Role of Decompressive Surgery in Disorders Associated with Spinal Cord Lesions

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1. Introduction

Paraplegia/tetraplegia represents a significant neurologic disability with loss of motor and sensory function in the lower extremities and/or impairment of sexual, urinary and intestinal functions. Involvement of the spinal cord explains most cases of paraplegia/tetraplegia with pathological lesions commonly resulting from trauma or a progressive neoplastic disease of the spine. In such cases, paraplegia/tetraplegia occurs either acutely or results from a chronically progressive spinal pathology, warranting urgent surgical decompression. Surgical decision-making and the rationale for spinal decompression are based on the anticipated increased risk of paraplegia/tetraplegia in cases where there is evidence of progressive functional loss. This chapter aims to review the current state of spinal surgery and to provide an evidence-based approach to the management of common compressive spinal disorders associated with paraplegia/tetraplegia, including degenerative conditions, such as acute traumatic spinal cord injury, cervical spondylotic myelopathy and spinal metastatic disease.The surgical management of each category is discussed separately below.

The anatomical structures maintaining spinal stability and various methods of assessment of spinal instability are discussed. The reminder of the chapter explores up-to-date evidence on the management of compressive myelopathies. In addition, we discuss the most recent evidence and clinical guidelines surrounding the acute management of traumatic cervical spinal cord injury and timing of surgical decompression. Furthermore, this chapter outlines the epidemiology and pathophysiology of cervical spondylotic myelopathy, which is explained in order to provide a foundation to the understanding of prognosis and timing of surgical decompression. Different approaches including anterior and posterior decompression are discussed, explaining the rationale for each approach based on an appraisal of published clinical evidence. The advantages and disadvantages of laminectomy with arthrodesis are

reviewed and compared to laminectomy alone and other techniques such as laminoplasty. Finally, management of spinal metastasis as an important etiology for paraplegia is explained. The rationale to surgical decompression is explored on the basis of clinical trials with brief elaboration on the epidemiology and pathophysiology of spinal metastasis.

2. Requirement for spinal stability

Spinal stability constitutes a crucial factor in the surgical management of most spine disorders, serving as a strong indication for surgical intervention in many diseases of the spine. Spinal instability may co-exist with traumatic disorders of the spine as well as non-traumatic disorders such as metastatic and degenerative disease.

Spinal stability has been defined conceptually by Panjabi et al. (1993) as the ability of the spine, under physiologic loads, to limit displacement and deformity in order to prevent neurologic deficits, due to injury to the neural elements (spinal cord and nerve roots), and pain as a result of structural changes. Loss of the ability of the spine to resist displacement is recognized as spinal instability, which increases the risk of neural injury or occurs in association with neural injury. Resistance against such deforming forces stems from passive, active and neural control spinal subsystems, which form the spinal stabilizing system. The skeletal system represents osseous and ligamentous structures including vertebrae, intervertebral discs, spinal ligaments, facet articulations and joint capsules, which all contribute to passive spinal resistance forces. The active subsystem is resembled by muscles and related tendons that surround the spinal column, possessing an active force against spinal deformity and neural injury. Finally, the neural and feedback subsystem is composed of a variety of sensory receptors in ligamentous and muscular structures forming part of the neural feedback system acting reflexively on active and thereby passive subsystems to prevent spinal deformity and neural injury.

The first structural description of spinal stability in the context of a two-column approach was published by Frank Holdsworth et al. (1970). He proposed that spinal instability is sufficiently accounted for by rupture of the posterior ligamentous complex (PLC). However, emerging biomechanical evidence is contradictory in that isolated disruption of the PLC is not necessarily a cause of spinal instability except in cases where evidence of disruption of the posterior longitudinal ligament and tearing of the annulus fibrosis also exists. Therefore, Denis et al. (1983) suggested a three-column approach in assessing the stability of the spine following acute spinal trauma. The anterior longitudinal ligament together with two thirds of the vertebral body form the anterior column, whereas the middle column encompasses the posterior longitudinal ligament, the posterior annulus fibrosis, and the posterior one-third the vertebral body. The posterior column resembles the posterior bony complex (posterior arch) and PLC (supraspinous ligament, interspinous ligament, capsule and ligamentum flavum). This approach will be helpful when describing fractures of the spine and their relation to clinical instability. For instance, one way to differentiate compression fractures from unstable burst fractures is failure of the anterior and middle columns, which is readily visualized on lateral radiographs and CT in burst fractures rendering the spine mechanically unstable (Louis

1985; Denis 1983). This is in contrast to failure of the anterior column only as seen in compression fractures.

More importantly, spinal instability is better represented as a spectrum of instability ranging from stable to unstable spinal injury rather than an all-or-none phenomenon. Two types of spinal instability are described: acute and chronic instability. Acute instability occurs most commonly in the context of trauma, infectious and neoplastic diseases of the spine, whereas chronic instability usually results from a degenerative spinal process or as a consequence of acute instability. In acute spinal instability, two different types occur; overt and limited. The former is defined as loss of the ability of the spine to support the trunk during normal movement, which occurs in the context of loss of the ventral and dorsal integrities of the spinal column. For instance, compromise of the vertebral body integrity is seen in compression and burst fractures resulting in ventral column disruption, which can be assessed with plain radiographs or CT. Compromise of the dorsal integrity of the spinal column often results from disruption of the ligamentous structures or fractures of the dorsal elements. Assessment of ligamentous injury is aided by MRI imaging with the addition of fat suppression or short T1 inversion recovery (STIR) sequences for better visual distinction of the ligamentous structures. Isolated MRI signal change indicates increased water content within the ligamentous structures and does not necessarily confirm complete disruption of the disco-ligamentous structures unless accompanied by evidence of locked facets or facet dislocation, which is considered an absolute indication of posterior ligamentous disruption (Vaccaro 2007). The presence of overt instability requires definite surgical stabilization.

On the other hand, limited instability is represented by disruption of either the anterior or posterior integrity of the spine with preservation of the other. For instance, wedge or burst fractures of the vertebral body with no evidence of disruption of the posterior integrity resemble limited instability, which allows for non-operative management, and may include external orthoses such as a brace. Having said that, overt instability can be missed and misjudged as limited instability especially when in the context of overlooking disruption of the posterior ligamentous structures.

In current practice, few scoring systems exist to aid assessment of spinal instability in cervical and thoracolumbar spinal injury. As discussed above, the Spine Trauma Study Group published a classification system for subaxial cervical spine injuries, named the Subaxial Injury Classification (SLIC) and Severity Scale, describing the morphological, discoligamentous complex (DLC) and clinical neurological parameters associated with cervical spine injury (Anderson 2007; Vaccaro 2007). In terms of describing the morphology of the fracture, the greater instability associated with the spinal fracture, the higher the number of points given (Table 1). For instance, facet dislocation and fracture-dislocation injuries are considered highly unstable with failure of three columns (4 points), compared to simple compression fractures, which are associated with single column failure (1 point). In addition, the SLIC severity scoring system sheds further light on the importance of disruption of the posterior column, which requires evidence of perched or dislocated facet and facet diastasis > 2mm, as well as MRI signal change at the entire disc (2 points). The presence of T2-weighted STIR MRI signal change at the ligamentous structures or isolated widening of the interspinous space on plain radio-

graphs is considered intermediate evidence of ligamentous disruption (1 point). SLIC score of ≥ 5 points is highly suggestive of spinal instability and requirement for surgical stabilization, with or without spinal cord or nerve root decompression (Arabi 2013).

Sub-Axial Injury Classfication Scale	Points
Morphology	
No abnormality	0
Compression	1
Burst	2
Distraction (facet perch, hyperextension)	3
Rotation/translation (facet dislocation, unstbale teardrop fracture)	4
Disco-ligamentous Complex (DLC)	
Intact	0
Intermediate (isolated interspinous widening, MRI signal change only)	1
Disrupted (widening of disc space, facet perch or dislocation)	2
Neurological status	
Intact	0
Root injury	1
Complete cord injury	2
Incomplete cord injury	3
Continous cord compression (in setting of neurological deficit)	+1

Table 1. Subaxial Injury Classification (SLIC) and severity scale

3. Traumatic cervical spinal cord injury

Trauma to the spinal cord is commonly associated with considerable disability and is manifested by loss of function, including tetra-/paraplegia as well as genitourinary and gastrointestinal dysfunction, and chronic pain. Acute SCI affects about 250,000 individuals in North America, and has been estimated to account for a lifetime cost of $500,000 to $2 millions per case, with an overall annual cost of $7 billion in the USA (DeVivo 1997; Sadowsky 1999). The annual incidence of traumatic SCI ranges from 28 and 55 cases per million people with about 10,000 cases reported annually in the USA (McDonald 2002). Patients sustain considerable deficits and disabilities that require multidisciplinary approach to treatment and an intensive

neurorehabilitation program. Much research has been published in an effort to establish what factors alter the neurologic and functional outcomes after SCI in order to optimize targeted management of acute SCI. The management of acute SCI, particularly cervical SCI includes a multifaceted and stepwise approach starting with pre-hospital care, leading to emergency medical or physiological strategies as well as decompressive spinal surgery with large emphasis on timely diagnosis of acute SCI. The main role of surgical interventions is to restore spinal stability and prevent further neurologic deterioration.

The most commonly injured part of the spinal cord is the cervical cord, accounting for more than two-thirds of all SCI and commonly associated with tetraplegia more so than paraplegia. This is important since patients with cervical traumatic SCI are prone to developing hemodynamic instability and respiratory failure in the acute setting, which are thought to worsen their end outcome. In this chapter, the scope is limited to cervical spine injuries, and their management, highlighting recent evidence and guidelines publications.

3.1. Epidemiology

Young males are most commonly affected by spinal cord injury. Males are 3 to 20 times more likely to suffer SCI than females. Bimodal age preference is observed in SCI patients with the second peak occurring in elderly patients following a fall (Hall 1978; DeVivo 1980). The prevalence of SCI in the USA is estimated to reach up to 400,000, with estimated hospital occupancy of about 2000 beds annually. Although about a third of spinal fractures occur in the cervical region, only 10-20% of these are associated with spinal cord injuries (Hu 1996). SCI co-exists with traumatic brain injuries in up to 8% of cases and up to 10% of patients with SCI demonstrate other spinal fractures (Holly 2002). The most common cause of traumatic SCI is traffic collisions including motor vehicle collisions, or other traumas involving a motorcycle or a pedestrian. Elderly patients over the age of 65 are at risk of SCI following a fall, which often occurs at home. Pre-existing cervical canal stenosis or degenerative spondylosis in this age group are associated with certain clinical types of incomplete SCI, specifically central cord syndrome.

3.2. Pathophysiology and types of cervical SCI

Timely and careful pre-hospital and initial in-hospital acute management should optimize the role of surgery in helping patients with SCI. Understanding the pathophysiology of cervical SCI is a pre-requisite to explaining the rationale and research basis of acute prompt management of cervical SCI. Respiratory compromise and hypoventilation are common in cervical cord injuries, resulting from paralysis of the intercostal muscles. Residual diaphragmatic function allows for independent breathing unless the injury is above the outflow of the phrenic nerves at the spinal nerve roots C3-C5. Furthermore, patients with cervical SCI can present frequently with hypothermia due to disruption of the connections to the sympathetic chain, which has a substantial outflow within the thoracic spinal cord segments T8-10. Hypotension in the context of cervical spine injury may result from loss of the sympathetic tone and reduced peripheral vascular resistance. This is commonly associated with bradycardia and hypothermia.

Injury to the spinal cord occurs because of stretching, crushing, vascular compromise or compression. Incomplete cervical SCI encompasses three different subtypes with potentially different pathophysiological mechanisms. These include central cord syndrome, anterior cord syndrome and spinal cord hemisection or Brown-Sequard syndrome. Traumatic central cord syndrome (TCCS) is the most common incomplete cervical cord injury accounting for up to half of SCI clinical syndromes and about 9% of all SCIs in one series (McKinley 2007; Bosch 1971). It occurs more frequently in elderly patients with spinal canal stenosis associated with cervical spondylosis in the form of bony spurs anteriorly and thickened ligamentum flavum posteriorly (Schneider 1954). The pathophysiology of TCCS is poorly understood, however, the proposed mechanism of injury is thought to be secondary to a hyperextension injury during a fall resulting in inward buckling of the ligamentum flavum and compression of the cord dorsoventrally, occasionally with central cord hemorrhage and venous infarction (Quencer 1992). The spinal segments C3-4 and C4-5 are commonly affected in more than two thirds of TCCS cases (Aarabi 2011). In post-mortem reports of patients deceased following TCCS, spinal cord damage adopts tubular and central orientation, which may or may not extend several cervical segments rostrocaudally (Schneider 1954). Histological examination suggests a predominant white matter injury with axonal damage associated with myelin loss affecting the lateral columns (Quencer 1992). Clinically, patients with TCCS exhibit motor weakness in the upper extremities out of proportion to weakness in the lower extremities. One systematic review of the literature searching a common diagnostic criterion of TCCS found an average 11 ASIA motor points difference between upper and lower extremities motor scores, suggesting it can be utilized to aid diagnosis (Pouw 2010). Some sensory disturbance occurs variably and includes allodynia as well as sphincter dysfunction in the form of urinary retention. The prognosis in more than two thirds of cases is favorable with recovery of lower extremities motor function permitting independent ambulation and recovery of bladder function (Schneider 1958; Roth 1990; Dvorak 2005). However, some residual fine motor deficits in the hands frequently persist.

Patients with traumatic anterior cord syndrome present with immediate or delayed bilateral paralysis associated with dissociated sensory loss manifesting as loss of pain and temperature consistent with the level of the lesion and preservation of dorsal column function including discriminatory touch, proprioception and vibratory sense. The incidence is very rarely and found to be less than 1% in one series by McKinley et al. (2007). Pollock et al. (1953) first described these neurologic deficits in a series of 27 patients, with a proposition that anterior spinal artery occlusion is the mechanism for the injury following traumatic vertical and anterior compression. However, acute traumatic injury to the anterior portion of the cervical cord by structural disruption and dislocated bone fragments or herniated disc or actual direct destruction of the ventral aspect of the cord was also described in the central cord syndrome (Schneider 1954). These patients unfortunately have the poorest prognosis especially if no improvement is observed within the first 24 hours post-injury (Schneider 1954; Foo 1981; Stuaffer 1975).

The Brown-Sequard syndrome is associated with a rare incidence of 3.6% and usually results from a penetrating injury, such as gunshot or knife wounds, although its development in the context of blunt injury and extra-dural cord compression was also described (McKinley 2007; Roth 1991). Patient manifest with ipsilateral motor and proprioceptive, touch and vibratory sense loss associated with contralateral pain sensation loss. The majority of patients with Brown-Sequard syndrome are able to ambulate independently and recover their bladder control (Roth 1991).

3.3. Initial evaluation and acute management of SCI

An initial rapid approach for assessment of the airway, circulation and breathing is employed in acute prompt management of cervical spine injuries. Pre-hospital safe immobilization of the cervical spine and maintenance of normal axial alignment of the body is required in order to avoid iatrogenic spinal cord injury or worsening of an existing injury. Cervical spinal cord injury is associated with respiratory failure manifesting as hypoventilation secondary to paralysis of chest wall musculature. Unilateral or bilateral paralysis of the diaphragm may result in injuries with tetraplegia when the C3-C5 spinal segmental outflow to the phrenic nerves is disrupted. The laryngeal mask airway has been used increasingly in the setting of acute trauma and respiratory insufficiency with satisfactory outcomes (Moller 2000). In addition to respiratory compromise, loss of sympathetic tone occurs in cervical SCI, resulting in decreased cardiac preload secondary to venous pooling and loss of compensatory sympathetic reflex tachycardia (Troll 1975), thereby causing hemodynamic instability and hypotension. According to clinical guidelines, admission of cervical SCI to the intensive care unit is recommended on the basis of class III evidence in order to ensure cardiac monitoring of respiratory and cardiovascular parameters and prompt treatment of respiratory and cardiovascular compromise (Hadley 2013; Casha and Christie 2011). Furthermore, data from retrospective investigations found significant association between mean arterial pressure of 85 – 90 mmHg post-operatively for 7 days and clinical recovery, necessitating adequate augmentation of blood pressure in an intermediate or intensive care unit (Casha and Christie 2011; Ryken 2013).

According to early retrospective studies, intravenous glucocorticoid administraiton in the early stage of traumatic SCI was thought to harbor some beneficial effect in halting secondary neuronal injury and improving neurologic outcome (Short 2000). However, prospective randomized studies provided class I, II and III evidence demonstrating increased risk of adverse effects such as wound infection, acute steroid myelopathy, respiratory failure, sepsis and death in SCI patients treated with steroids. A number of landmark studies have been published in the field including the National Acute Spinal Cord Injury Study (NASCIS) I, II and III trials. In NASCIS I, investigators conducted a multicenter, double-blinded randomized trial comparing low-dose methylprednisone (MP) to high-dose regimen in patients with acute SCI treated for 10 days (Bracken 1984 and 1985). The study failed to demonstrate a difference in outcome at 6 weeks, 6 months and 12 months follow-up periods. Although the study was limited due to lack of a control group and absent power analysis, the authors noted signifi-

cantly higher rate of infections at the surgical site with mortality being three-folds higher in the high-dose MP treatment group. The second NASCIS trial was published in 1990 with 487 patients with acute SCI randomized into to MP, naloxone and placebo groups (Bracken 1990, 1991 and 1992). No difference in primary neurologic utcomes was observed. However, post-hoc subanalysis demonstrated mean improvement of 5 points in the ASIA motor score and mean improvement of 4 points in the ASIA sensory score in the MP group compared to controls at 6 months. However, this treatment effect was only realized when treatment was administered within 8 hours of injury, excluding 291 patients who were treated outside this time window. Furthermore, complications such as gastrointestinal hemorrhage, wound infections and pulmonary embolism occured more frequently in patients treated with MP. NASCIS II has been downgraded by some to level III evidence indicating weak positive evidence supporting MP use. This is due to the inconsistency of claimed benefits, lack of functional outcome assessments, the arbitary nature of the eight-hour cut-off time and the high rate of patient exclusion in the subanalysis. NASCIS II provided class I evidence demonstrating harmful adverse effects of steroid use. In NASCIS III, 16 centers in the United States and Canada were enrolled in a prospective double-blinded study including 499 patients presenting with acute SCI within 8 hours randomized into treatment with MP IV infusion for 24 hours (n=166), MP IV infusion for 48 hours (n=166) and tirilazad treatment for 48 hours (n=167) which is a chemically engineered "super-steroid" (Bracken 1997 and 1998). Because of the reported positive effect of steroids in NASCIS II, all three groups patients received a loading dose of MP prior to randomization and no placebo-controlled group was included. The study failed to demonstrate a significant difference in neurologic outcome between the three treatment groups at one year (P=0.053), providing class I evidence lacking positive effect of steroid use in acute SCI even when initiated within 8 hours of injury. Of note, there was a transient 5 and 6 ASIA motor score improvements in the 48-hour MP treatment group compared to the 24-hour MP group at 6 weeks (P=0.04) and 6 months (p=0.01), respectively. Similar to NASCIS I and II, there was a trend towards serious complications associated with steroid use in NASCIS III reporting a consistent pattern of adverse effects. Furthermore, a French investigator group published the fourth prospective randomized trial investigating the use of steroids in acute SCI (Pointillart 2000). In this study, 106 patients were randomized into treatment with MP, nimodipine, MP+nimodipine and no pharmacological treatment. The authors demonstrated no significant difference in neurologic recovery between the treatment groups. Therefore, current clinical practice guidelines are not in favor of administering IV steroids even during the early stage of acute SCI due to the higher incidence of adverse effects and lack of clear clinical benefit (Hurlbert 2013). As a result a number of professional organizations in North America have relegated steroid use following spinal cord injury to a weak treatment option only.

3.4. Surgical indications

The goals of surgery in the context of cervical spinal cord injury are to facilitate neurologic recovery and prevent further injury to the neural elements and to restore spinal stability. This

is achieved via anterior, posterior or combined surgical approaches focused at decompression of the neural elements and surgical arthrodesis in patients with a mechanically unstable spine in order to provide immediate stabilization and early mobilization as well as preventing further spinal deformity and pain. Therefore, the presence of clinical evidence of cervical cord injury as well as spinal instability represents surgical indications for decompressive and stabilization surgery. In patients with complete cervical cord injury, the primary goal of surgery is to restore spinal stability due to the low likelihood of neurologic recovery given the severity of cord injury. On the other hand, patients with incomplete cervical cord injury and evidence of compromise of the spinal canal should undergo surgical decompression and stabilization in order to aid neurologic recovery. Class II evidence based on the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS) suggests improvement of neurologic function particularly when early surgery (within 24 hours) was instituted. In this prospective, multi-centre cohort study of 313 patients with acute cervical SCI, the authors found that about 20% of patients treated early showed 2 or more AIS grade improvements, compared to 9% in the late surgery group at 6 months follow-up (OR=2.6, 95% CI:1.1-6.0). However, in the context of other subgroups of incomplete cervical SCI, such as traumatic central cord syndrome, there is only class III evidence based on retrospective studies suggesting superiority of surgical decompression over conservative management (Dahdaleh 2013). There is no class I or II evidence examining the efficacy or timing of surgical decompression in TCCS. Therefore, early clinical diagnosis of spinal cord injury and characterization of its severity is crucial when considering surgical management to optimize the potential for neurologic recovery.

Furthermore, classification of cervical spine fractures may assist in surgical-decision making. Cervical spinal fractures or dislocations may or may not be accompanied by spinal cord injury or neurologic deficits such as paraplegia. In either case, reduction of these injuries can be achieved by closed reduction techniques including tong and halo traction, followed by restoration of spinal stability (if compromised). The latter is accomplished via surgical stabilization or external orthosis, such as various cervical collars, cervicothoracic braces and halo orthoses.

Cervical spine fractures are generally classified into fractures of the atlas, axis and fractures of the subaxial cervical vertebrae. Fractures of the atlas and axis rarely present with neurologic deficits (Sonntag 1988;Crockard 1993; Sonntag 1988), and therefore their discussion is out of the scope of this chapter. On the other hand, fractures of cervical spine below the level of the atlas and axis are relatively common and more frequently involved in decompressive spinal surgery; they affect C5 and C6 vertebrae accounting, respectively, for 40% and 36% of cervical spine fractures in one review (Benzel 1987). The morphology of these fractures is crucial in determining the course of management and likelihood of neurologic compromise, and includes compression, burst, teardrop fractures and facet dislocation injuries. The Subaxial Injury Classification (SLIC) and Severity Scale is recommended as a valid and useful tool to guide surgical management. It describes the morphological, ligamentous and clinical neuro-logical parameters associated with cervical spine injury (Table 1) (Anderson 2007; Vaccaro 2007). The overall inter-rater reliability has a correlation coefficient of 0.71. Clinical guidelines for acute cervical spine injuries published recommendations based on class I evidence to utilize

SLIC as a clinical and radiographic tool to assess and communicate information regarding spinal cord injury (Arabi 2013). SLIC scores of 1 to 3 suggest non-operative management, whereas scores 5 and above are suggestive of surgical management. A SLIC score of 4 represents indeterminate management when clinical judgment of the surgeon plays an important rule in deciding between operative and non-operative managements.

3.4.1. Surgical approaches

The determination of the surgical approach (anterior, posterior or combined) is influenced by the type of spinal cord injury, the mechanism of injury and the location of spinal cord compression in the anterior-posterior dimension of the cervical canal.

3.4.2. Posterior surgical approaches

In patients with flexion-type injuries to the subaxial cervical spine, the preferred surgical approach is posterior decompression and fusion. The rationale behind this surgical plan is restoring spinal stability and decompressing the spinal cord at the direction of main tissue disruption. The indications for posterior approaches include the presence of posterior ligamentous injury, facet dislocation and traumatic subluxation (Dvorak 2007). The integrity of the anterior column has to be preserved and there should be no evidence of anterior spinal cord compression, otherwise, a combined anterior-posterior approach should be considered.

Facet dislocation may occur unilaterally in association with flexion-rotation injury, or bilaterally in the context of hyperflexion injury indicating increased instability due to the disruption of the posterior ligamentous complex. A quarter of patients with unilateral dislocated facet are neurologically intact, with more than one-third manifesting with nerve root injuries and one-third with either complete or incomplete injuries (Andreshak 1997). On the other hand, bilateral facet dislocation is associated with a high rate of spinal cord injury and, hence, surgical reduction and stabilization with or without decompression may be indicated. For instance, in a retrospective review of 68 patients with facet fracture-dislocation injuries 68% of patients with bilateral facet dislocation were found to have complete spinal cord injuries, with ≤ 10 patients being neurologically intact (Hadley 1992). Since more than two-third of patients with unilateral or bilateral facet dislocations demonstrate evidence of poor anatomic alignment, surgical stabilization is indicated (Sears 1990). Despite that facet injuries result from flexion-type trauma, up to at least 50% of patients with facet dislocation injuries demonstrate evidence of disco-ligamentous injury with traumatic disc herniation in pre-reduction MRI. Although class I prospective, randomized evidence has demonstrated that surgical stabilization with anterior discectomy and fusion compared to posterior fixation is equally viable treatment option for unilateral facet dislocation injuries (Kwon 2007), the presence of traumatic disc herniation influences the choice of surgical approach. An anterior approach is favored in this context because of direct decompression of the anterior aspect of spinal canal and subsequent restoration of spinal stability by closed reduction and anterior bone graft placement and plate fixation (Lanuzzi 2006; Razack 2000). The risk profile of this approach in this clinical situation includes incomplete reduction intra-operatively and possible posterior ligament in folding. Therefore, tight and full reduction must be ensured prior to anterior fixation in cases with facet

dislocation associated with traumatic disc herniation. On the other hand, patients sustaining spinal cord injury in the context of unilateral or bilateral facet dislocation and no evidence of traumatic disc herniation, there is no evidence favoring one approach over another. However, an informed decision could be made based on patient's preferences in terms of the different risk profiles of both surgical approaches which include mainly dysphagia and hoarseness of voice and risk of injury to visceral organs such as the trachea and esophagus in anteriorly treated patients, versus local wound infection and post-operative pain with posterior approaches. The advantage of a posterior approach is increased surgeon's familiarity (Dvorak 2007). Should a posterior approach be employed, open reduction with complete resection of ligamentum flavum and lateral mass fixation and fusion are achieved. Of note, some degrees of post-surgical kyphosis are identified in patients treated with posterior fixation, which is thought to result from intervertebral disc injury and progressive collapse. Although the long-term clinical effects of this finding is yet to be evaluated, pre-operative sagittal alignment of the spinal column in patients with facet injuries should be noted prior to undergoing anterior or posterior stabilization (Lifeso 2000; Elgafy 2006).

3.4.3. Anterior surgical approaches

Anterior surgical decompression and stabilization can be utilized even in cases with posterior spinal instability as demonstrated above in the context of unilateral facet injury. Furthermore, burst fractures are associated with disruption of two columns and retropulsion of bone fragments into the cervical canal, rendering spinal cord injury common. The mechanism of injury is largely the result of axial compression forces. Post-traumatic syringomyelia may ensue in patients with persistent canal compression and impairment of CSF circulation. The presence of posterior column failure and neurologic deficits specific to neurologic injury at the level of the burst fracture necessitates surgical decompression and stabilization. An anterior surgical approach with corpectomy or cage fitting and plate fixation is suggested by one retrospective investigation favoring anterior rather than posterior approaches with better decompression and better neurologic recovery and mechanical reconstitution of the motion segments (Toh 2006; Lanuzzi 2006).

Teardrop fractures represent about 5% of cervical spine fractures and result from flexion compression injury, which is commonly seen in injuries associated with diving into shallow waters (Gehweiler 1979; Torg 1991). They represent chip fractures commonly affecting the anterior-inferior aspect of the vertebral body. The severity of injury varies considerably with the most severe injuries seen in the context of a coronal split through the anterior aspect of the vertebral body with dislocation of the other part of the vertebral body posteriorly into the spinal canal (Schneider 1956). Surgical management is indicated in these fractures due to their high likelihood of spinal instability and neurologic injury. Other surgical indications include posterior column failure suggested by distraction and dislocation of the facet joint(s) with or without increased interlaminar distance (Allen 1982). Fisher and Leith et al. (2002) published retrospective data showing greater degrees of improved sagittal alignment with lower rate of treatment failures when patients are treated surgically via anterior cervical plating. However,

a combined anterior and posterior approach has been recommended in cases with severe bony and ligamentous injury (Toh 2006; Cybulski 1992).

4. Cervical spondylotic myelopathy

Cervical spondylosis refers to a chronic degenerative process that affects the disco-ligamentous structures of the cervical spine leading to symptoms related to compression of the spinal cord (myelopathy) or nerve roots (radiculopathy). The progressive nature of the disease process warrants timely operative intervention in order to prevent motor paralysis and autonomic dysfunction related to severe myeloradiculopathy. Cervical spondylotic myelopathy (CSM) is the most common cause of myelopathy in elderly patients, and is associated with significant morbidity in its moderate and severe forms. Although some of the surgical approaches for the treatment of both is similar, the goal of surgery for cervical myelopathy differs in that it aims to provide decompression of the spinal cord to halt the progression of myelopathy, and to stabilize the spine and reinstate its alignment. In addition, the natural history of both disorders is different, with myelopathy being largely a progressive disease, interrupted by long periods of plateauing (Lees 1963; Nurick 1972). On the other hand, a certain degree of myelopathy and radiculopathy may co-exist warranting treatment of both.

4.1. Pathophysiology

Cervical spondylopathy results in loss of the intervertebral disc height secondary to non-inflammatory disc degeneration associated with a "wear-and-tear" process and, in some cases, repetitive trauma. Other accompanying changes include hypertrophy of the facet/zygopophyseal joint and hypertrophy of the posterior longitudinal ligament and ligamentum flavum causing ligamentous laxity and buckling into the cervical canal. Loss of the hydrophilic proteoglycan content of the intervertebral disc occurs as aging advances. This results in loss of the disc height and reduces its ability as a shock absorber, which in turn shifts axial loading force into the annulus fibrosis at the outer periphery of the disc. Eventually, the annulus undergoes wear and tear associated with thinning and weakening of the outer fibers of the annulus that provide anchoring to the bony matrix of the outer periphery of the vertebral body. This part of the annulus is named Sharpey's fibers. Their weakness is associated with formation of osteophytes due to reactive bony growth. Protrusion of the nucleus content of the disc through the strained and weakened annulus occurs, acutely. The process of disc herniation and osteophyte formation has a knock-on effect on the posterior longitudinal ligament causing ligamentous hypertrophy and ossification.

Mechanical pain symptoms have been postulated to originate from degenerative cervical disc and facet joints, based on the finding of rich innervations occurring in these structures (Ahn 2007; Dwyer 1990; Bogduk 2003). It is thought that a tear through the annulus fibrosis is sufficient to cause axial neck pain through afferent sensory fibers.

Pain related to acute or chronic radiculopathy is distinctively different from axial neck pain in that it follows the dermatomal distribution of the affected nerve root. Acute radiculopathy

usually occurs in a younger group of patients and results from acute cervical disc herniation in association with cytokine-mediated inflammatory demyelinating effect on the large-fiber axons leading to motor deficits in the first week (Yoshizawa 1995). In contrast, chronic radiculopathy is associated with osteophyte formation, annulus wear and tear, laxity and peeling of the ligamentous structures with facet hypertrophy.

Spinal cord injury or myelopathy in the context of degenerative cervical disease occurs in relation to static, dynamic and ischemic factors (Dadashev 2011). Static factors include the spondylotic process through which narrowing of the cervical canal occurs, as described above. The normal diameter of the cervical canal is about 17-18 mm wide, with significant cervical canal stenosis considered to be less than 13 mm (Yue 2001). Dynamic factors result in episodic compression of the spinal cord with flexion being association with ventral cord compression against osteophytes and with extension causing dorsal cord compression secondary to ligamentous hypertrophy. Finally, an ischemic process ensues as being evidenced from pathological changes within both gray and white mater undergoing ischemic changes. It is postulated that spinal cord compression secondary to cervical stenosis restricts pial and intramedullary arterioles as well as causing venous engorgement leading to infarction. In severe and chronic cases, formation of a syringomyelia can also occur.

4.2. Surgical management

The natural history of CSM is variable and differs across cases, making prediction of the clinical course very challenging. On the other hand, selection of cases and the indication for surgery can be guided by the extent of clinical severity (Matz 2009). Kadanka and colleagues et al. (2000) conducted a prospective trial of 48 patients with mild CSM (mJOA scale score >12), randomized to surgery (n=21) or non-operative treatment (n=27). The modified Japanese Orthopedic Association (mJOA) scale score is a grading system used for myelopathy, with mJOA scale score > 12 used to define mild CSM. Both groups in that study improved equally on the mJOA scale score, 10-minute walk test and activity-dependent livings at 2 years follow-up. Similarly, the same authors randomized a larger sample of 64 patients to surgical or conservative treatment groups, demonstrating no significant difference in neurologic recovery at a longer follow-up period of 3 years (Kadanka 2005). At much longer follow-up of 10 years, the authors presented results on 25 patients treated conservatively, compared to 22 patients treated surgically with no difference in improvement (Kadanka 2011). However, this study is limited with a small sample size and its power analysis showed reduced statistical capacity to detect smaller differences between the two groups. Based on these findings (Class II evidence), clinical guidelines and a systematic review of the literature suggested that both operative and non-operative management options may be offered in the treatment of mild CSM (defined as mJAO scale score > 12) in the short term (3 years) (Mummaneni 2009). Non-operative strategies include prolonged immobilization in a stiff cervical collar, ''low-risk'' activity modification or bed rest, and anti-inflammatory analgesia. Furthermore, Bednarik et al. (1999) and Wada et al. (2001) prospectively followed patients with moderate to severe CSM (mJOA scale score < 12) postoperatively at 2 years and 5-15 years, respectively, demonstrating neurologic improvement. However, a non-operative comparison group was lacking, thereby conferring Class III

evidence for the operative management of moderate to severe CSM (Matz 2009). On the other hand, patients with severely progressive CSM were observed to demonstrate low likelihood of spontaneous partial remission or cessation of progression of CSM (Clarke and Robinson 1956).

In addition to the severity of CSM, surgical treatment < 1 year from the onset of CSM is associated with improved neurologic outcome, compared to patients treated within 1-2 years or > 3 years (Phillips 1973). Early treatment within one year was found to be a predictor of good prognosis in one systematic review (Tetreault 2013). Similarly, the severity of baseline myelopathic changes correlates with the prognosis postoperatively suggesting reduced likelihood of reversibility of myelopathy in its severe stage. It is not entirely clear whether the progression of severe disease could be significantly halted by surgical decompression.

4.3. Surgical approaches

The surgical approach for the treatment of CSM is broadly categorized into anterior and posterior approaches. The superiority of any one approach over another in terms of the rate of neurologic recovery has been the subject of debate for a few decades. Furthermore, all up-to-date evidence demonstrated comparable neurologic recovery between the different anterior and posterior surgical approaches, although the risk profiles of these approaches are different as being shown by two systematic reviews of the literature (Mummaneni 2009; Cunningham 2010). Unfortunately, current studies suffer many methodological flaws associated with bias and the presence of confounding factors. Nonetheless, in order to select the optimal approach for the patient with CSM, knowledge of the advantages and disadvantages of each technique is pre-requisite for informed and rationale surgical decision-making (Table 2).

	Advantages	*Disadvantages*
Anterior approach	Direct decompression	Technically challenging
	Stabilization with arthrodesis	Graft complications
	Correction of deformity	Loss of motion
	Good axial pain relief	Adjacent segment disease
Posterior approach		Indirect decompression
	Less loss of motion	Postoperative kyphosis
	No graft complications	Instability limitations
	Less technically demanding	Late instability
		Inconsistent axial pain relief

Table 2. Summary of the advantages and disadvantages of anterior and posterior approaches for CSM. Adapted from Dadashev et al. (2011)

Options for posterior surgical approaches for the treatment of CSM encompass laminectomy without fusion, laminectomy with lateral mass fusion and laminoplasty. In comparing laminectomy alone with laminectomy with fusion, the retrospective review by Perez-Lopez et

al. (2001) revealed similar rates of neurologic improvement as represented by improved Nurick scores of 0.84 in the laminectomy group compared to 1.24 in the group treated with laminectomy and fusion, at 3.3 years follow-up. However, the authors also noted increased incidence of postoperative kyphotic deformity in the laminectomy alone group (24%), compared to 7% in the fusion group. This holds true in reviews of cases with CSM treated with laminectomy and fusion demonstrating very low or zero rate of swan neck deformity post-operatively (Kumar 1999;Houten 2003), whereas cases treated with laminectomy are predisposed to develop late deformity as well as destabilization which requires repeat surgery (Guigui 1998; Sim 1974; Mastunagna 1999). Therefore, laminectomy with fusion is recommended over laminectomy alone especially in young patients, or in cases associated with risk of spinal instability (Class III; strength of recommendation D) (Mummaneni 2009).

Laminoplasty has been used with comparable results to laminectomy with fusion in terms of improved neurologic recovery in the treatment of CSM (Class III; recommendation D) (Mummaneni 2009). In patients with CSM or ossification of the posterior longitudinal ligament, Heller et al. (2001) retrospectively compared laminectomy with fusion (13 patients) and laminoplasty (13 patients). The authors noted statistically non-significant greater improvement in Nurick scores in the laminoplasty group (from 2.2 to 1.1) compared to the laminectomy with fusion group (from 2.2 to 1.5). However, the range of cervical movement was retained in the laminoplasty group compared to laminectomy with fusion (P<0.002). In addition, a significantly greater complication rate was reported in the latter group with development of hardware failure in 2, neurologic deterioration in 2, pseudoarthrosis in 5 and deep infection in one case. No complications were noted in the laminoplasty group. The difference in complication rate is subject to criticism in relation to probable selection bias associated with selection of matched controls in whom fusion is more likely due to kyphosis, thereby rendering this study Class III evidence (Mummaneni 2009). In addition, two retrospective reviews of laminectomy with fusion found favorable neurologic recovery (improved neurologic outcome or no deterioration) and zero or low rate of complication associated with this approach (Houten 2003; Huang 2003). Therefore, no recommendation was made of laminoplasty over laminectomy with fusion in terms of improved neurologic recovery in evidence-based published guidelines.

Anterior surgical approaches for decompression of the cervical spine in CSM include anterior cervical discectomy with fusion (ACDF) and anterior cervical corpectomy with fusion (ACCF). Based on class III evidence, patients with CSM have been shown to respond to multilevel anterior cervical spine decompression, however, with varying proportions of complications associated with each technique (Mummaneni 2009; Cunningham 2011). In a retrospective study by Nirala et al. (2004), 201 patients underwent multilevel anterior cervical spine decompression with fusion (autograft) and without anterior plate fixation. Patients were subdivided into ACDF (n=69) and ACCF (n=132), with the functional outcome was assessed using Odom's criteria, whereas dynamic plain films were used to assess radiographic outcomes. Patients wore a hard cervical collar for 3 months postoperatively. After 10 years, the fusion rate was higher in the ACCF group (94%) compared to the ACDF group (69.6%) (P< 0.001). There was no statistically significant difference in the functional outcome between the

two groups. This study presents class III evidence favoring ACCF over ACDF when plate fixation is not used (Grade D recommendation). In contrast, anterior plate fixation in ACDF and ACCF is associated with equal fusion rates reported in one systematic review to reach greater than 90% (Fraser and Hartl 2007). However, in three-level disc disease, the fusion rate was significantly lower in the ACDF group (82.5%) compared to cases treated with ACCF (96%) (P=0.03). This systematic review represents class III evidence due to the lack of application of a standardized methodology for systematic reviews and to violating the inclusion and exclusion criteria. Therefore, a grade D recommendation underlies the utilization of either ACDF or ACCF with plate fixation in the treatment of multilevel anterior CSM.

Furthermore, the use of anterior plate fixation in ACDF and ACCF is associated with non-union rates of 42% and 31%, respectively at about 3.3-year follow-up (Swank 1997). Of note, a major confounding factor is the increased use of dynamic plates in ACDF compared to constrained plates in ACCF with the latter being associated with higher fusion rates. Another study by Wang et al. (2001) failed to find a statistically significant difference in fusion rates between the two groups.

Early complications in ACDF include dysphagia (9.5%), neck hematoma (5.6%) with 2.4% of patients requiring surgery, recurrent laryngeal nerve palsy (3.1%), dural laceration (0.5%) and esophageal perforation (0.3%). The latter was associated with death in one patient (1 about 1000 patients). Less common complications include wound infection and Horner's syndrome. Late complications of ACDF include non-union and adjacent-segment disease. The presence for adjacent-segment disease was found to be associated with a plate-to-disc distance of < 5 mm. This complication is thought to occur at an annual rate up to 3% over 10 years. Further studies are required to elucidate the clinical nature of these changes. Furthermore, other factors that can affect the fusion rate include plate fixation and smoking (Bolesta 2000; Fraser and Hartl 2007).

To summarize, the location of spinal cord compression in relation to the anterior-posterior diameter of the cervical canal is a crucial factor influencing the direction of the surgical approach. In cases with predominantly anterior multilevel disease affecting more three levels, ACCF with plate fixation could be considered over ACDF due to a suggestion of lower rates of fusion in the latter group. However, patients with CSM resulting from less than three-level disease, ACDF and ACCF with plate fixation are equally indicated. On the other hand, patients with features of CSM resulting from multi-level disease affecting more than three levels may benefit from a posterior approach. Laminoplasty is associated with significantly increased incidence of neck pain, but fewer complications and possibly greater range of cervical motion range as well as comparable neurologic improvement rate when compared to laminectomy with fusion and even to anterior approaches including ACDF and multilevel ACCF. Therefore, laminoplasty maybe utilized in patients who are able to tolerate some post-operative neck pain with the benefit of retained cervical mobility. Furthermore, laminectomy without fusion is discouraged in patients with a kyphotic deformity or straight spine due to a significant risk of development of postoperative swan-neck deformity of the cervical spine (Rao 2006; Benzel 1991;Anderson 2009; Kaptain 2009). In younger and healthier patients with significant anterior

and posterior compression of the cord resulting in significant progressive myelopathy, a combined anterior-posterior approach is recommended to ensure complete decompression.

5. Metastatic spinal diseases

5.1. Epidemiology

Cancer-related complications led to about half a million deaths in 2008, with annual newly detected cancer rate of about 1.4 million new cases (Sciubba 2010). Up to 70% of all cancer patients will develop metastasis, most commonly to the lungs and liver, followed by skeletal structures. The most common osseous site for metastasis is the spine, which occurs in 40% of all cancer patients (Aaron 1994;Black 1979; Zerick 1994). Of these patients with spinal meta-static disease, up to 20% will develop symptomatic epidural spinal cord compression, which accounts for 20,000 to 30,000 cases per year in the USA (Kwok 2006). Post-mortem studies showed that up to 90% of patients deceased with cancer were found to have evidence of spinal metastatic disease (Wong 1990; Cobb 1977). Up to half patients with spinal metastasis require treatment, with 5-10% being surgically treated (Bell 1997;Bilsky 2005; Walsh 1997; York 1999).

The incidence of metastatic spinal disease peaks at the age groups between 40-65 years (Perrin 1982). The most common primary tumors that metastasize to the spine are breast, lung, melanoma or prostate cancers, which correspond to the common occurrence of these primary malignancies (Constans 1983; Helweg-Larsen 1994). The rates of spinal metastases in prostate, breast, melanoma and lung cancers correspond to about 90%, 74%, 55% and 45%, respectively (Wong 1990). Of note, 10% of cases present clinically with spinal metastatic disease without previous history of known primary malignancy (Gerszten 2000), with 50% of these cases found to have primary lung malignancy (Stark 1982).

5.2. Characteristics of spinal metastasis

The most common region of the spine affected by metastatic disease is the thoracic spine, which corresponds to 70%, followed by the lumbar spine (20%) and cervical (10%) spine, (Gerszten 2000, Byme 1992; Gilbert 1978). Metastases occur extra-durally, with the intra-dural and intra-medullary spaces being very rare metastatic targets representing up to about 8% of cases (Schijns 2000). The vertebral body is involved in more than 80% of cases with the posterior half being the initial site of invasive disease (Gerszten 2000). The reminder of cases often manifest with paravertebral metastasis.

The routes of metastatic spread include hematogenous spread, which is the most common mechanism, manifest by metastases to the vertebral body occurring through hematogenous spread secondary to their rich blood supply (Arguello 1990), followed by direct invasion and spread through shedding of tumor cells in the CSF. Direct invasion to the sacral and lumbar spine were reported in the context of prostate cancer (Ross 2005). CSF seeding of tumor cells occurs following mobilization of intra-axial cranial malignancies, and may result in drop metastasis (Perrin 1982).

5.3. Clinical manifestation

Patients with spinal metastatic disease may present with pain symptoms and/or neurologic deficits, associated with constitutional or systematic symptoms including weight loss and anorexia.

Pain is the initial complaint in up to 95% of patients with spinal metastases, preceding any neurologic deficits by weeks to months (Bach 1990; Helweg-Larsen 1994; Weinstein 1987). In contrast, about 10% of patients with undiagnosed extra-spinal primary malignancy present with pain as their initial complaint (Livingston 1978). Patients with spinal metastases describe three different categories of pain; tumor-related, mechanical and radicular pain. Tumor-related or local pain is often progressive and characterized as dull constant ache localized to the metastatic region of the spine, and responsive to nonsteroidal antiinflammatory drugs (Gokaslan 1996). It may worsen in the morning or nocturnally. It's postulated to result from dilatation and engorgement of spinal venous channels secondary to tumor growth leading to mass effect on pain-sensitive structures, such as the dura, periosteum and spinal cord. Pain radiating to the sacro-iliac region and to the interscapular area occur in association with lumbar and thoracic metastatic disease, respectively. On the other hand, mechanical pain results from vertebral body destruction and collapse, associated with some degree of spinal instability leading to increased physiological stress on spinal support structures including ligamentous and muscular structures. Mechanical pain manifests as pain provoked by movement and standing, as well as coughing, and relieved by resting. Radicular pain is caused by invasion of the intervertebral foramina leading to compression of nerve roots and pain radiating across the dermatome subserved by the affected nerve root.

Neurological symptoms result from either compression of the spinal cord or nerve roots, causing myelopathy or radiculopathy, respectively, or both. Myelopathy related to spinal metastasis usually presents with gait difficulty associated with spasticity and motor weakness, which is the most common presenting symptom second to pain in up to 85% of patients (Greenberg 1980; Posner 1995). Myelopathic motor weakness is often followed by bladder and bowel dysfunction (Schiff 1996). Urinary retention and increased frequency of urinary tract infection in males suggest a diagnosis of neurogenic bladder. Isolated autonomic or bladder dysfunction rarely occurs in isolation and is usually accompanied by other symptoms, except in cases with conus medullaris compression. Without treatment, patients with motor deficits progress to complete paraplegia (Botterell 1959). The initial neurological status of the patient correlates with prognosis, thereby necessitating a thorough neurologic examination. Certain scales can be used for neurological and functional assessments, including the American Spinal Injury Association (ASIA) Impairment Scale (AIS), the Frankel scale and the Eastern Cooperative Oncology Group (ECOG) Performance Score.

5.4. Rationale for selection of cases for surgical management

The management of spinal metastatic disease can be challenging and requires a multidisciplinary approach involving neurosurgical expertise as well as radiation and medical oncology and patient's input. Surgical interventions in most cases are palliative, aimed at relieving pain

symptoms refractory to medical treatment, obtaining a tissue diagnosis and preserving ambulation and autonomic function by decompressing the neural elements.

Surgical intervention is considered in tumors relatively resistant to radiation treatment including sarcoma, lung and colon cancers, renal cell carcinoma, and breast cancer (Cole 2008). Other indications for surgery include evidence of spinal instability, compression of the cord or nerve roots, pain refractory to medical treatment and deterioration of neurologic function during radiation therapy indicating treatment failure. The three-column involvement, discussed above, has been used by Tomita et al. (Tomita 2001) as evidence of increased spinal instability and therefore an indication for surgical management. The authors discussed other features suggesting spinal instability including vertebral body collapse > 50%, transitional deformity and involvement of the same column in more than one level. Other investigators regarded bone fragments repulsion into the spinal canal as evidence of spinal instability (Cybulski 1989). Although spinal instability has been discussed as a strong indication for surgery in different conditions related to spinal injury, a clear unifying definition of spinal instability is still debated.

On the other hand, patient's life expectancy represents a crucial factor in surgical decision-making, with an estimated life expectancy greater than 3 or 6 months considered favorable in the context of surgical management of spinal metastatic disease (Sciubba 2010). Different prognostic systems have been devised in order to help stratify patients into different groups according to prognosis to help guide surgical treatment.

Tokuhashi and colleagues et al (Tokuhashi 2005; Tokuhashi 1990) established a scoring system based on the general medical condition as described by the Karnofsky performance status, number of extra-spinal metastases, number of vertebral metastases, the treatment status of major internal organ metastases, primary tumor type and the presence of neurologic dysfunction (Table 4). Non-operative or radiation treatment is indicated in cases with scores ranging from 0 to 8, with an estimated life expectancy less than 6 months. Patients with scores ranging from 12 to 15 were found to have a life expectancy of one year or more, and were treated with circumferential excisional surgery with reconstruction and stabilization. Palliative decompression surgery utilizing a posterior approach with or without instrumentation is offered to patients with a score of 9 to 11. Stratification of cases according to the Tokuhashi scoring system has been validated and used in other studies (Ulmar 2005; Enkaoua 1997).

Furthermore, Tomita and colleagues et al. (2001) devised a scoring system based on the advances of surgical techniques taking into account the grade of malignancy (slow, moderate or rapid growth), visceral metastases and bone metastases. Patients with scores of up to 3 points, wide marginal excision is recommended for local long-term control, whereas scores of 4 or 5 indicate marginal or intralesional excision for intermediate-term control. Scores of 6 or 7 suggest short-term palliation with palliative surgery, and scores of 8 to 10 indicates non-operative supportive care. These scoring systems represent useful tools to communicate a host of important prognostic factors rather than absolute conclusions for surgical decision-making, which relies on other factors such as spinal instability and patient's factors including co-morbidities.

The Spinal Instability Neoplastic Score (SINS) is a useful tool for the assessment of spinal instability in patients with spinal metastatic disease. It utilises clinical and radiographic data in order to facilitate the classification and assessment of spinal instability (Table 3). SINS was formulated by the Spine Oncology Study Group (Fisher and colleagues et. al.,2010) on the basis of a systematic review and modified Delphi criteria evaluating factors crucial for the assessment of spinal stability. With a sensitivity and specificity of 95.7% and 79.5%, respectively, and confirmed near-perfect inter-and intra-rater reliability (Fourney 2011; Fisher 2010), SINS stratifies patients with spinal metastatic disease into three categories; those with stable spine (0-6 points), potentially unstable spine (7-12 points) and unstable spine (13-15points).

Location	Rigid (S2-5)	0
Semi-rigid (T3-T10)	1	
Mobile spine (C3-C6,L2-L4)	2	
Junctional (Occiput-C2,C7-T2,T11-L1,L5-S1)	3	
Pain	Pain-free lesion	0
	Occasional pain but not mechanical	1
	Yes – mechanical pain	3
Bone lesion	Blastic	0
	Mixed (lytic/blastic)	1
	Lytic	2
Radiographic spinal alignment	Normal alignment	0
	De novo deformity (kyphosis/scoliosis)	2
	Sublaxation/translation present	4
Vertebral body collapse	None	0
	No collapse with "/> 50% body involvement	1
	< 50%	2
	"/> 50% collapse	3
Posterolateral involvement of spinal elements	None	0
	Unilateral	1
	Bilateral	3

Table 3. The Spinal Instability Neoplastic Score (SINS) system.

General condition	Poor PS <40%	0
Moderate 50-70%	1	
Good > 80%	2	
No. Of extraspinal bone metastases foci	3 or more	0
	1-2	1
	0	2
No of metastases in the vertebral body	3 or more	0
	1-2	1
	0	2
Metastases to the major organs	Unremovable	0
	Removable	1
	No mets	2
Primary cancer	Lung, osteosarcoma, stomach, bladder, pancreas, esophagus	0
	Liver, gallbladder, unknown	1
	Others	2
	Kidney, uterus	3
	Rectum	4
	Thyroid, prostate, breast, carcinoid tumor	5
Spinal cord palsy	Complete (Frankel A, B)	0
	Incomplete (Frankel C, D)	1
	None (Frankel E)	2

Table 4. Tokuhashi prognostic scoring system for spinal metastatic disease

5.5. Surgical management

Substantial development in the surgical techniques and approach for spinal stabilization over the past three decades have been associated with longer survival and improved neurologic outcomes in patients with spinal metastatic disease (Scuibba 2010). Historically, the mainstay of surgical intervention was based on simple laminectomy, representing the only surgical intervention at the time. The aim of the procedure was to obtain tissue diagnosis or relief of pain. However, a high rate of complications reaching up to 11% was associated with this approach, including spinal instability, wound infection and dehiscence (Findlay 1984). In addition, a retrospective study of 235 patients treated with posterior decompressive laminectomy with or without radiation demonstrated no difference in the rate of neurologic recovery between the two groups (Gilbert 1978). The association of simple laminectomy with morbidity such as increased risk of spinal instability and its susceptibility to failure rendered surgical management of spinal metastatic disease less efficacious with little value. In addition, simple

laminectomy did not also address anterior compression of the spinal cord or thecal sac resulting from a metastatic lesion at the vertebral body.

Therefore, radiation alone was the only effective treatment available until the evolution of spinal stabilization and instrumentation techniques. Some early reports of internal fixation in addition to laminectomy suggested improved surgical outcomes, which re-introduced surgical management as an effective and safe intervention in spinal metastatic disease. For instance, more than 90% of patients treated with internal fixation demonstrated increased ambulation and improved pain control postoperatively, compared to 57% treated with laminectomy alone (Sherman 1986). Results from the first prospective randomized controlled trial were presented in 2005 by Patchell et al. comparing the efficacy of radiation treatment alone and combined surgical circumferential decompression of the spinal cord with tumor resection and stabilization, followed by adjuvant radiation therapy. There was a statistically significant higher rate of post-treatment ambulation in the surgery group reaching 84% compared to 57% in the radiation treatment group (P=0.001) (Table 5). The median duration of ambulation in the surgery group was found to be 122 days, compared to 13 days in the radiation group (P=0.003). About 60% of patients regained the ability to walk post-surgically compared to 19% receiving radiation alone (P=0.012). Other secondary outcomes associated with surgery included improved continence rates, muscle strength (ASIA scores) and improved functional ability (Frankel scores).

	Ambulation				
	Posttreatment ambulatory rate (%)	Retained (days)	Maintained ambulation (%)	Re-gained (%)	Mean survival (days)
Surgery and XRT	84	122	94	62	126
XRT alone	57	13	74	19	100

Table 5. Outcomes following treatment with radiation alone versus surgery with radiation (Patchell 2005).

Furthermore, Witham et al. (2006) performed a systematic review assessing the literature on the treatment of spinal metastatic disease between 1964 and 2005. The author found a mean 64% improvement in motor function associated with mean 88% improvement of pain control when laminectomy with posterior stabilization is utilized, compared to a mean 42% improvement in motor function in laminectomy with or without radiation treatment. Importantly, patients with anterior decompression and stabilization demonstrated the highest rate of neurologic improvement with 75% of cases exhibiting improvement. The role of anterior decompression of the spinal cord has become more apparent since the majority of the tumour burden in metastatic disease is often found anterior or antero-lateral to the spinal cord. This finding was highlighted by Siegal and colleagues et al. (1982), illustrating 91% rate of regaining ambulation in patients with ventral metastatic compression of the cord following anterior decompression. Multiple studies demonstrated similar results, thereby underlining circumferential spinal cord decompression as one of the principles of surgical management of spinal metastatic diseases beside reconstruction and stabilization (Klimo 2011).

5.6. Surgical approach

Posterior approaches to surgical management of spinal metastatic disease have become more popular especially with the introduction of the transpedicular approach, which allows for circumferential decompression of the spinal cord and reconstruction of the vertebral body. This approach has been found effective in the lumbar and thoracolumbar spine according to a review of 140 patients in whom this approach was utilized leading to 75% rate of regain of the ability to walk post-operatively and more than 95% improvement of pain. Alternatively, single-stage posterolateral vertebrectomy (SPLV) with costotransversectomies provide wider exposure compared to direct posterior approaches in the surgical management of thoraco-lumbar spinal metastases. Street and colleagues et al. (2007) provide data on 42 patients treated with this approach demonstrating that all patients remained neurologically stable or improved after surgery. The complication rate was 26% (n=11) with nine patients requiring early reoperation including seven patients for wound failures. The approach involves performing laminectomy at the metastatic level with pedicle screw insertion prior to bilateral total facetectomies and complete pedicle resection to the base of the vertebral body. Circumferential decompression of the neural elements is achieved with resection of the posterior rib, rib head and costrotransverse joint to facilitate wide resection. Reconstruction of the vertebrectomy defect is achieved by introducing cement. Placing bilateral rods to ensure spinal stabilization completes the procedure. The authors favor this approach over the combined anteroposterior approach due to the increased risk of respiratory adverse effects and prolonged anesthetic time in the combined approach. In addition, the wide exposure and improved working angle offered by SPLV provide greater advantage compared to the conventional posterolateral transpedicular approach.

The utilization of minimally invasive spine surgery has been extrapolated to thoracolumbar spinal metastatic disease (Deutsch 2008; Huang 2006; Singh 2006). Deutsch and colleagues et al. (2008) described the results of a minimally invasive transpedicular vertebrectomy in 8 patients with spinal thoracic metastatic disease in whom an anterior approach via thoracotomy was deemed unsuitable due to significant co-morbidities and limited life expectancy. For patients presenting with metastases affecting thoracic spinal levels T4 to T11, in whom minimally invasive surgery was performed, the authors described resection of the pedicles though a 22-mm diameter tubular retractor, followed by dorsal decompression of the neural elements with partial vertebrectomy and ventral decompression. A bilateral approach with transpedicular resection was used in order to ensure total decompression of the ventral canal. No instrumentation was used in this approach and all patients received postoperative radiation treatment. The average length of the procedure is 2.2 hours. The authors noted neurologic improvement in 5 out of 8 patients (62.5%) post-surgically with a similar rate of improvement in pain. In addition, two patients with paraparesis preoperatively were able to ambulate unassisted post-surgery. The one-year survival was 37.5% and no evidence of tumor recurrence and spinal instability at one-year follow-up in survivors. The authors recommend-ed this approach as a palliative measure in selected cases in order to provide pain relief and improved ambulation without significant tissue trauma and increased risk of adverse effects otherwise noted in open anterior approaches. A major disadvantage of this approach is limited

visualization and risk of incomplete decompression. On the other hand, the role of minimally invasive technique is greatly employed in percutaneous vertebroplasty and kyphoplasty in the treatment of painful pathological fractures secondary to underlying metastases (Fourney 2003; Binning 2004). Vertebroplasty is performed by injecting cement percutaneously into the vertebral body. This technique is used in patients with a painful osteolytic metastatic lesion without evidence of disruption of the posterior aspect of the body cortex and without severe loss of the body height (Jensen 2002; Weill 1996). Vertebroplasty is particularly helpful in this group of patients since radiation treatment may not provide pain relief for up to two weeks post-treatment (Binning 2004). Kyphoplasty differs from vertebroplasty in that an expandable balloon is placed into the vertebral body to create space hosting the cement. This technique has been shown to reduce the risk of kyphotic deformity and provides effective and sustained pain relief (Pflugmacher 2007; Fourney 2003.

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