemorrhaging should be controlled and vascular access via IV catheter should be obtained to allow for the delivery of fluids and to allow for blood studies. The patient should be assessed for shock. In most trauma patients, blood loss is the cause of shock. However, as stated previously, a patient with SCI above the fourth thoracic vertebra often presents with neurogenic shock. Neurogenic shock should be suspected in any spinal-cord-injured patient who presents in shock without evidence of any other injuries, or in a patient who does not respond to adequate fluid resuscitation. In a study by Soderstrom and Ducker (14), 23 of 111 patients with complete SCIs presented in shock. Of these 23, 19 had neurogenic shock. In those patients presenting with a complete lesion, 60 of 190 presented in shock. In these 60, 49 developed neurogenic shock.

After the primary survey has been completed and the patient’s respiratory and circulatory status have been secured, a more thorough secondary survey should be performed. A thorough neurological exam should be performed to assess whether an SCI has occurred and if so, to determine the extent of the neurological deficit. Recognizing the need for uniform standards to assess neurological deficit in cases of spinal cord injury, the American Spinal Injury Association (ASIA) created the Standards for Neurological and Functional Classification of Spinal Cord Injury (2). These standards provide guidelines for the systematic examination of the dermatomes and myotomes in order to determine the neurologic level of injury. The ASIA Impairment Scale provides a method to characterize any residual function below the level of the spinal cord injury. The neurologic examination should be repeated frequently, so as to detect any deterioration or improvement in neurological function (15).

It is important to determine whether an SCI is complete or incomplete. As stated previously, an incomplete injury is one where there is preservation of sensory and/or motor function below the level of the injury. This must include the lowest sacral segment. Sacral sensation is defined as sensation at the anal mucocutaneous junction, or deep anal sensation. Sacral motor function is defined by the presence of voluntary contraction of the external anal sphincter. A complete spinal cord injury is one in which there is no sensory or motor function in the lowest sacral segments. Surgical intervention and decompression, which will be discussed later, may be based on the completeness of the neurologic injury.

Radiographic imaging plays a crucial role in the evaluation of patients with cervical spinal cord injuries. Routine radiographs remain the single best initial examination for cervical spine trauma. While computed tomography (CT) is a reliable technique to evaluate cervical spinal injuries, it is not an appropriate screening examination (16). The first spine x-ray that should be done is a cross-table lateral view. Hopefully, this can be done in the emergency room with a portable x-ray machine. The patient should remain on the rigid spine board or, if necessary, be transferred carefully to a CT-compatible x-ray cart. It is important that all seven cervical vertebral bodies be visualized on the x-ray, because fractures and dislocations may be missed if the lower portion of the cervical spine is not included (17). It is critical to remember that an apparently normal lateral x-ray does not rule out the presence of a ligamentous injury. Other views such as anteroposterior, swimmer's, oblique, or open-mouth odontoid views may be required. If the initial cervical x-rays are normal and there is no neurological deficit, then voluntary active flexion/extension lateral x-rays may be helpful in determining stability of the cervical spine. In these instances, a physician must be present during the time of imaging.

In cases of cervical SCI, even if the x-rays appear normal, Green et al. (9) recommend the use of Gardner-Wells tongs and at least 10 lbs of traction. This is done because occasionally muscle spasms in the presence of ligamentous instability can cause delayed column deformity and increased neurological deficit. If fracture or fracture dislocation of the cervical spine is demonstrated on x-ray, Gardner-Wells tongs and traction are applied to reestablish spinal alignment. Muscle relaxants are given to aid in the reduction. Serial x-rays are taken to monitor the success of the reduction. More weight may be added if necessary. Closed reduction of the dislocation is then done under fluoroscopic or x-ray control. If these conservative measures are not effective in reestablishing spinal alignment in patients with cervical spinal injuries, then the patient should be taken immediately to the operating room for open reduction and stabilization. An aggressive approach to reestablishing spinal column alignment is an essential part of reestablishing physiologic homeostasis in patients with SCI.

Once reduction has been achieved, or in those cases where reduction is not successful, the patient is taken for high resolution CT scans. High resolution CT scans can be used to detect spinal cord compression by displaced bone and to determine residual canal size. Metrizamide myelograms to assess spinal cord compression are not necessary if high resolution CT scans are available. CT scans can also be used to better elucidate subluxation, fractures, and subtle signs of ligamentous injuries. Magnetic resonance imaging is not yet a practical test for an acute SCI in the Emergency Department, though it can precisely characterize cord integrity and compression later on.

Once all the historical, physical and neurological examinations have been completed, and radiographic data have been collected, a decision is made on the appropriate treatment course for each patient with cervical SCI. It is at this point that surgical management of the spinal injury is discussed.

Surgical Management

The role of surgical intervention in treatment of traumatic cervical spinal cord injuries is controversial. Ideally, its purpose is to improve neurological function where possible, prevent further neurological damage, and restore spinal stability and alignment quickly (18 – 19). However, some believe that surgical intervention is not necessary, and even futile in most cases (20 – 22). Their argument is based on the fact that many studies fail to demonstrate that surgical intervention improves neurological outcome (23 – 27). Further, spinal alignment and stabilization can often be effectively achieved through conservative, nonoperative means such as postural reduction.

When discussing the surgical treatment of a patient with a traumatic cervical SCI, one must distinguish between skeletal injury and neurological injury. Treatment of skeletal injury to the spinal column is directed at reduction, approximation, and stabilization of the spine. Treatment of neurological injury is directed at relieving spinal cord compression by disrupted bone, disc or ligamentous tissue. Therefore, depending on the extent of the injury, indications for surgery may be either orthopedic, neurosurgical, or both.

The orthopedic management of traumatic cervical injuries focuses on determining whether the spinal column is stable or not. Instability may be thought of as the inability to resist physiological forces. An injury is unstable if the injured segments are capable of shifting position and causing nerve damage during the healing phase. The extent of instability can be determined by assessing the pattern of the fracture (i.e., dislocations, compression fractures, burst fractures), the amount of vertebral displacement, and the types of forces involved in creating the injury (i.e., flexion and compression, flexion and rotation, vertical compression, extension). These factors can be determined by the history of the injury, the physical exam of the patient, and the various imaging techniques mentioned previously.

The presence of neurological deficit in itself is usually indicative of significant spinal column injury, and therefore instability should be suspected in these cases. However, there are many instances when patients with tetraplegia present with a stable spine, so neurological deficit is not an absolute indication of spinal instability. It is important to note that major ligamentous injury often creates spinal instability without fracture. In these cases the spine is not only acutely, but also chronically unstable, and will require more aggressive surgical treatment. For the cervical spine, any vertebral subluxation greater than 3.5 mm or angulation of the vertebrae greater than 11 degrees indicates major ligamentous injury, though there are different criteria defining instability for the occiput-C1 and C1-C2 levels.

The treatment of most patients with stable cervical spinal injuries (e.g., compression fracture) is conservative and nonoperative. Nonoperative treatment of cervical SCI is based on Guttmann's methods of postural reduction. These consist of bed rest with spinal alignment maintained through traction, pillows with sandbags, or a cervical collar. Once pain decreases, the patient resumes activities with a collar for a period of 6 – 12 weeks. The fractured area is periodically evaluated radiographically to ensure that progressive deformity does not develop. If deformity is noted, surgical stabilization is necessary. In addition, any sign of progressive neurologic deficit is an indication for surgical stabilization and possibly decompression.

In the case of unstable spinal injuries, many advocate surgical stabilization, whether a neurologic deficit is present or not. Better spinal alignment is achieved in patients treated surgically. In addition, early surgical stabilization allows for earlier mobilization and rehabilitation of patients. For patients with flexion-distraction injuries, surgical stabilization is also required, because these patients are at risk of progressive spinal column deformity if treated conservatively (36). As mentioned above, surgical stabilization also is required in cases of major ligamentous damage because these cases will result in a chronically unstable spine (36).

Surgical stabilization procedures for the cervical spine consist of anterior and posterior fusions. The type of procedure selected depends on the extent of bone and ligamentous damage. Posterior fusion often is used in those cases of cervical injury where decompression is not required. In unstable injuries also requiring decompression, anterior fusion is preferentially performed. Care must be taken in performing anterior fusion in cases with major posterior ligamentous injury. It has been observed that, in these cases, anterior fusion has led to increased cervical spine instability. This is due to the fact that, during anterior fusion, manipulation of the anterior longitudinal ligament and the anterior portion of the vertebral body disrupts anterior column stability. As a result, if anterior fusion is done in a case with major posterior ligamentous injury, then a separate posterior fusion may be required to stabilize the spine.

Since the advent of the halo vest, many unstable injuries in the cervical spine have been treated nonoperatively by this technique. This method of management is satisfactory as long as the reduction of the fracture can be maintained. Stabilization of subluxations and dislocations can also be managed by means of a halo vest after reduction. After 6 – 12 weeks, the injury is evaluated by flexion and extension views under the supervision of a physician. If the injury is stable, the halo vest can be removed. If it is unstable, an additional month in the halo vest is recommended. If the bodies ultimately fail to fuse, surgical fusion is recommended. The halo vest has fallen out of favor in part because it impedes rehabilitation, especially in the higher level tetraplegic.

Neurological deficits in traumatic cervical SCI are often managed by the neurosurgical team. Following spinal cord injury there may be compression on the spinal cord by bone, disc or ligamentous elements. Cord compression compromises neurological function, so it seems logical that surgical decompression be performed if there is any hope of recovering neurological function (28). However, surgical decompression after traumatic cervical SCI is the subject of much controversy. It is uncertain what effect persistent compression on the cervical spinal cord after a traumatic injury has on neurological outcome. Some believe that maximum damage to the spinal cord occurs at the time of injury, so that surgical decompression after the initial trauma will not improve neurological outcome. Wagner and Chehrazi (27) agree that initial injury to the cervical spinal cord remains the primary determinant of neurological outcome, and severe canal narrowing (>30%) with cord compression thereafter appears to have comparatively little effect. However, it is impossible to state that decompression has no effect on neurological outcome, since there have been no studies using a control group whose spinal canals remained compromised. The opinion of many other physicians on this subject is summarized by Bohlman et al. (1). Even though the initial contusion may have caused most or, in many cases, all of the neurological damage, it is the obligation of the treating physician to free the patient of any pathological process that may continue to contribute to the malfunction of the cord.

Despite the controversy, there is some agreement on surgical decompression. It is generally agreed that surgical decompression with stabilization is indicated in patients with cervical spinal injuries who show signs of progressive neurological deterioration and who have evidence of neural compression. Early surgical decompression with stabilization is also recommended for patients with incomplete injuries who, while they may be neurologically stable, have bone or ligamentous material compressing the spinal cord. Bohlman et al. (1) have reported recovery of neurologic function after anterior decompression in these patients. However, there is no reason for early surgery in patients with incomplete injuries who are showing progressive improvement in neurological function. If there is evidence of significant spinal cord compression, surgery at a later date may be considered when neurological improvement has reached a plateau.

Most studies indicate that patients with complete SCIs do not improve neurologically with decompression. As a result, there is no absolute indication for decompression surgery in these patients. However, there may be relative indications to consider. For example, in cases of cervical SCI with radiographic evidence of nerve root compression, an anterior decompression of the cervical roots may lead to recovery in the function of one motor level that ultimately is extremely important in determining the physical capabilities of a tetraplegic.

In many cases, adequate spinal alignment will prevent the need for operative decompression. However, if satisfactory spinal alignment cannot be achieved, operative reduction and decompression are indicated. There are two surgical decompressive procedures: anterior decompression with fusion, and laminectomy. The selection of a spine decompression procedure depends on the location of the spinal cord compression. Posterior laminectomy for decompression in SCI is rarely indicated. In most cases of traumatic SCI, compression occurs at the anterior aspect of the spinal cord. Laminectomy does not provide adequate decompression. In fact, removal of the posterior part of the spinal column could contribute to further instability and neurologic loss. Instead, anterior decompression is performed to remove disc, bone, and ligamentous tissue that is compressing the spinal cord anteriorly. Studies have shown that anterior decompression with fusion in incomplete SCI gives better results than laminectomy or conservative treatment. Laminectomy may be indicated in those cases in which blood, bone, or ligamentous elements are causing compression posterior to the spinal cord. Once anterior decompression is completed, it is important to assure spinal stability by performing a fusion procedure to prevent any further spinal cord damage.

Pharmacological Management

Prevention of further injury to the spinal cord and reestablishment of "physiologic homeostasis" are the most important goals in the early treatment of traumatic cervical SCI. Until recently, this was achieved solely by the methods described previously: normalization of vital signs, maintenance of sufficient blood oxygen levels and reestablishment of spinal alignment and stabilization. However, recent advances in the understanding of the pathophysiology of SCI have led to the realization that post-traumatic changes occurring locally at the cellular level contribute to further injury of the spinal cord. In fact, so damaging is the secondary injury from these pathophysiological and pathochemical changes, that sensory and motor function initially present after the injury may progressively be lost over the next few hours (29). With this in mind, a great deal of attention has been directed at methods of reducing the secondary injury.

The synthetic glucocorticoid, in the form of methylprednisolone sodium succinate (MPSS), has become standard treatment in an acute SCI. The Second National Acute Spinal Cord Injury Study (NASCIS-2) was a multicenter, randomized, double-blind placebo controlled trial which evaluated the efficacy of MPSS and naloxone, an opiate receptor blocker, in the treatment of traumatic SCI (30). This landmark study found that patients receiving exceptionally high doses of MPSS (intravenous bolus of 30 mg/kg body weight, followed by infusion at 5.4 mg/kg per hour for 23 hours) begun within the first 8 hours of the injury showed improved neurological outcome as compared with those receiving placebo or naloxone. This improvement in motor function and sensation was seen at 6 weeks and at 6 months after injury. Further follow-up showed these neurological improvements continued to be observed one year after injury (31).

NASCIS-2 not only confirmed the role of MPSS in the treatment of traumatic SCI, but it redefined its role in the early stages of the injury. The timing of the first dose of MPSS is crucial. Only those patients receiving the drug within the first 8 hours following their injury showed improved neurological outcomes. In addition, a follow-up study found that patients receiving MPSS more than 8 hours post-injury actually recovered less motor function than those given the placebo. The results from NASCIS-2 also altered attitudes toward complete spinal cord injuries. Conventional wisdom stated that while incomplete spinal cord lesions may recover, complete lesions do not. As a result, many people believed that patients with complete spinal cord lesions would not benefit from treatment with MPSS. NASCIS-2 showed that while patients with incomplete injuries recovered more function than those with complete injuries, both groups benefited from the treatment.

GM-1 ganglioside (monosialotetrahexosyl ganglioside) is another drug that has received a great deal of attention for its potential role in the treatment of SCI. GM-1 is a complex acidic glycolipid found at high levels in the cell membranes of the mammalian central nervous system. It is believed to have neuroprotective and neurofunctional restoration potential (32). The Maryland GM-1 trial was a prospective, randomized placebo-controlled double-blinded clinical trial to evaluate the efficacy of GM-1 in the treatment of traumatic SCI (33). The trial group consisted of 34 patients with major motor deficits. Of this group, 16 received GM-1 and the other 18 received a placebo. The GM-1 group received 100 mg/day IV GM-1 for anywhere from 18 32 days (mean of 25.9 days). The first dose was given within 72 hours (mean of 48.2 hours) postinjury. Both study groups also received 250 mg MPSS IV on admission, followed by 125 mg IV every 6 hours for 72 hours. The researchers found that patients receiving the GM-1 ganglioside showed enhanced neurological recovery after one year. Analysis of individual muscle recoveries revealed that the increased recovery in the GM-1 group was attributable to initially paralyzed muscles regaining useful motor function rather than to paretic muscles gaining more strength. It was also noted that recovery consisted of enhanced motor recovery in the lower extremities rather than solely in the upper extremities. The researchers believed that enhanced recovery in the lower extremities corresponded with improved recovery through the injury site. The results from the Maryland GM-1 trial are promising and may point toward another drug for the treatment of traumatic spinal cord injuries. However, a larger study, combining high dose MPSS with GM-1, has yet to confirm a benefit from this treatment. GM-1 has not yet become an approved agent in the United States for this purpose.

In 1997, the Third National Acute Spinal Cord Injury Study (NASCIS-3) was published (34). The three arms of this study were: (1) 24-hour treatment with methylprednisolone; (2) 48-hour dosing (30 mg/kg bolus followed by 48 hours of a 5.4 mg/kg intravenous infusion); and (3) treatment with tirilizad mesylate, a potent inhibitor of lipid peroxidation (35). The tirilizad was administered by intravenous bolus every 6 hours for 48 hours following a standard 30 mg/kg bolus dose of MPSS. Lipid peroxidation, a destructive chemical reaction known to occur as a component of the secondary injury, is inhibited by both high dose MPSS and tirilizad mesylate, a synthetic glucocorticoid analog.

The study, which enrolled nearly 500 spinal-cord-injured individuals from 15 North American centers, demonstrated equivalent efficacy of the 3 treatments if the initial bolus dose of MPSS was given within 3 hours of the injury. Individuals treated with the 48-hour infusion of MPSS had neurologic outcomes superior to those of the other treatments when the initial steroid dose was given between 3 and 8 hours after injury. Though 48-hour treatment with MPSS was associated with more episodes of sepsis and severe pneumonia than 24-hour treatment or with tirilizad, the authors felt that the small increases in these adverse events should not prevent using a prolonged course of MPSS in individuals treated between 3 and 8 hours after their injury.

It is clear that the ultimate outcome for an individual suffering a cervical SCI is largely determined by the quality of the acute treatment provided. Careful management at the injury scene, efficient transport to the hospital, and skilled, experienced personnel with appropriate knowledge of surgical and pharmacological treatment give the injured person the best chance to make a meaningful neurological and functional recovery, while limiting the acute medical complications.

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