Approach and considerations regarding the patient with spinal injury

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Summary¹ Spinal trauma often results in a complex interaction of injuries to the musculoskeletal and nervous systems. This combination of biomechanical and neurological considerations provides a unique challenge to those dealing with the spinally injured patient.

Proper assessment of the injuries sustained by the patient remains the initial, yet key, step in determining appropriate management. The aim of the physical examination is not only to characterize the nature of the injury to the vertebral column, but also to determine the extent of actual and potential damage to the neural elements. It is also concerned with detecting associated injuries of the brain, viscera, and limbs that can impact on management and outcome, particularly of any neurological deficit. Further information about the spinal column and spinal cord is derived from appropriate radiological assessment, which is evolving with the increasing sophistication of imaging modalities. In spinal injury, classification systems are particularly important as they simplify a diverse range of injury patterns into a useable and reproducible form that may be used to aid communication among clinicians, guide management for individual patients, and provide the basis for research consistency.

The medical management involves consideration of the impact of spinal injury, in particular cord injury, on aspects including resuscitation and anticoagulation, as well as the role of steroids. The definitive management of the spinal column injury may be operative or nonoperative. Factors influencing this decision are biomechanical (stabilization of the unstable spine and reduction of deformity) and neurological (improvement in deficit and decompression of neural elements). This article considers these issues and aims to present a balanced and useful algorithm for clinicians to use when faced with spinal injury.

Introduction

Trauma provides the spine surgeon with an almost limitless number of variations in injury etiology, patterns, and severity. This diversity can result in confusion as to the most appropriate investigations and management, and the timing of these interven-

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The management of each episode of spine trauma passes through three phases, ie, prehospital care, assessment, and finally treatment. Prehospital care is important in the management of spine trauma, but is not the focus of this article, which addresses the latter two phases.

The modern spine surgeon has the benefit of being able to blend the timeless instrument of clinical examination with modern radiological, pathological, and neurological assessment. Following this assessment, management considerations are addressed. The surgeon must be cognizant of non-surgical treatment considerations and these are outlined. The surgical approach under discussion will be addressed mostly as concepts as detailed discussion is contained elsewhere within this supplement.

This paper attempts to provide a practical yet safe and clear approach to the patient with spinal trauma. The general concepts covered in this article provide a basis for the detailed discussions of the complex management questions that follow in the subsequent papers. An attempt has been made to provide useable guidance while maintaining an appropriate degree of scientific discussion. Areas of controversy in the literature have been clearly delineated, and in these circumstances we have provided the management approach used in our institution as a basis for further discussion.

### Assessment

#### Examination

There are two key objectives of the clinical assessment of the patient who has suffered an injury to the spine. The first is to ascertain the presence of concomitant injuries. One study [2] found 47% of patients with spine trauma had associated injuries; 26% with head injuries, 24% chest injuries, and 23% long bone injuries. Abdominal injuries and lumbar spine fractures often coexist and are overlooked. There is a common association between flexion-distraction (Chance-type) lumbar injuries and hollow viscus injuries in seatbelt injuries. In one study, 12 of 20 patients with a Chance fracture had life-threatening intra-abdominal trauma, the majority being a bowel wall injury [3]. Most had abdominal wall bruising, which should be considered as a sentinel sign.

The second objective is to ascertain the presence of a neurological deficit. A thorough, accurate, and well-documented neurological examination at the primary hospital is paramount. If the information is incomplete and the patient’s neurological deficit varies when re-examined, it is unclear whether the situation has changed or whether the initial assessment was flawed. This may alter the urgency of subsequent management. Neurological assessment should be performed according to the guidelines developed by the American Spinal Injury Association [4] and recorded on the Standard Neurological Classification of Spinal Cord Injury worksheet, which is readily downloadable (http://www.asia-spinalinjury.org/publications/2001_Classif_worksheet.pdf) (Fig 1). This chart both guides the clinician through the examination and provides a concise summary of the neurological status. It is important to include a rectal examination because it has implications when assessing the

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### ASIA IMPAIRMENT SCALE

- **A = Complete:** No motor or sensory function is preserved in the sacral segments S4-S5.
- **B = Incomplete:** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.
- **C = Incomplete:** Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.
- **D = Incomplete:** Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.
- **E = Normal:** Motor and sensory function are normal

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### CLINICAL SYNDROMES

- Central Cord
- Brown-Sequard
- Anterior Cord
- Conus Medullaris
- Cauda Equina

Fig 1: Classification worksheet.
completeness of the deficit. The only difference between a complete and incomplete neurological deficit may be the presence of sacral sparing as identified by the presence of anal sensation. It also has relevance to determining the presence of spinal shock.

Spinal shock is a commonly used but poorly understood term. By definition, it refers to the loss of spinal reflexes (somatic and visceral) caudal to a spinal cord injury [5]. It is thought to be due to the loss of background excitatory input from supraspinal axons [6]. Its resolution is defined by the recovery of spinal reflexes, which is likely to be due to denervation supersensitivity. Spinal shock may be considered as the first phase of the response of the spinal cord to injury, with later phases representing the development of hyperreflexia and spasticity. The clinical significance of spinal shock is the associated loss of motor function, resulting in an initial flaccid paralysis below the lesion. As spinal shock resolves, residual motor function in an incomplete lesion can be unmasked. The return of the bulbocavernous reflex is usually cited as marking the resolution of spinal shock. The bulbocavernous reflex is the contraction of the anal sphincter in response to a tug on a bladder catheter, or to pinching of the penile shaft. This usually occurs within 24 hours of injury, but the reflex is not always initially lost and may take longer to recover, which can make assessment confusing. The other clinical relevance of spinal shock is the associated loss of autonomic reflex activity, which has implications on maintenance of blood pressure [7]. This phenomenon, which is termed neurogenic shock, is discussed later.

Imaging

The relative role of plain films, CT scan, and MRI scan to image the injured spine is evolving. Changes such as improvements in scan availability, image quality, acquisition time, and image reformating have cast doubt upon long-held beliefs regarding appropriate investigation.

Figure 2: Algorithm for imaging the cervical spine.
Cervical imaging: In the evaluation of cervical spine injuries, the standard protocol has been a 3- or 5-view plain film series, including lateral, AP, and odontoid films, with or without oblique views. However, there is an increasing trend advocating the use of helical CT scan to supplement or even replace plain x-rays [8, 9]. This is due to the fact that plain films often do not provide an adequate view of the whole cervical spine and even when they do, significant numbers of injuries are missed. In a prospective study, a large group of blunt trauma patients with altered mental status or distracting injuries underwent CT head and cervical spine, and then had plain films with five views of the cervical spine. Plain films missed 52.3% of cervical spine injuries, including unstable injuries, in five of 17 patients [10].

Ligamentous injuries are particularly problematic as they are often overlooked in static plain x-ray and CT. Although unstable ligamentous injuries without fractures are rare [11], their potential presence causes considerable concern and often delays "clearing" the cervical spine in the unconscious patient. Ligamentous injuries can be assessed by flexion-extension plain films [12], dynamic fluoroscopy [13], or MRI [14]. None is ideal or universally applicable. Flexion-extension plain films cannot be safely obtained in the unconscious or uncooperative patient. In the alert patient, subtle instability may be initially masked by muscle spasm. Dynamic fluoroscopy is time-consuming, difficult in the ICU or ward setting, and must be performed by experienced staff [11]. MRI is a significant undertaking in critically ill patients, and the sensitivity of MRI for posterior ligamentous injuries is not yet defined. Using established clinical guidelines [15, 16], a practical algorithm for imaging the cervical spine has been developed (Fig 2). The algorithm maintains the use of the readily obtainable single lateral plain film in the unconscious or multitrauma patient, despite subsequent CT scan, as it may provide an early indication of the likelihood of a significant cervical spine injury. The algorithm also highlights the importance of repeat assessment. Where there is ongoing clinical concern despite normal imaging, subsequent review and reassessment may identify a previously missed injury. It is in this setting that flexion-extension plain films are probably of most value.

Thoracolumbar imaging: In the thoracolumbar spine, similar concepts apply. In the alert patient without distracting injury or neurological deficit, the requirement for imaging is guided by symptoms and signs. The absence of back pain and tenderness has been shown to exclude a thoracolumbar injury [17]. If there is a clinical suspicion of spinal injury, plain x-rays are obtained, possibly including erect films to demonstrate loss of integrity of the posterior tension band under axial loading. Suspicious areas should be further investigated with high definition CT scan.

There is an increasing trend in trauma management to exclude visceral injury through the use of helical acquisition CT of the chest, abdomen, and pelvis before formal imaging of the spine is considered. Through these images, visualization of the whole spine is immediately available. It has been shown that the quality of the truncal CT is sufficient and actually more accurate than plain films in diagnosing thoracolumbar spine trauma [18].

MRI scan is indicated in the presence of neurological deficit and also may have a role in the diagnosis of discoligamentous injuries.

Caveat: The treatment of life-threatening injuries takes precedence over "clearing the spine", as long as the spine is adequately immobilized. Maintenance of airway patency is of paramount importance in trauma management. Insistence on a complete imaging series, with associated time delays and transfer out of the Emergency Department to imaging facilities, can adversely affect the management of other injuries.

Classification

Classification of spinal injury has great relevance. It facilitates communication among clinicians, assists in making treatment decisions, and aids in predicting outcome. It also provides a standardized language to assist research.

Thoracolumbar spine: There are two classification systems in common use, the Denis system and the AO classification. The Denis system [19], based on the concept of the 3-column spine, became a near-universal standard after its introduction, and remains so in many parts of the world. It divides major spinal injuries into four categories—compression, burst, seat-belt-type, and fracture-dislocation. The advantage of the Denis system is that it uses familiar descriptive terms, making it easier to remember. But it has a number of disadvantages. The middle column upon which it is based is a conceptual rather than an anatomical structure, consisting of the posterior longitudinal ligament and the posterior part of the vertebral body and annulus. While some studies support its significance in determining spinal stability [20], others have found that the integrity of the posterior elements is more important [21]. Another disadvantage is that it is not hierarchical, with no pattern of increasing injury severity within or across groups. This decreases its value in assisting with treatment decisions or outcome prediction. It does
not specifically recognize the burst fracture with posterior bony or ligamentous injury, the presence of which has important treatment implications.

The thoracolumbar injury classification adopted by AO was developed in 1994 [22]. As with other AO classifications, it is hierarchical, and based on an alphanumerical grid (e.g., A.1.2.3). It is mechanistic rather than descriptive, and unlike the Denis system, is based on two columns, the anterior compression-resistant vertebral body and the posterior elements that resist tension. The distinctions between and within the three groups (types A-C) reflect injury severity and guide treatment. 'A' type fractures are compression injuries to the anterior column. They may be crush fractures (A1), split fractures (A2), or burst fractures (A3), but the posterior tension band is intact. 'B' type injuries are distraction injuries. Of importance is that the posterior tension band is disrupted. In B1 injuries, the posterior disruption is primarily ligamentous, and B2 injuries involve posterior bony disruption. Both B1 and B2 injuries also involve the anterior column, and do so in one of two ways. The first is with disruption of the disc, and the other is with an A3 burst-type injury to the vertebral body. It is vital to distinguish this B-type "complex" burst fracture with posterior disruption from the more stable "simple" A3 burst fracture, as added disruption of the posterior tension band has important treatment implications. This distinction is often overlooked, especially if the injury is ligamentous. Its presence is suggested by local tenderness and swelling with a palpable gap on examination, increased interspinous distance on plain x-ray and sagittal reformatted CT scan, and increased posterior soft tissue signal intensity on sagittal T2 weighted MRI. A B3 injury is a rare extension injury through the disc. This is the exception to the rule, where the posterior column may be intact. 'C' type injuries are high-energy injuries to both anterior and posterior columns with associated rotation. They are...
subclassified according to whether they are primarily A-type injuries with rotation (C1), B-type injuries with rotation (C2), or rotational shear injuries (C3). While precise classification of fractures using the AO system is useful for research, use of the classification at a more basic level, by understanding the fundamental concepts and using a simple algorithm to determine the broad groups, makes the system a very useful clinical tool (Fig 3).

Cervical spine: Unlike the thoracolumbar spine, the cervical spine does not lend itself to a single classification system. The atypical C0-C2 region necessitates separate consideration of different injury patterns, including atlanto-occipital dissociations, occipital condyle fractures, fractures of the atlas, atlanto-axial rotatory instabilities, odontoid fractures, and traumatic spondylolisthesis of the axis. Fortunately, well established and accepted classification systems exist for each of these injuries. In the subaxial cervical spine, it seems that the Allen and Ferguson classification system [23] is most widely used. It is mechanistic and divides injuries into six groups, each named according to the dominant force leading to failure and the presumed position of the head at the time of injury (Fig 4). Each phylogeny has a number of stages, representing increasing severity of injury. Adoption of the classification system can facilitate communication and minimize confusion, avoiding ill-defined terms such as teardrop injury (which can refer to highly unstable flexion-compression injury or a more benign extension-avulsion injury). It can improve injury assessment by ensuring that fracture patterns are carefully scrutinized in order to classify them. For example, the less common extension-compression type injury can often be confused with a flexion-distraction (facet dislocation) injury as both result in a forward displacement of the cephalad vertebra, but these injuries behave quite differently and require different treatment approaches. Attempts have been made to apply the concepts of the AO thoracolumbar classification to the cervical spine to gain the benefits of a hierarchical classification that reflects increasing injury severity and helps dictate treatment. However, because of inherent differences between the two anatomical regions, there are limitations of this approach and the classification has not been widely accepted.

Medical treatment

Resuscitation

Effective resuscitation is critical to the early management of the patient with spinal cord injury. While reversal of the primary injury is not currently

Fig 4: A mechanistic classification of subaxial cervical injuries, as modified from Allen et al [2].
possible, secondary injury may be reduced through maintenance of adequate tissue oxygen delivery. Hypotension is commonly seen in spinal injury, and may be due to hypovolemia or neurogenic shock. Hemorrhagic shock from associated injuries of the abdomen, pelvis, or long bones requires prompt recognition and control, and simultaneous aggressive fluid resuscitation.

Neurogenic shock is unique to spinal cord injury, and is a result of the loss of sympathetic outflow, related to spinal shock. This causes vasodilatation of the viscera and peripheries, resulting in relative hypovolemia and subsequent hypotension. The reduced blood pressure is not accompanied by reflex tachycardia in cervical cord injury due to the loss of sympathetic outflow and the unopposed vagal effects.

It is important to determine the correct cause of hypotension in spine trauma. The administration of copious intravenous fluids to a patient with normal blood volume who is in neurogenic shock may result in pulmonary edema, particularly if the cardiac responses to increased venous return are impaired. While the pulmonary edema may be reversed with i onotrope management and ventilation, further neurological injury cannot. Hence, it is reasonable to err on the side of aggressive fluid resuscitation for hypotension of uncertain cause.

Early insertion of an indwelling catheter is vital, both to prevent bladder overdistention and to monitor urine output.

Respiratory difficulties may arise either as a result of primary trauma to the chest, or due to reduction in respiratory function related to paralysis. Both these pathologies may result in hypoxia with its implications for secondary neurological injury, and predispose the patient to lung infection. Supplemen tal oxygen should be initiated immediately, and oxygen saturation monitored. Arterial blood gas testing may be used where pulse oximetry may be inaccurate as well as to assess for an increase in blood carbon dioxide levels, which may be the first sign of respiratory failure.

**Steroids**

Initially based on the effect on cerebral edema and on animal studies, the use of corticosteroids in spinal injury was established by the National Acute Spinal Cord Injury Studies (NASCIS). After the release of the NASCIS II study [24], the use of high-dose methylprednisolone in spinal cord injury became the standard of care. More recently, many have advocated against its use [25], primarily due to the shortcomings of the NASCIS II study, with its post hoc substratification into arbitrary groups, the seemingly contradictory outcomes within these groups, and the lack of widespread reproducibility of its results. On the other hand, the fact that there is some hope of benefit, that side effects (possibly apart from pneumonia) do not appear to be overly problematic, and the fear of adverse medicolegal implications has meant that others continue to advise its use. Most centers currently adhere to the NASCIS II guidelines but many are revising them to discontinue or limit the use of methylprednisolone. It remains to be seen whether this change will fundamentally alter the outcome of neurological injury.

**Anticoagulation**

The prevention of deep vein thrombosis (DVT) and pulmonary embolism (PE) is an important consideration. The risk of thromboembolism is greatly increased after spinal cord injury, with a real risk of death from PE of an otherwise healthy young patient. It is also increased in spinal trauma without neurological injury, as a consequence of associated injuries, prolonged immobilization and spinal surgery. In spinal cord injury, clear guidelines have been established [26]. Mechanical prophylaxis should be instituted on admission, ideally with compression stockings and pneumatic compression devices, and should continue for two weeks. Chemoprophylaxis is also indicated. Low molecular weight heparin (LMWH) should be commenced on admission, and continued for eight weeks (or until discharge for incomplete lesions). Substitution of unfractionated heparin for LMWH should be considered if there is likelihood of surgery, because of the difficulties in reversing LMWH and the risks of anticoagulation in spinal surgery (see below). LMWH should be instituted 48-72 hours postoperatively to avoid complications of wound and epidural hematoma. If anticoagulant therapy is contraindicated or has failed, the use of a vena cava filter should be considered.

For neurologically intact patients requiring prolonged immobilization, thromboprophylaxis should be tailored to the presence of recognized risk factors for thromboembolism. For those undergoing surgery, it is impossible to devise a standardized prophylaxis regimen because of the number of variables that need to be considered [27]. There are three types of variables: patient-related, such as age and past history; disease-related, such as the presence of other injuries; and surgery-related, such as the approach and operating time. The other impediment to the development of guidelines is the reluctance of spinal surgeons to use chemoprophylaxis because of the particular risks in the spine. Epidural
hematoma is a potentially disastrous complication, as it may result in permanent neurological deficit despite early decompression. Wound hematoma may predispose to both superficial and deep infection with considerable consequences in the presence of instrumentation.

Surgical treatment

Indications

It is beyond the scope of this article to provide specific recommendations for each type of fracture. In broad terms, surgery can be considered for a number of reasons.

1 Biomechanical

To stabilize an unstable spine: This is the primary indication for surgery, as an unstable spine has the potential to cause deformity and neurological injury. However, defining stability adequately is difficult, especially when attempting to extrapolate the definition to assist in surgical decision-making.

In the thoracolumbar spine, the AO classification system provides some guidelines for surgery. Some fractures are clearly stable (such as A1 crush fractures) and some are highly unstable (such as C3 rotational shear injuries). However, there is a grey zone between these extremes that encompasses injuries such as severe A3 burst fractures, which are stable except to a compressive force, and undisplaced B2 bony Chance-type fractures, which are unlikely to further displace. This concept is schematically demonstrated in Fig 5. In almost all cases, C fractures require surgical stabilization. The majority require anterior and posterior fixation to resist translation and shear. Most B fractures should also be considered for surgery. The posterior tension band is disrupted, reducing resistance to flexion and predisposing to kyphosis. Surgery usually involves reconstructing the tension band with posterior instrumentation. Occasionally, minimally displaced primarily osseous injuries can be treated with an orthosis.

In the cervical spine, similar concepts to guide treatment exist but are not as clearly defined by the classification system. In general, injuries involving both the anterior and posterior columns require surgical stabilization, especially if they involve the soft tissues (ie, the disc anteriorly and the ligaments posteriorly). Examples are high-grade flexion-compression (flexion teardrop) fractures and flexion-distraction injuries (bifacetal dislocations). Flexion-compression fractures are usually treated with anterior vertebrectomy and plate fixation. Bifacet dislocations may be treated with anterior discectomy and fusion, or posterior fixation alone. In some cases where there is gross circumferential soft tissue disruption, anterior and posterior fixation may be indicated.

To reduce a deformity: This discussion primarily applies to simple burst fractures, both in the cervical and thoracolumbar spine. These injuries are never grossly unstable because of the intact posterior tension band. Gradual loss of anterior height and progressive kyphosis may still occur with collapse of the vertebral body, which is why surgery may be advocated. The literature reveals a great divergence of opinion, particularly with respect to A3 burst fractures of the thoracolumbar junction. Traditional guidelines for surgery have used the degree of kyphosis or loss of anterior height to determine whether or not to operate, but it has been shown that residual deformity is a poor indicator of ultimate clinical outcome [28], and that most burst fractures can be successfully treated nonoperatively with early mobilization with or without an orthosis. A prospective randomized trial compared the outcome of patients with burst fractures without neurological deficit, randomized to surgery or an orthosis. No significant difference was found with regard to the final degree of deformity or canal compromise, and those treated nonoperatively had less pain, less disability, and fewer complications [29]. A proviso of nonoperative treatment is the requirement for regular clinical review, using erect x-rays to permit detection of unsuspected posterior tension band injury (type B fractures) that may require surgical stabilization.

In the cervical spine, burst fractures with some deformity can similarly be successfully treated with the use of an orthosis. There is a tendency to accept less kyphosis than in the thoracolumbar spine, as there may be a greater propensity for premature adjacent segment degeneration and pain. Again, if
Nonoperative treatment is employed, regular monitoring is vital to allow early detection of posterior injuries.

2 Neurological

To improve neurological deficit: Prima facie, it remains reasonable, at least in the minds of some, to relieve neural compression in the hope that function returns. These concepts are not without a valid basis in the cranial cavity, yet this experience has not translated into compression of the spinal cord.

Complete neurological deficit suggests neuronal death and would therefore not be expected to improve with surgery. Progressive neurological deficit is a well accepted indication for surgical intervention. However, in a stable incomplete lesion, it remains to be resolved whether surgical intervention improves neurological recovery. It is likely that in any acute incomplete injury there is a cohort of “sick” neurons that may respond to improved oxygen delivery. Reduction of local tissue pressure through decompression may assist in this recovery.

Experimental studies in animal models show improved neurological outcome after surgical decompression [30], and some observational clinical studies report improvement in clinical outcome with surgery [31]. However, a review of the literature by Boerger et al, failed to establish a significant advantage of surgical treatment for neurological improvement.

A high energy impact injury, where a considerable degree of force is transmitted to the cord, is likely to result in irreversible injury to the neurons and their connections. Although a low energy injury may not cause significant direct neuronal damage, it may be associated with a compressive lesion such as in bifacet dislocation. Both scenarios may present with extensive loss of neurological function. Where the former is unlikely to respond to decompression, the latter may respond favorably, especially in younger patients [33]. Until this question is definitively answered in the literature, it is likely that many surgeons will continue to offer surgical decompression to patients with incomplete neurological deficits.

To decompress the neural elements: Canal compromise in the absence of neurological deficit may be considered a reason for surgery [34], especially if the canal is severely narrowed by bony retropulsion. However, the evidence for this is sparse. The canal has been shown to remodel spontaneously [35] and within twelve months one can expect more than 50% improvement in canal dimensions [36]. There is no evidence that spinal stenosis will result in the future when degenerative changes occur later in life.

When fixing a fracture for biomechanical reasons where there is neurological deficit, and the canal is narrowed by bony retropulsion, it is tempting to perform a laminectomy to decompress the neural elements, and even to attempt to reduce the retropulsed fragment directly. However, it has not been shown to improve outcome, and exposure of the dura increases the risk of further neural injury. An alternative strategy is to rely on indirect reduction via ligamentotaxis.

Timing

Optimal timing of surgery is a result of a complex range of variables related to the institution, the patient, and the surgical team. Life threatening injuries need to be treated immediately, followed by salvage of the threatened limb. If decompression of the spinal cord is advocated, earliest possible intervention may be desirable [37-39]. However, logistical and ethical constraints may limit preferred practice and even prospective randomized assessment of the influence of timing on outcome. The role of early decompression is comprehensively dealt with elsewhere in this supplement.

The future

Some new surgical techniques that have been developed in other areas of spine surgery may be applicable in trauma.

Minimally invasive surgery purports to promote faster recovery through reduced approach-related tissue damage and intraoperative blood loss while maintaining surgical efficacy at the operative bed [40]. Perhaps the best use of this technology will be in anterior approaches to the thoracolumbar spine in the multiply injured patient, for whom reduced blood loss and tissue exposure will promote hemodynamic stability and limit exposure to the risk of respiratory disease. While percutaneous thoracolumbar pedicle screw systems have been available for several years [41], their usefulness in trauma is limited by an inability to undertake significant reduction and provide stabilization over any more than two motion segments.

Image guidance systems have a significant benefit for the surgical team with respect to better three-dimensional understanding of the fracture complex, reduced exposure to ionizing radiation and perhaps an improvement in the accuracy of instrumentation placement in difficult trauma cases. The development of navigation from image intensification, and more recently three-dimensional fluoroscopy-
guided navigation [42] has increased the utility and ease of application of the technology. However, it is unlikely that any of these advances in surgery will make a significant contribution to improving the outcome of spinal cord injury. This privilege will lie with scientists developing novel therapies to regenerate the spinal cord or limit secondary injury [43]. Hopefully, surgeons will have a role in delivering these treatments. Cellular therapies for regeneration have shown great promise in animal models and human trials have commenced. A randomized phase 1 study of autologous adult olfactory ensheathing cells has begun and is in the observation phase following implantation [44]. Other modalities using a variety of stem cells and fetal cells have been proposed. It is essential that in the future clinicians forge closer cooperative collaborations to address the issues of spinal cord injury, questioning dictums, and approaching the new possibilities and technologies in an open and considered manner. Perhaps this remains the most fundamental consideration and approach in the management of spinal injury.

References


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