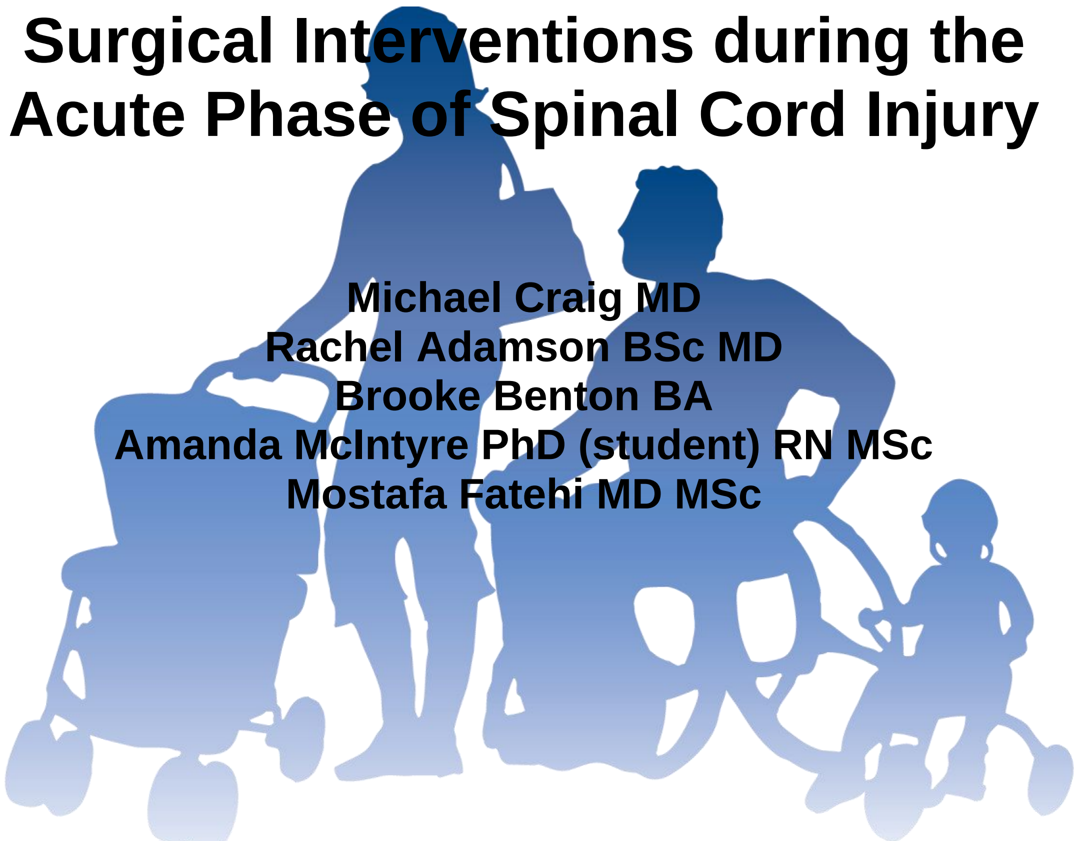
SPINAL CORD INJURY REHABILITATION EVIDENCE

Surgical Interventions during the Acute Phase of Spinal Cord Injury



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Spinal cord injuries (SCI) often causes life-altering sequelae and can lead to significant morbidity. As such, there has been long-standing interest in improving the interventions used in the management of affected individuals. In the acute phase, various medical and surgical approaches have been proposed and studied to reduce the tremendous impact of trauma. In addition to evaluating the efficacy of different surgical strategies, clinicians have evaluated the benefit of early surgical decompression and stabilization. In this chapter, we will describe and evaluate current surgical approaches and summarize the evidence for these interventions.

4.0 Surgery for Traumatic SCI

Surgical treatment of traumatic SCI has several proposed benefits. First, after the primary insult has occurred, relief of any ongoing spinal cord compression is theorized to minimize any secondary neurologic injury that might occur via ischemia, inflammation, etc. In a similar manner, surgical decompression is thought to minimize the risk any further cord injury at the injured level. Mechanical stabilization of the injured spinal segment is thought to reduce the risk of future instability and reduce pain at the injured segment. Surgical stabilization often also obviates the need for activity limitations or a cervical collar, thereby facilitating nursing care, and allowing earlier mobilization and ongoing rehabilitation. The purported benefits must be weighed against the risks of surgical treatment. These include the physiological stress of a potentially long, time-intensive, and morbid procedure in a population of individuals who are often critically ill at the time of surgery. Several aspects of surgical treatment of SCI will be reviewed here, including surgical timing, anterior-vs-posterior approaches, prognosis, and comparisons with other treatment methods.

4.1 Decompression Surgery

Acute traumatic SCI is a unifying syndrome that represents a variety of underlying pathologies and structural abnormalities. Generally, one of the primary goals of surgical management is decompression of neural structures. Studies evaluating depression surgery for SCI are reviewed.

Table 1. Decompression Surgery for SCI

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Ojo et al. (2017) Nigeria Pre-Post N=35	**Population:** Mean age: 38.6±13.3 yr; Gender: male=24, female=11, Level of injury: cervical=27, thoracic=7, lumbar=1; Severity of injury: Frankel A=17, B=8, C=2, D=2, E=6. **Intervention:** Individuals who presented with acute, traumatic SCI were assessed at baseline and six mo following surgical decompression and spinal stabilization to determine whether surgical intervention enhances rehabilitation of individuals with SCI. Outcome measures were assessed at baseline and six mo following surgery. **Outcome measures:** Frankel grade; Complications. **Chronicity:** All individuals who had SCI and cord decompression surgery within a two-yr period were included in this study.	1. Frankel grade at six mo following surgical intervention showed improvement in nine (25.7%) individuals. 2. All individuals who presented as Frankel Grade C or Grade D improved to Grade E, while none of those who presented with Frankel Grade E deteriorated. 3. Common complications of spine decompression and fixation were surgical site infections (11.4%) and spine and chest infections (11.4%).
Rahimi-Movaghar et al. (2006) Iran Case Series N=24	**Population:** Mean age: 26.7 yr; Gender: males=21, females=3; Injury etiology: motor vehicle accident=14, fall=5, unknown=5; Level of injury: T12-L3; Level of severity: Frankel A=17, C=5, D=2. **Intervention:** Individuals with traumatic conus medullaris SCI who underwent surgical decompression were retrospectively analyzed. Median follow-up time was 32 mo. **Outcome Measures:** Frankel Grade.	1. Of the 17 individuals with Frankel Grade A, seven improved to C, two improved to D, two improved to E, and six remained the same. 2. Of the five individuals with Frankel Grade C, four improved to D and one improved to E. 3. Of the two individuals with Frankel Grade D, both improved to E.
Beisse et al. (2005) USA Pre-Post N=30	**Population:** Mean age: 39.4 yr; Gender: males=23, females=7; Injury etiology: fall=12, sports=10, motor vehicle accident=3, violence=2, tumor=1, infection=1, degeneration=1; Level of injury: T5=1, T6=1, T7=1, T9=1, T12=10, L1=11, L2=5; Level of severity: Frankel scale A=4, B=3, C=7, D=10, unclassified=6; Mean time since injury: 10.6 days. **Intervention:** Individuals with thoracolumbar canal compromise underwent endoscopic anterior spinal canal decompression, interbody reconstruction, and stabilization. Mean follow-up time was 42 mo. **Outcome Measures:** Frankel Scale, Complications.	1. Complications occurred in 11 individuals (36.7%). 2. There was no deterioration of the neurological function in any individual. 3. Based on the Frankel scale, 25% of individuals with complete paraplegia and 65% of those with incomplete neurological deficit improved at least one level on neurological examination.
Hu et al. (1993) USA Case Series N=69	**Population:** Mean age: 30.0 yr; Gender: males=51, females=18; Level of injury: L1=36, L2=12, L3=11, L4=9, L5=3; Injury etiology: motor vehicle accident (n=36), fall (n=31), struck with object (n=2); Level of severity: incomplete. **Intervention:** Individuals who underwent decompression surgery following lumbar SCI injury were retrospectively analyzed	1. Overall, the average initial ASIA score was 19.4; 20.1 for the anterior decompression, 20.1 for the posterior decompression, and 17.2 for the fusion. 2. Anterior decompression improved by an average of 9.9 points. 3. Posterior decompression improved by an average of 10.2 points.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	by type of decompression. Outcomes were assessed at a mean follow-up time of 19 mo. **Outcome Measures:** American Spinal Injury Association (ASIA) Motor Score.	4. Fusion individuals improved by an average of 4.2 points. 5. There was no significant difference between those treated with anterior and posterior decompression (p>0.05); there was a significantly greater improvement seen in anterior and posterior decompression compared to fusion treated individuals (p<0.05).
Levi et al. (1991) USA Case Control $N_{Initial}$=103, N_{Final}=71	**Population:** *Incomplete deficit (INC, n=50)*: Median age: 32.5 yr; Gender: males=40, females=10; Injury etiology: motor vehicle accident=28, diving=9, fall=10, other=3; Level of injury: C3=7, C4=7, C5=19, C6=12, C7=5; Mean time since injury: 10.6 days. *Complete deficit (COM, n=53)*: Median age: 25.4 yr; Gender: male=45, female=8; Injury etiology: motor vehicle accident=27, diving=15, fall=5, other=6; Level of injury: C3=2, C4=4, C5=29, C6=13, C7=5; Mean time since injury: 5.1 days. **Intervention:** Individuals who underwent anterior decompression were retrospectively analyzed based on timing of surgery: INC early (<24 hr, n=10), COM early (n=35), INC late (>24 hr, n=40), and COM late (n=18). **Outcome Measures:** Motor Score, Functional Grade, Hospitalization, Respiratory Procedures, Mortality.	1. INC early: 37.2% improved motor score at discharge; 50% improved functional grade at discharge; 20 days in acute hospitalization. 2. INC late: 45% improved motor score at discharge; 22.5% improved functional grade at discharge; 22 days in acute hospitalization; one individual died. 3. There was no significant difference between INC early and late groups in motor score, functional grade, or hospitalization (all p>0.05). 4. COM early: 3.9% improved motor score at discharge; 11.4% improved functional grade at discharge; 38.7 days in acute hospitalization; 6.0 respiratory care procedures. 5. COM late: 4.5% improved motor score at discharge; 5.6% improved functional grade at discharge; 45.2 days in acute hospitalization; 9.86 respiratory care procedures. 6. There was no significant difference between COM early and late groups in motor score or functional grade (all p>0.05); however, the early group had significantly less days of hospitalization and significantly less respiratory procedures (all p<0.05).
Benzel & Larson (1987) USA Case Series N=99	**Population:** Level of injury: C4-C7; Level of severity: Neurological Grading System (NGS) I=35, II=11, III=8, IV=6, V=3, VI=23, VII=13; Mean time since injury: NGS I=22.5 days, II=46.2 days, III/IV/V=51.7 days, VI/VII=17.4 days. **Intervention:** Individuals who underwent decompression surgery to restore normal nerve connections following cervical spine fractures were retrospectively analyzed for outcomes post-surgery. **Outcome Measures:** Complications, Neurological Grading System.	1. Four individuals died; three had NGS I and significant pulmonary problems and the 4th was NGS II at 3 mo post-op. 2. Complications included pneumonia (n=7), deep vein thrombosis (n=3), respiratory failure (n=4), and sepsis (n=1). 3. All NGS I individuals remained Grade I following surgery. 1. Of the 11 NGS II individuals eight improved (III=3, IV=3, V=2) and three remained the same following surgery. 2. Of the eight NGS III individuals six improved (IV=1, V=4, VI=1) and two

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		remained the same following surgery. 3. Of the six NGS IV individuals five improved (V=5) and one remained the same following surgery. 4. Of the three NGS V individuals all three improved (VI=3) following surgery. 5. Of the 23 NGS VI individuals 19 improved (VII=19) and four remained the same following surgery. 6. All 13 NGS VII individuals remained the same following surgery.
Kiwerski (1986) Poland Case Control N=1180	**Population:** Level of injury: C1-C3=74, C3-C5=421, C5-C7=685; Level of severity: Frankel A=506, B=171, C=212, D=291. **Intervention:** Individuals who underwent cervical decompression surgery (SG; n=548) or conservative treatment (CG; n=632) following cervical SCI injury were retrospectively analyzed. **Outcome Measures:** Frankel score, Mortality.	1. There was an improvement in 49% of CG individuals and 66% of SG individuals. 2. Mortality was 30% in individuals with complete SCI injuries and 4.3% in incomplete SCI injuries. 3. CG group: in individuals who were admitted within 6 hr there was an improvement of 2-3 Frankel grades in 41% of individuals and decreases with a greater time to admission. 4. SG group: in individuals who were admitted within 6 hr there was an improvement of 2-3 Frankel grades in 59% of individuals and decreases with a greater time to admission.
Benzel & Larson (1986a) USA Case Series N=105	**Population:** Mean age: 31.3 yr; Level of injury: T3-L4; Level of severity: Neurological Grading System (NGS) I=34, II=10, III=10, IV=12, V=11, VI=21, VII=7; Mean time since injury: NGS I=48.3 days, II=44.5 days, III/IV/V=35.4 days, VI/VII=19.4 days. **Intervention:** Individuals who underwent anterior decompression following thoracic and lumbar spine fractures were retrospectively analyzed for outcomes post-surgery. **Outcome Measures:** Complications, Neurological Grading System.	1. Complications included pneumonia (n=5), deep vein thrombosis (n=3), respiratory failure (n=2), renal failure (n=2) and superficial infection (n=1). 2. All NGS I individuals remained Grade I following surgery. 3. Of the 10 NGS II individuals four improved (III=2, IV=1, V=1) and six remained the same following surgery. 4. Of the 10 NGS III individuals nine improved (IV=2, V=6, VI=1) and one remained the same following surgery. 5. Of the 12 NGS IV individuals all 12 improved (V=6, VI=6) following surgery. 6. Of the 11 NGS V individuals 10 improved (VI=10) and one remained the same following surgery. 7. Of the 21 NGS VI individuals 17 improved (VII=17) and four remained the same following surgery. 8. All seven NGS VII individuals remained the same following surgery.
Benzel & Larson (1986b) USA	**Population:** Level of injury: C4-C7.	1. For those individuals treated with spinal decompressions, 15 showed

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Case Control N=35	**Intervention:** Individuals with complete myelopathies secondary to cervical spinal fractures underwent spinal decompressions (anterior; n=23, posterior; n=2) or nerve root decompression (n=10). **Outcome Measures:** Recovery of nerve root function.	substantial recovery of nerve root function. 2. None of the individuals treated with nerve root decompression showed recovery of nerve root function.

Discussion

Several early studies have reported the effect of surgical decompression in cervical SCI. Kiwerski (1986) reported a retrospective series of individuals treated from the late 1960s to the time of publication. Individuals treated surgically and conservatively both had what was then an acceptable neurological outcome, but with surgery individuals showing superior results, with 66% and 49% of individuals showing neurological improvement at follow-up, respectively. Benzel et al. (1987) examined a series of surgically treated individuals with cervical SCI from 1979 to 1986 and demonstrated the possibility of neurological improvement with surgery even in groups of motor-complete injuries; however, there was no non-surgical control group in this study.

With respect to thoracolumbar SCI, Benzel et al. (1986a) described a series of 105 operative cases predominantly treated with anterior-only decompression (a formerly preferred approach). Despite no significant neurological improvement in those individuals with motor complete injuries, individuals with motor incomplete injuries went on to experience only minimal permanent neurological deficit. In this series, surgical efficacy could not be assessed due to absence of a comparator group. Hu et al. (1993) published a retrospective comparison of anterior-vs-posterior decompression in thoracolumbar SCI, finding no difference between approaches in terms of neurological outcome. Ultimately it is difficult to pinpoint the appropriateness of these studies today due to the vast improvements in surgical instrumentation in the intervening decades. Some centres perform endoscopic decompression in the setting of thoracolumbar SCI, with the thought of avoiding the significant morbidity of a thoracolumbar approach, while also achieving decompression of the compressive abnormality culprit (often the vertebral body). Beisse et al.(2005) report such a series, collected prospectively, that demonstrated comparable neurological outcomes to open surgery. Limitations to this approach include the inability to correct significant deformity.

Direct injury to the conus medullaris can present in a variety of neurological syndromes, as upper motor neuron fibres coalesce here and synapse with all anterior horn cells for the caudal lumbar and sacral spine. As such, a mix of upper motor neuron and lower motor neuron deficits to motor, bowel and bladder occur, depending on the specific anatomy of the injury. With respect to decompression of traumatic conus injuries, Rahimi-Movaghar et al. (2006) assessed a retrospective case series of individuals who primarily had suffered lumbar burst injuries with associated conus injuries. In this group, approximately 40% of individuals experienced neurological improvement after surgery, and a large majority experiencing an improvement attributed to recovery of an adjacent nerve root. As there was no non-operative control group, comparative efficacy of surgery could not be studied. The authors reported no effect of surgical timing on neurological outcome.

In addition to cord injury, there can often be an associated nerve root injury at or adjacent to the level of spinal trauma. In an important retrospective analysis, Benzel et al. (1986b) described substantial rates of improved nerve root function at the level adjacent to, or directly above, the injured spinal cord with surgical decompression of the neural foramen at the time of primary surgery. In contrast, none of the individuals who did not receive neural foramen decompression demonstrated nerve root function improvement. This suggests the reasonableness of pursuing nerve root decompression during surgery for SCI, despite nerve root compression not being a surgical indication in itself.

With respect to environments with economic limitations, Ojo et al. (2017) reported outcomes among a group of surgically treated individuals with SCI in Nigeria. Of 35 individuals, nine demonstrated improved Frankel grade at 6 months, and the group had an overall acceptable complication profile. Although there was no comparator group, the authors propose decompression and stabilization surgery as a reasonable proposition to enhance functional outcome, despite the challenges of complex spinal instrumentation in their economic setting.

Conclusion

There is level 3 evidence (based on 1 case control; (Kiwerski, 1986) that cervical decompression results in improved neurological functioning in comparison to conservative treatment. This is supported by level 4 evidence (based on 1 case series; (Benzel & Larson, 1987) showing neurological improvement but without a control group.

There is level 4 evidence (based on 1 case series; (Benzel & Larson, 1986a) that thoracolumbar decompression results in improved neurological functioning among individuals with incomplete SCI but not complete SCI.

There is level 4 evidence (based on 1 case series; (Hu et al., 1993) that there is no difference in neurological improvement after thoracolumbar decompression by either an anterior or posterior approach.

There is level 4 evidence (based on 1 pre-post study; (Beisse et al., 2005) that endoscopic thoracolumbar surgery results in improved neurologic outcomes for both motor complete and incomplete SCI, although those with incomplete injuries have greater rates of improvement.

There is level 4 evidence (based on 1 case series; (Rahimi-Movaghar et al., 2006) that decompression of lumbar burst injuries with associated conus injuries results in neurological improvement and recovery of adjacent nerve root.

Cervical decompression may improve neurological functioning post SCI.

Thoracolumbar decompression may improve neurological functioning among those with incomplete, but not complete SCI. Anterior and posterior approaches may be equally effective. Endoscopic approaches may be similarly effective to open decompression approaches.

Decompression surgery for lumbar burst and conus injuries may improve neurological outcomes and adjacent nerve root.

4.2 Effect of Timing on Decompression and/or Stabilization Surgery Post SCI

Surgical timing has been one of the most eagerly studied clinical questions in acute spinal cord injury. Generally, the current treatment paradigm states that acute traumatic SCI can involve the acquisition of secondary injury due to ongoing compression, ischemia, inflammatory cascades, vascular phenomena or immune response. As such, it is thought that early correction of ongoing compression and/or instability would limit these processes and produce a favourable neurological outcome. For these reasons, there has been a presumption that earlier surgery is superior; there has therefore not been appropriate clinical equipoise for randomized studies of surgical timing.

The pertinent details relevant to surgical timing tend to relate to whether the individual has residual neurological function that is salvageable with surgery. Individuals with an incomplete SCI are therefore seen as a more emergent surgical problem, although Bourassa et al. (2013) demonstrate that individuals with motor complete SCI can also benefit from early surgery. In addition, the presence of ongoing mechanical compression of the spinal cord is seen as another inherently emergent problem, and one that is generally not specified in the studies reviewed here.

Most of the notable studies on surgical timing use a dichotomized analysis, for example within 24 hours of injury or after. Some studies use a 72 hours cut-off and this distinction must be kept in mind when comparing different results.

Table 2. Effect of Timing on Decompression and/or Stabilization Surgery Post SCI

Author Year Country Research Design Score Total Sample Size	**Methods**	**Outcome**
Dakson et al. (2017) Canada Case Control N=56	**Population**: Mean age: 47.6±20.7 yr; Gender: male=74, female=20; Level of injury: cervical=66, thoracolumbar=28; Severity of injury: AISA A=31, B=12, C=16, D=29, unknown=6. **Intervention**: No intervention. A retrospective review of individuals with SCI to determine the effect of early (<24 hr, n=23) or late (>24 hr, n=33) surgical decompression and maintenance of Mean Arterial Pressure (MAP) ≥85 mmHg for 5 days on neurological recovery.	1. Individuals with MAP <85 mm Hg for at least two consecutive hr during the five-day period post injury were 11 times less likely to have an improvement in AIS grade when compared to individuals with MAP ≥85 mm Hg (p=0.006). This association was independent of early surgery or the severity of SCI. 2. At a mean of 252 days post injury, a significant proportion of individuals with SCI treated with early surgical decompression improved

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome measures: American Spinal Injury Association (ASIA). **Chronicity**: The mean time from injury to surgical decompression was 13.4±5 hr and 127.7 hr for the early and late groups.	neurologically when compared to late decompression (p=0.031).
Bourassa-Moreau et al. (2016) Canada Case Control N=53	**Population:** Mean age: 42.4 yr; Gender: males=45, females=8; Level of injury: C1-C7=20, T1-L2=33; Level of severity: American Spinal Injury Association Impairment Scale (AIS) A ; Mean time since injury: 22.6 hr. **Intervention:** Individuals who underwent decompression surgery following SCI injury were retrospectively analyzed. Comparisons were made between early (<24 hr) and late (>24 hr) surgery as well as cervical (n=20) and thoracolumbar (n=33) injuries. **Outcome Measures:** Demographics, AIS.	1. Individuals operated <24 hr (n=38) were significantly younger than the 15 individuals operated >24 hr (p=0.049). 2. Overall, 28% (15/53) had improvement in AIS: 34% (13/38) who were operated <24 hr and 13% (2/15) who were operated >24 hr (p=0.182). 3. 64% (9/14) of cervical complete SCI operated <24 hr had improvement in AIS as opposed to none in the subgroup of six individuals with cervical SCI operated >24 hr (p=0.008).
Furlan et al. (2016) Canada Case Control N=61	**Population:** *Motor Complete Early (COMe, n=12):* Mean age: 52.1 yr; Gender: males=11, females=1; Level of injury: C1-C4=4, C5-C8=8; Level of severity: AIS A=9, B=3. *Motor Complete Late (COMl, n=14):* Mean age: 46.8 yr; Gender: males=12, females=2; Level of injury: C1-C4=10, C5-C8=4; Level of severity: AIS A=9, B=5. *Motor Incomplete Early (INe, n=11):* Mean age: 52.8 yr; Gender: males=7, females=4; Level of injury: C1-C4=4, C5-C8=7; Level of severity: AIS C=7, D=4. *Motor Incomplete Late (INl, n=24):* Mean age: 49.3 yr; Gender: males=15, females=9; Level of injury: C1-C4=12, C5-C8=12; Level of severity: AIS A=11, B=13. **Intervention:** individuals who underwent decompression surgery following cervical SCI injury were retrospectively analyzed. Comparisons were made between early (<24 hr) and late (≥24 hr) surgery as well as complete and incomplete injuries. Outcomes were assessed at baseline and 6 mo follow-up. **Outcome Measures:** Cost Effectiveness.	1. Overall early spinal decompression is more cost effective than late spinal decompression. • For individuals with complete SCI injury, cost-effectiveness ratio analysis revealed a savings of US$ 58,368,024.12 per quality adjusted life years gained. 2. For individuals with incomplete SCI injury, cost-effectiveness ratio analysis revealed a savings of US$ 536,217.33 per quality adjusted life years gained.
Liu et al. (2015) China Case Control $N_{Initial}$=595, N_{Final}=489	**Population:** Early Decompression (ED, n=212): Mean age: 40.4 yr; Gender: males=166, females=46; Injury etiology: motor vehicle accident=121, fall=52, object hit=21, sports=18; Level of injury: C3=16, C4=53, C5=75, C6=43, C7=25; Level of severity: Frankel A=42, B=65, C=68, D=37; Time since injury range: <24 hr. Late Decompression (LG, n=383): Mean age: 41.9 yr; Gender:	1. Overall, 23 individuals died and 83 failed to receive a follow-up. 2. 106 individuals (61.6%) in the ED group and 204 (64.4%) individuals in the LD groups experienced at least one Frankel grade (all p<0.001); however, there was no significant difference between groups (p=0.825).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	males=290, females=93; Injury etiology: motor vehicle accident=234, fall=102, object hit=26, sports=21; Level of injury: C3=26, C4=91, C5=141, C6=78, C7=47; Level of severity: Frankel A=82, B=132, C=123, D=46; Time since injury range: >24 hr. **Intervention:** Individuals who underwent surgical decompression after lower cervical (C3-C7) spine trauma were retrospectively reviewed and analyzed by timing of decompression surgery (ED versus LD). Outcomes were assessed at a mean follow-up time of 24.9 mo. **Outcome Measures:** Frankel Grade, Hospital Length of Stay (H-LOS), Neurological Deterioration, Mortality, Complications, Intensive Care Unit Length of Stay (ICU LOS), Ventilation (VENT) Days.	3. ED group individuals had significantly fewer H-LOS (p<0.001), greater post-op neurologic deterioration (p<0.001), and greater mortality (p=0.003). 4. There was no significant difference between ED and LD groups in other complications (all p≥0.166), ICU LOS (p=0.150), or VENT days (p=0.056).
Grassner et al. 2015 Germany Case Control N=70	**Population**: Early decompression (n=35): Mean age: 51.9±16.4 yr; Gender: male=26, female=9, Level of injury: not reported; Severity of injury: American Spinal Injury Association (ASIA) A=14, B=5, C=3, D=13, E=0. Late decompression (n=35): Mean age: 50.1±18.2 yr; Gender: male=33, female=2, Level of injury: not reported; Severity of injury: ASIA A=17, B=5, C=2, D=11, E=0. **Intervention**: A retrospective study examining functional and neurological outcomes at one yr post-surgical decompression in individuals with SCI who underwent surgery early (first 8 hr after injury) or late (>8 hr after injury). **Outcome measures:** American Spinal Injury Association (AISA) score; Spinal cord compromise; Neurological level; Sensory level; Motor level; Total motor score; Upper extremity motor score; Pin prick score; Light touch score; SCIM. Chronicity: The mean length of hospital stay was 127±58 days. The mean time from injury to surgical intervention was not reported.	1. Individuals from the early decompression group had significantly increased AIS grades (p<0.006) and increased AIS conversion rate (p<0.029). 2. No significant difference was observed in spinal cord compromise, sensory level, pin prick or light touch score between groups. 3. The motor and neurological levels of individuals who were operated on within eight hr were significantly more caudal after one yr (p<0.003 and p<0.014). 4. A significant increase in total motor performance (p<0.025) and upper extremity motor function (p<0.002) after one yr was observed in the early decompression group. 5. Individuals who were decompressed earlier had a significantly higher SCIM (45.8 vs 27.1, p<0.005). 6. A regression analysis showed that timing of decompression, age, basal AISA and SCIM scores were independent predictors of a better functional outcome.
Bourassa-Moreau et al. (2013)a Canada Case Control N=431	**Population:** *Early Surgery (ES, n=90)*: Mean age: 37.0 yr; Gender: males=74, females=16; Level of injury: C1-L2, paraplegic=61, tetraplegic=29; Level of severity: AIS A=55, B=16, C=8, D=11; Time since injury range: <24 hr. *Midrange Surgery (MS, n=231)*: Mean age: 40.7 yr; Gender: males=181, females=50; Level of injury: C1-L2, paraplegic=130, tetraplegic=51; Level of severity: AIS	1. Individuals who underwent decompression surgery earlier tended to be paraplegic and had a more severe ASIA grade. There were no differences in the other demographic and clinical variables with respect to surgical timing. 2. Individuals who had later surgery had significantly increased rates of pneumonia (p=0.025); no other

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	A=109, B=42, C=38, D=42; Time since injury range: 24-72 hr. *Late Surgery (LS, n=110)*: Mean age: 47.9 yr; Gender: males=80, females=30; Level of injury: C1-L2, paraplegic=36, tetraplegic=74; Level of severity: AIS A=33, B=13, C15, D=49; Time since injury range: >72 hr. **Intervention:** Participants who underwent surgery following SCI were retrospectively analyzed by timing of surgery. **Outcome Measures:** American Spinal Injury Association (ASIA) Grade, Complications.	complications were different between groups (p>0.1). 3. There was no significant difference in mortality rate between groups (p=.393). 4. ASIA grades A and B were significant predictors of all complications (p≤0.05).
Bourassa-Moreau et al. (2013)b Canada Case Control N=197	**Population:** *Early Surgery (ES, n=55)*: Mean age: 36.4 yr; Gender: males=49, females=6; Level of injury: C1-C4=6, C5-T1=10, T2-T10=17, T11-S1=22; Level of severity: AIS A=55; Time since injury range: ≤24 hr. *Late Surgery (LS, n=142)*: Mean age: 40.4 yr; Gender: males=116, females=26; Level of injury: C1-C4=15, C5-T1=36, T2-T10=57, T11-S1=34; Level of severity: AIS A=142; Time since injury range: >24 hr. **Intervention:** Participants who underwent surgery following SCI were retrospectively analyzed by timing of surgery. **Outcome Measures:** Hospitalization Cost, Mortality, Complications.	1. The cost of hospitalization was significantly lower for the ES group (p<0.05). 2. The total complication rate indicates that 57% of individuals had at least one complication. The rate of total complications (p=0.01), pneumonia (p=0.04), and UTI (p=0.03) were significantly lower in individuals operated ≤24 hr after injury; the rate of PU was not statistically different between groups (p=0.255). 3. There was no significant difference in mortality between groups (p=0.672). 4. Tetraplegia (p=0.006) and late surgery (p=0.01) were significant predictors of total complications.
Fehlings et al. (2012) Canada Case Control $N_{Initial}$=313, N_{Final}=222	**Population:** Mean age: 47.4 yr; Gender: males=236, females=77; Level of injury: C1-C7; Injury etiology: motor vehicle accident=119, fall=121, assault=13, sports=3, other=3; Level of severity: AIS A=101, B=54, C=66, D=92; Mean time since injury: 14.2 hr (early surgery), 48.3 hr (late surgery). **Intervention:** Individuals who underwent decompression surgery following cervical SCI injury were retrospectively analyzed. Comparisons were made between early (<24 hr) and late (≥24 hr) surgery. Outcomes were assessed at baseline and 6 mo follow-up. **Outcome Measures:** American Spinal Injury Association Impairment Scale (AIS) Change, Complications.	1. At 6 mo post injury, 19.8% of individuals undergoing early surgery showed a greater than two grade improvement in AIS compared to 8.8% in the late decompression group (p=0.03). 2. At 6 mo post injury, there was no significant difference in number of individuals who improved by one AIS grade between early and late surgery groups (p=0.31). 3. Complications occurred in 24.2% of early surgery individuals and 30.5% of late surgery individuals (p=0.21).
Wilson et al. (2012) Canada Case Control N=84	**Population***: Early Decompression (ED, n=35):* Mean age: 41.6 yr; Gender: males=29, females=6; Injury etiology: motor vehicle accident=13, fall=13, assault=1, other=8; Level of injury: C=14, T=12, L=9; Level of severity: AIS A=18, B=6, C=5, D=6; Time since injury range: <24 hr. *Late Decompression (LG, n=49)*:	1. Baseline assessment until acute hospital discharge: • Seven individuals (21.2%) in the ED group and nine individuals (18.4%) in the LD group experienced at least 1-Grade AIS improvement (p=0.47).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Mean age: 47.9 yr; Gender: male=38, female=11; Injury etiology: motor vehicle accident (n=10), fall (n=29), assault (n=3), other (n=7); Level of injury: C=30, T=9, L=10; Level of severity: AIS A=15, B=3, C=6, D=25; Time since injury range: >24 hr. **Intervention:** A group of individuals who underwent surgical decompression after spine trauma were retrospectively reviewed and analyzed by timing of decompression surgery (ED versus LD). Outcomes were assessed at baseline, acute discharge (mean: 24.8 days), and rehabilitation discharge (mean: 89.6 days) **Outcome Measures:** American Spinal Injury Association (ASIA) Motor Scale (AMS) Score, ASIA Impairment Scale (AIS).	• Three individuals (9.1%) in the ED group and one individual (2.0%) in the LD group experienced at least a 2-Grade AIS improvement (p=0.15). • The mean AMS improvement in the ED and LD groups were 6.2 and 9.7 points, respectively (p=0.18). 2. Baseline assessment until rehabilitation discharge: • Nine individuals (40.9%) in the ED group and 10 individuals (30.3%) in the LD group experienced at least 1-Grade AIS improvement (p=0.42). • Six individuals (27.2%) in the ED group and one individual (3.0%) in the LD group experienced at least a 2-Grade AIS improvement (p=0.01). • The mean AMS improvement in the ED and LD groups were 19.5 and 15.4 points, respectively (p=0.46).
Mac-Thiong et al. (2012) Canada Cohort N=477	**Population:** Mean age: 41.4 yr; Gender: males=374, females=103; Level of injury: C=228, T/L=249; Level of severity: AIS A=205, B=73, C=68, D=131. **Intervention:** Participants who received early surgical stabilization and/or decompression (<24 hr; n=93) were compared to those who received late surgery (>24 hr; n=384). **Outcome Measures:** Length of Stay; Hospitalization cost.	1. Rates of complete injury (58% versus 39%, p=0.001) and thoracic/lumbar injury (66% versus 49%, p=0.004) were significantly higher in the early than late surgery group. 2. Mean length of stay was significantly shorter with early than late surgery (28.1d versus 36.7d, p<0.001). 3. Mean hospitalization cost was significantly lower with early than late surgery ($20,525 versus $25,036, p<0.0001). 4. In a dichotomized model (early versus late), timing of surgery was significantly associated with stay (p=0.04) and cost (p=0.003). 5. In continuous model (time post injury), timing of surgery was significantly associated with cost (p=0.003) but not stay (p=0.32). 6. Stay and cost were significantly associated with older age, greater injury severity, and higher injury level.
Rahimi-Movaghar (2005) Iran Case Series N=12	Population: Mean age: 26.0 yr; Gender: males=11, females=1; Injury etiology: motor vehicle accident=9, unknown=3; Level of injury: thoracic; Level of severity: Frankel A=12. Intervention: Individuals with SCI who underwent surgical decompression were retrospectively analyzed. Mean follow-up time was 43.75 mo.	1. One individual improved from Frankel Grade A to C and one individual improved from Frankel Grade A to B following surgery. 2. Ten individuals remained at Frankel Grade A following surgery.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: Frankel Grade.	
Mirza et al. (1999) USA Case Control N=30	**Population:** Mean age: 32 yr; Gender: males=26, females=4; Level of injury: C2-C7; Level of severity: Frankel I=20, II=1, III=2, IV=7. **Treatment:** Participants who received early surgical stabilization and/or decompression (≤3 days; n=15) were compared to those who received late surgery (>3 days; n=15) in a retrospective review. **Outcome Measures:** American Spinal Injury Association Motor Score (AMS); Frankel Grade; Hospitalization periods; Complications.	1. Early surgery showed significant improvements from baseline in mean AMS (39.2 to 77.1, p=0.006) and Frankel Grade (1.9 to 3.7, p=0.0026). 2. Late surgery showed non-significant improvements from baseline in mean AMS (23.5 to 39.1, p=0.14) and Frankel Grade (1.8 to 2.1, p=0.30). 3. Mean postoperative scores were significantly greater with early surgery than late surgery for AMS (77.1 versus 39.1, p=0.01) and Frankel Grade (3.7 versus 2.1, p=0.01). 4. There was no significant difference between groups in length of surgery, mechanical ventilation, or time in ICU, but overall acute care stay was significantly greater for late than early surgery (37 versus 22 days, p=0.036). 5. There was no significant difference between groups in the number of minor (p=0.24), major (p=0.12), or total (p=.05) complications.

Table 3. Systematic Reviews Assessing the Effect of Timing on Decompression and/or Stabilization Surgery Post SCI

Authors Year Country Date of Studies Included AMSTAR Score Total Sample Size	Method	Conclusions
Liu et al. (2016) China Meta-Analysis AMSTAR=9 N=9 studies	**Objective:** To compare outcomes is individuals with traumatic SCIwho had early surgery (<24 hr) with those who had late surgery (>24 hr). **Methods:** Comprehensive literature search of controlled trials reporting on surgery for individuals with traumatic SCI published in English. Data analysis was performed by calculating mean difference (MD) or odds ratio (OR) and 95% confidence intervals (95%CI). **Databases:** PubMed, MEDLINE, EMBASE, Cochrane. **Evidence:** Studies were assessed for quality using the Newcastle-Ottawa Scale (NOS, 0-10). Statistical significance was defined as p<0.05**.**	1. Quality of studies was high: NOS=8 (n=7) and NOS=9 (n=2). 2. In four studies (n=196), motor improvement was significantly greater in early surgery than late surgery (MD=3.30, 95%CI=0.82-5.79, p=0.009). 3. In seven studies (n=634), neurological improvement was significantly greater in early surgery than late surgery (OR=1.66, 95%CI=1.19-2.31, p=0.003). 4. In four studies (n=196), length of stay was significantly shorter in early surgery than late surgery (MD=-4.76, 95%CI=-9.19,-0.32, p=0.04). 5. In six studies (n=502), complication rate was significantly lower in early surgery than late surgery (OR=0.61, 95%CI=0.40-0.91, p=0.02). 6. In eight studies (n=650), mortality rate was not significantly different

		between groups (OR=1.39, 95%CI=0.51-3.75, p=0.52).
Van Middendorp et al. (2013) UK Meta-Analysis AMSTAR=7 N=22 studies	**Objective:** To compare outcomes is individuals with traumatic SCIwho had early surgery (<24 hr) with those who had late surgery (>24 hr). **Methods:** Comprehensive literature search of all English studies reporting on surgery only for individuals with acute traumatic SCI aged >14 yr. Data analysis was performed by calculating weighted mean difference (WMD) or odds ratio (OR) and 95% confidence intervals (95%CI). **Databases:** MEDLINE. **Evidence:** Studies were assessed for quality using a tailored scoring instrument (0-25) that was normalized into a quality index (0-1).	1. Total of 22 studies were found in systematic review, but only 18 were included in meta-analysis. 2. Quality scores were 0.08 (n=2), 0.12 (n=2), 0.16 (n=6), 0.20 (n=2), 0.24 (n=5), 0.28 (n=1), 0.32 (n=1), 0.40 (n=1), 0.52 (n=1), and 0.56 (n=1). 3. In seven studies (n=815), motor improvement was greater with early surgery than late surgery (WMD=4.73, 95%CI=-0.13-9.59). 4. In six studies (n=495), neurological improvement was greater with early surgery than late surgery (OR=1.74, 95%CI=1.04-2.91). 5. In six studies (n=1103), length of stay was shorter with early surgery than late surgery (WMD=-8.51, 95%CI=-12.78 -4.25). 6. In nine studies (n=1148), mortality was similar with both surgeries (OR=0.97, 95%CI=0.40-2.31). 7. In twelve studies, adverse events were similar with both surgeries (OR=0.86, 95%CI=0.69-1.07).
La Rosa et al. (2004) Italy Meta-Analysis AMSTAR=6 N=27 studies	**Objective:** To compare outcomes is individuals with traumatic SCI who had early surgery (<24 hr) with those who had late surgery (>24 hr) or conservative treatment. **Methods:** Comprehensive literature search of all English studies reporting on surgery for acute traumatic SCI. Data analysis was performed by calculating improvement rate (>1 on Frankel scale) and 95% confidence intervals (95%CI). **Databases:** MEDLINE, Cochrane. **Evidence:** Levels of evidence were assigned based on class (I=RCTs, II=prospective, III=retrospective, IV=case reports). Statistical significance was defined as p<0.05.	1. Evidence was Class I (n=1), Class II (n=8), and Class III (n=18). 2. For early surgery, 11 studies with 409 individuals were found, with only 226 individuals considered in meta-analysis. 3. For early surgery, improvement rate was 42% (95%CI=33.1-50.8) for complete deficit and 89.7% (95%CI=83.9-95.5) for incomplete. 4. For late surgery, 13 studies with 827 individuals were found, with 567 individuals considered in meta-analysis. 5. For late surgery, improvement rate was 8.3% (95%CI=4.8-11.8) for complete deficit and 58.5% (95%CI=53.1-63.9) for incomplete. 6. For no surgery, nine studies with 1335 individuals were found, with 890 individuals considered in meta-analysis. 7. For no surgery, improvement rate was 24.6% (95%CI=21-28.2) for complete deficit and 59.3% (95%CI=54-64.6) for incomplete. 8. Improvement rate was significantly different among all three groups for complete deficit ($\chi2$=55.4, p<0.001) and incomplete ($\chi2$=37.6, p<0.001). 9. Improvement rate was significantly greater with early surgery than late surgery in complete deficit ($\chi2$=58.1, p<0.001) and incomplete ($\chi2$=35.1, p<0.001).

		10. Improvement rate was significantly greater with early surgery than no surgery in complete deficit ($\chi2=15$, $p<0.001$) and incomplete ($\chi2=33.7$, $p<0.001$).

Discussion

An earlier retrospective analysis performed by Mirza et al. (1999) compared neurological and functional outcomes of individuals treated at one hospital versus another, each with a different policy for surgical timing (within 72 hours versus after 72 hours). Of note, all individuals received immediate closed reduction/decompression, with the late surgery group then waiting a period of 10-14 days before surgery. In this group, early surgery was associated with better ASIA Impairment Scale (AIS) motor score improvement as well as Frankel grade improvement. This study was limited by the fact that the two institutions could have varied in a number of other ways. Furthermore, every individual received immediate closed reduction suggesting that a process in addition to mechanical decompression may be occurring that confers neurological benefit with surgery.

Two Canadian multicentre studies demonstrated an association of early surgery with neurological recovery. Wilson et al. (2012) demonstrated an improvement in AIS Grade conversion and AIS motor score improvement using a 24-hour time cut-off for surgery. Similarly, Fehlings et al. (2012) published the STASCIS trial (Surgical Timing in Acute Spinal Cord Injury Study) using the same time cut-off in a prospective population of cervical SCI. They also reported a higher grade of AIS conversion at 6 months, as well as fewer complications, in the early surgery group.

Despite the overwhelming, positive outcomes associated with early surgery, the literature does have some heterogeneity. For example, Liu et al. (2016) reported that in their retrospective review, early surgery individuals (<72 hours) had a higher rate of neurological deterioration and mortality, thus arguing for the relative safety of delayed decompression.

Other than neurological outcomes, early surgery is supported in several other dimensions. According to Furlan et al. (2016), early surgery is more cost effective when considered in terms of complications and length of stay. Mac-Thiong et al. (2012) reported comparable results, with early surgery favouring lower complications, shorter length of stay and less overall cost. Similarly, higher medical and postoperative complication rates were found in the late surgery group identified by Bourassa et al. (2013), even despite higher numbers of motor complete injuries in the early group, whom are prone to such complications.

Because one of the rationales for early surgery involves protecting salvageable neural tissue, the role of surgical timing in motor complete injuries is not entirely clear. In their prospective cohort study, Bourassa (2016) demonstrated a statistical difference in AIS grade improvement in a population of individuals with motor complete SCI when dichotomized into early (34%) versus late surgery (13%). Similarly, the same group showed that the above-mentioned advantage in terms of complications and length of stay may also apply to cohorts of motor complete individuals.

Three systematic reviews have been published on surgical timing in acute SCI. La Rosa et al. (2004) conducted a meta-analysis comparing early surgery (defined within 24 hours) versus late surgery versus no surgery. They concluded that early surgery was superior to both other options, in subsets of both motor complete and incomplete injuries. One challenge is that this meta-analysis uses the loosely defined outcome measure “neurological improvement rate,” which is heterogenous and difficult to interpret across studies. The systematic review of Liu et al. (2016) reached similar conclusions regarding motor outcome and found superiority of early surgery regarding length-of-stay and complication rate, but not reduction in mortality. The systematic review of van Middendorp et al. (2013) reached similar conclusions as the other reviews and relayed the continued methodological limitations of included studies. Interestingly, using a funnel plot analysis, the authors found evidence of publication bias in the surgical timing literature but note that equipoise for prospective randomized studies does not exist.

Conclusion

There is level 3 evidence (based on several case control studies) that surgery within 24 hours of injury leads to improved neurological outcomes, shorter length of stay, and fewer complications, but not a reduction in mortality after acute, traumatic SCI.

In acute traumatic SCI, surgery within 24 hours is associated with better neurological outcome, lower complications and shorter length of stay but not a reduction in mortality. Generally, surgery within 72 hours is an acceptable standard of care.

4.3 Surgery for Traumatic Central Cord Syndrome

Central cord syndrome is a clinical entity with acute SCI that affects the upper extremities more profoundly than the lower extremities. This can include motor deficit or varying degrees of neuropathic pain in the upper extremities. The lamination of the long white matter tracts in the spinal cord puts the upper extremity fibres at greater risk when lesions occur in the centre of the cord. The exact mechanism of this injury is not fully understood. Traumatic aetiologies of central cord are thought to involve a relative ischemia in the central part of the spinal cord, which is a vascular watershed area between the anterior spinal artery and the posterior blood supply. This can be induced by a hyperextension injury in the setting of pre-existing stenosis or degenerative changes, for example. Several case series have assessed the role of surgical decompression in the setting of central cord syndrome and will be reviewed here.

Table 4. Surgery for Traumatic Central Cord Syndrome

Author Year Country Research Design Score Total Sample Size	**Methods**	**Outcome**
Liu et al. (2017) China Case Series N=11	**Population:** Mean age=54.1 yr; Gender: male=10, female=1; Level of injury: not reported; Severity of injury: ASIA A=0, B=1, C=6, D=4, E=0. **Intervention:** Individuals with delayed cervical central cord syndrome were retrospectively studied to investigate the efficacy of surgical intervention. **Outcome measures:** American Spinal Injury Association (ASIA) motor score; Japanese Orthopedic Association (JOA) score; SF-36; Neurologic status. **Chronicity:** The mean time from injury to surgical intervention was 92.4 days.	1. ASIA motor scores significantly improved post-surgical intervention (p<0.05). 2. A significant improvement in JOA scores was observed within the first six mo following surgical intervention (p<0.05). 3. The mean scores of physical functioning, bodily pain, vitality, social functioning, and mental health of individuals significantly improved post-surgical intervention on the SF-36 questionnaire (p<0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		4. ASIA grade significantly improved after surgical intervention (p<0.05).
Jug et al. (2015) Slovenia Cohort $N_{Initial}$=48, N_{Final}=42	**Population:** *Early group (n=20):* Mean age: 52.0 yr; Gender: males=16, females=4; Level of injury: C=19, C/T=1; Level of severity: AIS A=13, B=1, C=6. *Very Early group (n=22)*: Mean age: 44 yr; Gender: males=18, females=4; Level of injury: C=20, C/T=2; Level of severity: AIS A=13, B=5, C=4. **Intervention:** Participants received early (8-24 hr) or very early (<8 hr) decompression and fusion. Outcomes were assessed before treatment and at 6 mo follow-up. **Outcome Measures:** American Spinal Injury Association (ASIA) Impairment Scale (AIS); ASIA Motor Scale (AMS).	1. The rate of AIS improvement >1 grade was 28% greater in the very early group than in the early group, but the difference was not significant (RR=1.81, 95%CI=0.76-4.30, p=0.115). 2. The rate of AIS improvement >2 was 36% greater in the very early group than in the early group (RR=2.08, 95%CI=1.12-3.87, p=0.015). 3. The odds of AIS improvement >2 was over 100% greater in the very early group than early group after adjusting for pre-operative AIS grade and degree of spinal canal compromise (OR=11.08, p=0.004). 4. The odds of AIS improvement >2 did not significantly differ based on completeness of injury (OR=0.26, p=0.087) or degree of spinal canal compromise (OR=0.94, p=0.066). 5. The odds of AIS improvement >2 were at least 2% lower for each additional hr from injury to surgery (OR=0.83, p=0.029). 6. The median improvement in AMS score was significantly greater in the very early group than early group (+38.5 versus +15.0, p=0.0468).
Kepler et al. (2015) Canada Case Control N=68	**Population:** *Early surgery (n=19):* Mean age=52.1 yr; Gender: male=63%, female=37%; Level of injury: not reported; Severity of injury: mean ISS=18.1. *Delayed surgery (n=49):* Mean age=59.2 yr; Gender: male=72%, female=27%; Level of injury: not reported; Severity of injury: mean ISS=19.8. **Intervention:** A retrospective review was conducted to characterize changes in ASIA motor scores within the first week after traumatic central cord syndrome to identify predictors of improved early outcome in individuals treated with early versus delayed surgical intervention. **Outcome measures:** American Spinal Injury Association (ASIA) motor score; Overall Length of Stay (LOS); LOS in Intensive Care Unit (ICU). **Chronicity:** The average length of hospital stay in ICU was 3.4 days, while overall hospital length of stay was 10.5 days.	1. No significant differences were observed in ASIA motor scores (p=0.36), the change in ASIA motor score within seven days (p=0.34), the number of individuals who had early improvement (p=.94), time spent in ICU (p=0.84), or overall LOS (p=0.59) between the early and delayed groups.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Samuel et al. 2015a USA Case Series N=2636	**Population:** Mean age: 56.6 yr; Gender: males=833, females=227; Injury etiology: fall=586, motor vehicle accident=317, bicycle=59, other=98; Level of injury: T12-L3. **Intervention:** Individuals with acute traumatic central cord syndrome who underwent surgery were retrospectively analyzed. Individuals were analyzed by time to surgery. Mean time to surgery was 3.5 days. **Outcome Measures:** Mortality, Adverse Events.	1. Delayed surgery was associated with a decreased odds of inindividual mortality (p=0.04) 2. Delayed surgery was associated with a 19% decrease in odds of mortality with each 24 hr increase in time until surgery. 3. The association of time to surgery with serious adverse events was not statistically significant (p=0.09). 4. The association of time to surgery was associated with increased odds of minor adverse events (p<0.001).
Samuel et al. 2015b USA Case Series N=1060	**Population:** Mean age=56.6 yr; Gender: male=833, female=227; Level of injury: not reported; Severity of injury: mean ISS score=19.5. **Intervention:** A retrospective review of surgically treated individuals with acute traumatic central cord syndrome to determine the association of time to surgery on mortality and adverse events. **Outcome measures:** Mortality; Serious adverse events; Minor adverse events. **Chronicity:** The mean time to surgical decompression was 3.5 days, while the mean length of hospital stay was 14 days.	1. Delayed surgery was associated with decreased odds of individual mortality (OR=0.81, p=0.04), or a 19% decreased in odds of mortality with each 24 hr increase in time to surgery. 2. No significant differences were observed between time to surgery and serious adverse events (p>0.05), however, time to surgery was associated with increased odds of minor adverse events (OR=1.06, p<0.001).
Anderson et al. (2012) USA Case Series N=69	**Population:** Mean age: 59.0 yr; Gender: males=39, females=30; Injury etiology: falls=49, motor vehicle accident=13, sports=6, traumatic intubation=1; Injury severity: AIS C=28, D=41. **Intervention:** Individuals with traumatic central cord syndrome were retrospectively analyzed. Individuals had early surgery (<24 hr, n=14), midrange surgery (24-48 hr, n=30), or late surgery (>48 hr, n=25). Mean length of acute care hospitalization was 13 days and mean follow-up time was 11 mo. **Outcome Measures:** American Spinal Injury Association (ASIA) Grade, ASIA Motor Score (AMS).	1. There was a significant improvement in mean AMS between initial presentation and hospital discharge, and between hospital discharge and final follow-up (p=0.01 and p<0.001, respectively). 2. Overall, 74% of individuals improved one or more AIS grades. 3. ASIA-C individuals: 6 (21.4%) were still ASIA-C at final follow-up, 19 (67.9%) had improved to ASIA-D, and 3 (10.7%) had improved to ASIA-E. 4. ASIA-D individuals: 12 (29.3%) were still ASIA-D at final follow-up and 29 (70.7%) had improved to ASIA-E. 5. There was no significant difference in rate of AMS improvement between all surgery groups.
Chen et al. (2009) China Case Series $N_{Initial}$=56, N_{Final}=49	**Population:** Mean age: 55.9 yr; Gender: males=40, females=9; Injury etiology: motor vehicle accident=29, fall=16, sports=3, Other=1; Level of injury: cervical. **Intervention:** Individuals with traumatic central cord syndrome who underwent surgical repair were retrospectively analyzed.	1. Significant improvement in ASIA scores was achieved during the first 6 mo after surgical intervention. 2. Younger individuals had a significantly greater improvement in the ASIA motor score compared to older individuals (p=0.023). 3. On the SF-36, many individuals complained that spasticity and

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: American Spinal Injury Association (ASIA) Motor Scores, Short Form 36 (SF-36), Walking Index for Spinal Cord Injuries (WISCI).	neuropathic pain were major factors leading to poor quality of life. 4. There was no significant difference between individuals who underwent surgery within 4 days of injury or after 4 days of injury. 5. There was no significant difference in WISCI scores.
Aito et al. (2007) Italy Case Control N=82	**Population:** Mean age: 52.0 yr; Gender: males=72, females=10; Injury etiology: motor vehicle accident=47, falls=30, sports=5; Injury severity: AIS A=2, B=12, C=37, D=31; Time since injury range: >18 mo. **Intervention:** Individuals with traumatic central cord syndrome were retrospectively analyzed and compared to those receiving conservative treatment. **Outcome Measures:** Type of Treatment, Length of Stay (LOS), Neuropathic Pain, Functional Independence Measure (FIM), Walking Index for Spinal Cord Injuries (WISCI), American Spinal Injury Association (ASIA) Impairment Scale.	1. 45% of participants were treated surgically and 55% conservatively. 2. Average LOS was 120 days (24–390), but less for those treated without surgery. 3. Individuals under 65 years had better outcomes with less neuropathic pain. 4. FIM and WISCI scores highly correlated with the younger to older age groups (p<0.001). 5. ASIA impairment scale, both from admission to discharge and from discharge to follow-up, showed a significantly greater improvement for younger age groups (p<0.01).
Dvorak et al. 2005 Country Design N=X		1.
Guest et al. (2002) USA Case Control N=50	**Population:** Mean age: 45.0 yr; Gender: males=31, females=19; Injury etiology: motor vehicle accident=22, fall=19, sports=9. **Intervention:** Individuals with traumatic central cord syndrome (CCS) who underwent surgical repair were retrospectively analyzed based on timing of surgery: early (<24 hr, n=16) and late (>24 hr, n=34). Mean follow-up period was 36 mos. **Outcome Measures:** American Spinal Injury Association (ASIA) Motor Score (AMS), Post-Spinal Injury Motor Function Scale (PSIMFS).	2. Individuals with CCS secondary to acute disc herniation or fracture/dislocation who underwent early surgery significantly greater overall motor improvement was observed than in those who underwent late surgery (p=0.04). 3. Overall motor outcome in individuals with CCS secondary to spinal stenosis or spondylosis who underwent early surgery was not significantly different from that in those who underwent late surgery (p=0.51). 4. Worse motor outcomes were found in individuals who were older than 60 years of age and in whom initial bladder dysfunction was present (p=0.03 and p=0.02, respectively) compared with younger individuals without bladder dysfunction.

Discussion

The evidence reviewed here consists of retrospective, unselected individuals, and as such represent a biased sample of traumatic central cord individuals. Generally, a common management strategy is to conservatively manage those individuals who have mild pathology or show spontaneous early neurological improvement, and to consider surgery for those that fail to improve or who worsen. As such, these publications likely represent individuals that failed a period of initial observation. Furthermore, most studies here do not enlist a control group to compare surgical versus nonsurgical intervention, which precludes a robust assessment of the efficacy of decompression.

Aito et al. (2007) reported their retrospective comparison of surgically and non-surgically treated individuals and is the only study here to use a non-surgical control group. They found no effect of surgery on neurologic outcome. This is consistent with Dvorak et al. (2005) who demonstrated no difference in long-term neurologic outcomes in surgically versus non-surgically managed individuals with traumatic central cord syndrome.

The largest case series for this population is that of Samuel et al. (2015b) which followed 1060 surgically treated individuals. Using multivariate analysis, they reported an association between earlier surgery and mortality. Earlier surgery was also associated with minor, but not major, adverse events. Because other associations with mortality included advanced age and comorbidity status, it is possible that medically optimizing and stabilizing these individuals before surgical intervention may reduce minor complications and confer some survival advantage. This study did not assess neurologic outcome. This finding regarding advanced age is consistent with the Aito et al. (2007) and Chen et al. (2009) studies.

Other assessments of surgical timing in central cord syndrome reveal mixed results with respect to neurologic recovery. Kepler et al. (2015) found that early (<24 hours) surgery conferred no advantage in terms of AIS motor recovery, but that age was a significant predictor of worse neurological outcome. Anderson et al. (2012) found no association between surgical timing and AIS motor outcome. In a cohort study Jug et al. (2015) found a significant neurological benefit to those receiving very early surgery (<8 hours) compared to “late” surgery which was performed 8-24 hours post SCI. Guest et al. (2002) found that early surgery conferred a neurological recovery advantage in those individuals with an acute lesion such as an acute disc herniation or a compressive fracture, but not in those with a chronic process such as spondylosis.

Chen et al. (2009) followed surgically treated individuals and noted that at 6 months, there were improvements in AIS motor score, but there was no non-surgical comparator group. Among surgically treated individuals, there were no differences in health-related quality of life when assessing early (<4 days) versus late surgery. Similar to previous studies, older age was a negative prognostic factor.

Liu et al. (2017) reported on a series of 11 individuals presenting who underwent surgical treatment for central cord syndrome in a delayed fashion (mean of 90 days after injury). In this cohort, postoperative AIS and quality of life scores showed improvement, but the absence of a nonsurgical comparator group again makes conclusions difficult.

Conclusion

There is level 3 evidence (based on one case control; (Aito et al., 2007) that surgical treatment of traumatic central cord syndrome does not confer neurologic benefit compared to conservative management.

There is conflicting level 2 and 4 evidence (based on one cohort (Jug et al., 2015) and five case series studies; (Chen et al., 2009; R. Guest, Craig, Tran, & Middleton, 2015; Kepler et

al., 2015; Y. Liu et al., 2017; Samuel et al., 2015)that early decompression of central cord lesions have similar neurologic outcomes to late surgery but that the latter may have lower mortality, possibly due to age-and-comorbidity-related factors.

> With respect to traumatic central cord syndrome, there is no clear evidence of a neurologic benefit from decompression or its timing. Available evidence suggests that age and comorbidities may be appropriate justifications to delay surgery with possible survival benefit for doing so.

4.4 Surgical Stabilization

After traumatic SCI, surgical stabilization serves multiple purposes. Apart from the primary goal of decompression of neural structures, the restoration of mechanical stability can reduce pain, eliminate the need for a cervical collar or other activity restrictions, and facilitate nursing and other rehabilitation. The precise method of mechanical stabilization can be variable but consists of non-surgical rigid orthosis, versus open stabilization through a variety of anterior, posterior or circumferential instrumentation and fusion manoeuvres.

Table 5. Surgical Stabilization after SCI

Author Year Country Research Design Score Total Sample Size	**Methods**	**Outcome**
Rimoldi et al. (1992) USA Case Series N=147	**Population:** Mean age: 30 yr; Gender: males=115, females=32; Level of injury range: T9-L5; Level of severity: complete=56, incomplete=91; Mean time since injury: 23 days. **Intervention:** Participants who received surgical stabilization and/or decompression were retrospectively analyzed. **Outcome Measures:** American Spinal Injury Association (ASIA) Impairment Scale (AIS); Operation time; Rehabilitation time; Complications.	1. 120 stabilizations were performed: 112 posterior and eight anterior. 2. 68 decompressions were performed: 34 posterior and 34 anterior. 3. AIS motor score improved an average of eight points in participants with incomplete injury but did not improve in those with complete. 4. AIS motor score improvement was positively correlated with earlier surgery and with performing stabilization before/instead of decompression. 5. Operation time was shorter for sublaminar wires than Harrington rods and Drummond wires (292 min versus 297 min versus 351 min) and for posterior than anterior procedures (292-351 min versus 380 min). 6. Rehabilitation time was shorter in participants stabilized with sublaminar wires than with Drummond wires or Harrington rods (73 versus 92 versus 119 days) and was longer in those requiring postoperative immobilization. 7. Surgical complications (n=37) included kyphosis, pseudarthrosis, infection, pain, and hardware failure; these were correlated with later time-to-surgery. 8. Non-surgical complications (n=19) included deep vein thrombosis, pulmonary embolism, and pressure sores; there was no correlation with time-to-surgery. 9. Blood loss was greater in anterior than posterior procedures.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Bucci et al. (1988) USA Case Series $N_{Initial}$=49, N_{Final}=48	**Population:** Mean age: 30.3 yr; Gender: males=42, females=7; Injury etiology: motor vehicle accident=28, fall=7, sports=14; Level of injury: cervical. **Intervention:** Individuals who underwent immobilization (n=20) or immobilization and fusion (n=28) following SCI. Outcomes were assessed at 3 mo. **Outcome Measures:** Spinal Instability, Treatment Failure, Malalignment, Neurological Improvement, Neurological Deterioration.	1. There were significantly more individuals in the immobilization group with spinal instability ($p<0.01$). 2. There was no significant difference between groups in treatment failure, malalignment, neurological improvement or deterioration.
Capen et al., (1985) USA Case Series $N_{Initial}$=212, N_{Final}=166	**Population:** Mean age: 26.7 yr; Gender: males=179, females=43; Level of severity: complete=96, incomplete=99, normal=17. **Intervention:** Participants who received surgical stabilization of the cervical spine were retrospectively analyzed. Stabilization involved posterior fusion (n=114), anterior fusion (n=88), or combined fusion (n=10). **Outcome Measures**: Mortality, Complications, Neurological impairment, Stabilization maintenance.	1. No perioperative mortality occurred in any of the groups. 2. Complications were reported in the anterior group (n=18), posterior group (n=22), and combined group (n=3). 3. Neurological impairment occurred in the anterior group (n=4) and posterior group (n=1), but not combined group. 4. In the anterior group at 4 yr follow-up (n=59), six participants required graft replacement, 36 demonstrated loss of reduced alignment, and 36 demonstrated degenerative changes around the fusion mass. 5. In the posterior group at 4 yr follow-up (n=98), four participants required rewiring, none demonstrated loss of reduced alignment, and two demonstrated degenerative changes around the fusion mass; 73 demonstrated significant extension of fusion mass beyond intended levels. 6. In the combined group at 2 yr follow-up (n=9), no participants demonstrated issues with graft/wire, loss of reduced alignment, or degenerative changes around the fusion mass; two demonstrated extension of fusion mass beyond intended area.

Discussion

Non-operative methods of spine stabilization are sometimes used, especially for cervical spine injuries. Halo vest immobilization is most commonly indicated for injuries of the atlantoaxial joint or high cervical spine. To specifically assess individuals with sub-axial cervical spine injuries, Bucci et al. (1988) published a retrospective review of immobilization plus surgery versus immobilization with halo vest alone. Many of the nonsurgical individuals eventually required crossover to receive surgical treatment, and some experienced neurological worsening during halo vest application. As such, for this type of sub-axial cervical spine injuries, surgery is generally preferred to halo vest immobilization in sufficiently unstable injuries.

Rimoldi et al. (1992) assessed the effect of stabilization method on rehabilitation time in thoracolumbar SCI. Although the surgical constructs used are outdated and no longer in use, the finding that individuals judged to have a more mechanically stable construct, and whom were able to avoid orthosis use, may be generalizable.

Among individuals receiving surgical stabilization of the cervical spine, a common management dilemma is whether to provide stabilization from an anterior approach, a posterior approach, or both. Capen et al. (1985) published a retrospective analysis suggesting small proportions of neurologic worsening in each group; however, this study is of limited use today as the fixation techniques are no longer in use.

Conclusion

There is conflicting level 4 evidence (based on three case series;(Bucci et al., 1988; Capen et al., 1985; Rimoldi et al., 1992)on the effectiveness of surgical and non-surgical mechanical stabilization methods post SCI; methods described in the literature are quite dated and no longer used clinically.

Method of mechanical stabilization can be variable and consist of non-surgical rigid orthosis or open stabilization (e.g., anterior, posterior or circumferential instrumentation and fusion manoeuvres); however, the methods described in the literature are no longer used in clinical practice today.

4.5 Prognosis Following Surgery for SCI

In the acute period of traumatic spinal cord injury, interventions are aimed primarily at preserving or improving long-term function. Although recovery of neurologic function after injury is notoriously difficult to predict, much work has gone into identifying prognostic factors that might help guide individual expectations for long-term function. In general, prognosis and neurological outcome are described using outcomes tools including changes in the AIS motor score, and the Frankel grade, which is general measure of functional independence.

Table 6. Prognosis Following a Surgery for SCI

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Razaq et al. (2018) Pakistan Case Series N=149	**Population:** Mean age=32±13.1 yr; Gender: male=117, female=32; Level of injury: C3–C4=3, C4–C5=2, C5–C6=7, C6–C7=7, C7–T1=1; Severity of injury: ASIA A=65, B=12, C=59, D=13. **Intervention:** A retrospective review to assess neurological recovery in terms of ASIA grading in individuals with traumatic SCI. Outcome measures were assessed preoperatively and at six mo follow-up. **Outcome measures:** Cause of injury; ASIA score. **Chronicity:** All participants were operated on within 24 hr after injury.	1. The majority of individuals presented with fall (64.4%), while the remainder presented with motor vehicular accidents (35.6%). 2. The AISA grading at six mo was ASIA A=40.9%, B=2.7%, C=17.4%, D=22.1%. E=16.8%. 3. Overall neurological improvement was observed in 45% of individuals. 4. Improvement of one ASIA grade was observed in 32.9% of individuals, while a two-grade improvement was observed in 11.4% of individuals and three grades in 7%.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Abdel Fatah (2017) Egypt Case Series N=53	**Population:** Mean age=39.4 yr; Gender: male=22, female=31; Level of injury: T10=4, T11=7, T12=31, L1=11; Severity of injury: AISA A=6, B=18, C=29. **Intervention:** A retrospective review of walking recovery after surgical management of traumatic burst fractures at the thoracolumbar junction in paraplegic individuals. **Outcome measures:** Walking ability. **Chronicity:** The mean time from injury to surgical intervention was 9.3 hr and the mean length of hospital stay was 21.6 days.	1. All individuals with L1 fracture and 70.96% of individuals with T12 fracture regained the ability to walk, however, all the individuals with T10 and T11 fractures did not regain walking ability 12 mo after surgery. 1. The severity of SCI and walking ability was related to the spinal level of fracture.
Park et al. 2017 Korea Case Series N=73	**Population:** Mean age=44.2 yr; Gender: male=58, female=15; Level of injury: C2–C7; Severity of injury: AISA A-D. **Intervention:** A retrospective review of the prognostic factors affecting the outcomes of decompression surgery in individuals with SCI. **Outcome measures:** Early intervention; Sex; Age; Surgical level; American Spinal Injury Association (ASIA) score; Blood Pressure (BP); Mean Arterial Pressure (MAP); Cord compression; Steroid use; Surgery time; Estimated blood loss measured after surgery and at 3 mo. **Chronicity:** The mean time from injury to surgery and length of hospital stay was not reported.	1. The MAP, AIS before surgery and BP were significant prognostic factors affecting recovery in the immediate post-operative period ($p<0.001$, $p=0.033$, $p=0.004$), while early decompression, sex, age, surgical level, maximal cord compression, use of steroids, surgery time and EBL were not significant ($p>0.05$). 2. In the late recovery period, three mo after surgery, the AIS before surgery, BP, and MAP were significant prognostic factors affecting recovery ($p=0.006$, $p=0.004$, $p=0.003$), while early decompression, sex, age, surgical level, maximal cord compression, use of steroids, surgery time, and EBL were not significant ($p>0.05$).
Konomi et al. (2018) Japan Case Control N=78	**Population:** Mean age=67 yr; Gender: male=66, female=12; Level of injury: C3–C6; Severity of injury: Not reported. **Intervention:** The effectiveness of decompression surgery for individuals with traumatic cervical SCI and pre-existing cord compression ≥40% (n=32) or <40% (n=46) was compared. **Outcome measures:** American Spinal Injury Association (ASIA) score; Barthel index; SCIM. **Chronicity:** Individuals underwent surgery on average 27 days after injury. The mean duration of hospital stay was 46 days.	1. In the severe compression group (≥40%), AIS grade improvement >2 was observed in 30% of individuals with surgical treatment, although it was not observed in any individual without surgery. 2. SCIM improvement rate at discharge was 60% in the surgical group and 20% in the non-surgical treatment group. 3. In the minor compression group (<40%), AIS grade improvement >2 was observed in 18% of individuals with surgical treatment and 11% without surgery. 4. The SCIM improvement rate at discharge was 52% in the surgical treatment group and 43% in the non-surgical treatment group.
Biglari et al. (2016) Germany Cohort N=51	**Population:** *Early intervention (n=29):* Mean age=38.2±17.9 yr; Gender: male=25, female=4; Level of injury: cervical=12, thoracic=10, lumbar=7;	2. No significant difference in neurologic function, measured with ASIA score, was found between cohorts ($p>0.05$).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Severity of injury: AISA A=13, B=8, C=7, D=1. *Late intervention (n=22):* Mean age=50.2±18.9 yr; Gender: male=15, female=7; Level of injury: cervical=10, thoracic=6, lumbar=6; Severity of injury: AISA A=11, B=3, C=4; D=4. **Intervention:** Individuals with SCI received early (within the first four hr) or late (between four and 24 hr) surgical decompression to determine if either improves neurological outcomes. Outcome measures were assessed at the time of admission and 6 mo after trauma or longer depending on the time of release. **Outcome measures:** American Spinal Injury Association (ASIA) score. **Chronicity:** All individuals received early stabilization and decompression within 24 hr.	
Kreinest et al. (2016) Germany Case Series N=133	**Population:** Mean age=50.5±21.2 yr; Gender: male=104, female=29; Level of injury: C3–L4; Severity of injury: not reported. **Intervention:** A retrospective review to analyze the influence of previous comorbidities and common complications on motor function outcome in individuals with traumatic spinal cord injury that received early surgical intervention. **Outcome measures:** Motor function; Complications. **Chronicity:** The mean time from injury to surgery was 22.1±56.6 hr. The mean length of hospital stay was 122.8±100.4 days.	1. Motor function improved from 51.5±24.8 to 60.1±25 (improvement: 25.7%). 2. The most common complications were urinary tract infection and pneumonia. 3. A significant relationship between a lack of previous spinal comorbidities and increased motor function was observed (p<0.05). 4. No other comorbidities or complications showed a significant effect on motor function outcome.
Jug et al. (2015) Slovenia Cohort N=48	**Population:** *Early intervention (n=26):* Mean age=44 yr; Gender: male=18, female=8; Level of injury: C3–C4=1, C4–C5=4, C5–C6=5, C6–C7=10, C7–T1=2; Severity of injury: AISA A=13, B=5, C=4. *Late intervention (n=22):* Mean age=52 yr; Gender: male=16, female=6; Level of injury: C3–C4=3, C4–C5=2, C5–C6=7, C6–C7=7, C7–T1=1; Severity of injury: AISA A=4, B=1, C=15. **Intervention:** Individuals with SCI received surgical decompression and instrumented fusion early (within 8 hr) or late (between eight and 24 hr) after injury to determine if either improves neurological outcomes. Outcome measures were assessed at baseline and at six mo follow up.	1. At the six mo follow up, a significant improvement of at least two AIS grades was found in 45.5% of individuals in the early intervention compared to 10% of the late intervention cohort (p=0.017). 2. A significant improvement in ASIA motor score was found in the early intervention (38.5) compared to the late (15.0) (p=0.0468). 3. The odds of an at least two-grade AIS improvement were 106% higher for individuals in the early intervention than for individuals in the late intervention (OR=11.08, p=0.004). 4. No significant differences in rate of complications was found between cohorts.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome measures: American Spinal Injury Association (ASIA) score; Complications. **Chronicity:** All individuals received early stabilization and decompression within 24 hr.	
Lehre et al. (2015) Norway Case Series N=146	**Population:** Mean age=31.7 yr; Gender: male=129, female=17; Level of injury: lumbar=60, cervical=50, thoracic=32, combined=4; Severity of injury: AISA A=32.2%, B/C/D=46.6%, E=21.2%. **Intervention:** A retrospective review of outcomes after surgical treatment for SCI. **Outcome measures:** Mortality; Neurological status; Quality of life; Complications. **Chronicity:** Not reported.	1. Twenty-five individuals (17.1%) were confirmed dead and 85 individuals (58.2%) were alive. 2. Eight out of 47 individuals (17%) with a complete injury and 29 out of 68 individuals (42.6%) with an incomplete injury showed neurological improvement. 3. The reported incidences of pressure wounds, recurrent urinary tract infections, pneumonia, and thromboembolic events were 22.5%, 13.5%, 5.6% and 1.1% respectively. 4. No significant differences were observed in quality of life.
Kawano et al. (2010) Japan Prospective Control Trial N=54	**Population:** *Surgery (SG, n=17)*: Mean age: 61.4 yr; Gender: males=11, females=6; Level of injury range: C3-C6; Level of severity: AIS B=3, C=14. *Conservative Compression (CC, n=17)*: Mean age: 64.6 yr; Gender: males=15, females=2; Level of injury range: C3-C6; Level of severity: AIS B=5, C=12. *Conservative Mild Compression (MC, n=20)*: Mean age: 61.3 yr; Gender: males=18, females=2; Level of injury range: C3-C6; Level of severity: AIS B=4, C=16. **Intervention:** Individuals with cervical spinal cord compression without bone and disc injury were assigned to either a surgical treatment group or a conservative treatment group. Outcomes were assessed at baseline, 2 wk, 3 mo, 6 mo, and 1 yr after injury. **Outcome Measures:** American Spinal Injury Association (ASIA) Motor Score.	1. The mean ASIA motor scores were 25.1 points (SG) and 27.1 (CC), at the time of admission; 41.0 (SG), 42.5 (CC), at 2 wk; 61.8 (SG), 61.2 (CC), at 3 mo; 64.2 (SG), 63.0 (CC), at 6 mo; 65.1 (SG), 64.1 (CC), at 1 yr. There was no significant difference in the recovery process. 2. The mean ASIA motor score of the MC group was 25.0 at admission, 38.3 at 2 wk, 60.8 at 3 mo, 64.0 at 6 mo, and 64.9 at 1 yr. Not significantly different from the SG or CC groups.
Singhal et al. (2008) UK Case Series $N_{Initial}$=57, N_{Final}=37	**Population:** Mean age: 40.8 yr; Gender: males=43, females=14; Injury etiology: motor vehicle accident=17, fall=15, sports=2, assaults=2; Level of injury: C2-C7; Level of severity: Frankel B=25, C=7, D=5. **Intervention:** Individuals with traumatic cervical SCI who underwent surgery were retrospectively analyzed. Follow-up time was >12 mo. **Outcome Measures:** Frankel Grade.	1. Of the 25 individuals with Frankel Grade B, 14 improved to C, six improved to D, and five remained the same. 2. Of the seven individuals with Frankel Grade C, all improved to D. 3. Of the five individuals with Frankel Grade D, one improved to E and four remained the same.
McKinley et al. (2004) USA Case Series	**Population:** *Nonsurgical (NS, n=176)*: Mean age: 42.8 yr; Gender: males=149, females=27; Injury etiology: motor vehicle	1. ASIA motor score improvements were significantly greater in the NS

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
N=54	accident=89, falls=52, sports=7, medical complication=17, violence=2, other=9; Level of severity: incomplete paraplegia=34, complete paraplegia=34, incomplete tetraplegia=73, complete tetraplegia=35. *Early Surgical (ES, n=307)*: Mean age: 36.7 yr; Gender: males=228, females=79; Injury etiology: motor vehicle accident=175, falls=75, sports=29, medical complication=4, violence=3, other=21; Level of severity: incomplete paraplegia=65, complete paraplegia=93, incomplete tetraplegia=82, complete tetraplegia=67; Time since injury range: <72 hr. *Late Surgical (LS, n=296)*: Mean age: 35.6 yr; Gender: males=237, females=59; Injury etiology: motor vehicle accident=148, falls=93, sports=35, medical complication=1, violence=3, other=16; Level of severity: incomplete paraplegia=40, complete paraplegia=85, incomplete tetraplegia=101, complete tetraplegia=70; Time since injury range: >72 hr. **Intervention:** Individuals with spinal cord injury were retrospectively analyzed based on timing of surgery. Outcomes were assessed at baseline and 1 yr after injury. **Outcome Measures:** American Spinal Injury Association (ASIA) Motor Score, Length of Stay (LOS), Cost, Complications, Neurologic Levels, AIS Grade, Functional Independence Measure (FIM) Motor.	group compared to both the ES and LS groups (p<0.05). 2. The LS group had significantly (p<0.05) increased acute care and total LOS and hospital cost along with higher incidence of pneumonia and atelectasis. 3. There was no significant difference between groups in neurologic levels, AIS grade, or FIM motor efficiency (all p>0.05).

Discussion

Park et al. (2017) performed a prognostic factor analysis to determine variables that might influence prognosis for traumatic SCI. In summary, they found that at one-year follow-up, the presenting neurological status of the individual, as well as their mean arterial pressure during the acute phase of hospital stay, was associated favourably with AIS motor score improvement.

Another potential determinant of neurological outcome is the overall medical state of the individual both before injury, and in terms of their complication profile after injury. Kreinest (2016) retrospectively reviewed a heterogenous series of individuals with SCI and found that long-term AIS motor score changes were adversely affected if the individual had previous spinal co-morbidities such as ankylosing conditions, or significant degenerative conditions. It is unclear whether spinal comorbidities are primary drivers of outcome or whether they may act as a surrogate for increased age, for example. Interestingly, further analysis of these individuals showed that other pre-injury comorbidities, as well as common in-hospital complications such as urinary tract infection and pneumonia, had no effect on AIS motor score improvements in these individuals.

Walking ability is clearly an important functional outcome after traumatic SCI. In a population of individuals with thoracolumbar SCI, Abdel-Fatah (2017) demonstrated that walking ability at one year was strongly related to the level of injury, with T12 and L1 injuries having significantly more function, and T10 and T11-injured individuals not regaining the ability to walk. This may potentially be due narrowing of the spinal canal at T10-11.

Another retrospective review was performed by Razaq (2018) who reported an SCI cohort with mixed neurology, demonstrating an overall AIS motor grade conversion of 45% at follow-up, with AIS A individuals demonstrating a substantially lower chance of improvement than those with incomplete injuries.

Despite the clear focus on early surgical decompression of traumatic SCI for improved outcome, there is some evidence that individuals undergoing delayed treatment can still experience neurological recovery. Konomi et al. (2018) assessed a retrospective cohort of individuals with late surgery and found that those individuals with severe cord compression still demonstrated neurologic improvement (2 or more AIS grades) in 30% of cases when late surgery was performed. This compared favourably to no improvement in the same individuals without surgery. In contrast, the subgroup of individuals with only mild-moderate ongoing cord compression demonstrated similar rates of recovery in surgical vs nonsurgical groups, and this rate was lower (11-18%) than the severe group.

Lehre et al. (2015) report a series of surgical individuals from a resource-limited setting in Ethiopia. In their series, 17% of individuals did not survive to follow-up, but among survivors 17% of complete SCI and 42% of incomplete individuals with SCI demonstrated motor recovery on examination. The authors propose that even in resource-limited settings, individuals can still derive benefit from surgical management of SCI.

McKinley et al. (2004) describe a retrospective comparison between nonsurgical, early surgery, and late surgery with respect to long-term motor improvement. They reported that nonsurgical individuals demonstrated a higher AIS motor score improvement at follow-up, as well as higher scores on the Functional Independence Measure. This was felt to be a confounded result due to the higher proportion of incomplete SCI in the nonsurgical group, who have a greater rehabilitation potential. Otherwise no differences were found with respect to prognosis between early and late surgery.

One well-recognized pattern of SCI is so-called hyperextension injury, which can occur as a dynamic process resulting in cord impingement without structural damage to the spine itself. In terms of AIS motor score improvement, these individuals tend to demonstrate a consistent improvement after 1 year (Kawano et al., 2010), and surgical intervention seems not to affect recovery. This is intuitive as there is not necessarily a structural process to correct in the setting of this injury.

In a (2008) study, Singhal et al. compared the motor recovery of 37 individuals with cervical SCI who were managed conservatively and with surgery. Despite not finding a statistical difference, they did report preservation of sensation below the injury as an important prognostic factor.

Conclusion

There is conflicting level 2, 3, and 4 evidence (based on several mixed studies) that a number of prognostic factors are important in the neurological outcomes after surgery for SCI which may include, but are not limited by, prior neurological and general medical status, mean arterial pressure, spinal co-morbidities, age, complications (e.g., pneumonia, urinary track infections), walking ability, level and completeness of injury, and timing of surgery.

Although neurological recovery is difficult to predict in traumatic SCI, a number of prognostic variables may influence neurological recovery after surgery post SCI. Individuals with incomplete injuries tend to fare better than those with complete injuries. Surgical correction of ongoing spinal cord compression can improve prognosis, especially if performed early.

4.6 Surgical Management versus Other Methods

Surgical treatment of traumatic SCI should be contemplated in context of other treatment alternatives. Non-surgical management can offer the same theoretical therapeutic affect in properly selected individuals. Closed reduction of cervical injuries can lead to effective decompression of neural elements, and prolonged deliberate immobilization can achieve bony fusion and stability of the injured segment.

Table 7. Surgical Management versus Other Methods

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Tator et al. (1987) Canada Case Control N=208	**Population:** Injury etiology: motor vehicle accident=86, sports=47, work=29, domestic=25, other=21. *Surgical (SG, n=116)*: Mean age: 32.5 yr; Gender: males=94, females=24. *Non-surgical (NS, n=92)*: Mean age: 37.0 yr; Gender: males=70, females=12. **Intervention:** Individuals with traumatic SCI who underwent surgery or conventional treatment were retrospectively analyzed. **Outcome Measures:** Mortality, Complications, Length of Stay (LOS), Neurological Recovery.	1. Overall, SG group was associated with a lower overall mortality rate (6.1%) than NS group (15.2%). 2. The SG group had a higher frequency of thrombo-embolic complications. 3. Overall, there was no difference between SG and NG groups in LOS or neurological recovery.

Discussion

One Canadian study (Tator et al., 1987) prospectively enrolled individuals into observational, non-randomized cohorts of surgical or nonsurgical treatment for traumatic SCI. This study reported a decreased mortality in the surgically treated individuals, although neurological recovery was not different. Of note, the non-surgical group comprised significantly more cervical injuries; this is unsurprising as cervical injuries are more amenable to closed decompression and immobilization, compared to more caudal injuries. This possibly influenced the main findings including increased mortality in the nonsurgical group may be explained by the higher proportion of cervically injured individuals, many of whom died of respiratory failure, as might be anticipated. Furthermore, the surgical technology of the 1970s cannot be extrapolated to modern day medical practice, which implies that surgically treated individuals in the modern era may have better outcomes than reported in this study.

Conclusion

There is level 3 evidence (based on one cohort study; (Tator et al., 1987) that surgical treatment results in lower mortality but equivalent neurological outcome compared to nonsurgical treatment; this analysis is from an early surgical era (1970s) and should be interpreted with significant caution.

> Compared to patients treated without surgery, those receiving surgery post SCI experienced lower mortality but no difference in neurological outcome; however, the techniques are from an early surgical era and should be interpreted with caution.

4.7 Bone Marrow Transfer

After traumatic SCI, secondary neurologic injury happens in large part because of cellular-level events including demyelination and axonal degeneration. Bone marrow, with its associated pluripotent stem cells, is purported to enhance the cellular milieu for neuronal regrowth. This therapeutic option has an undeniable theoretical appeal. To date, a very limited number of human studies have been performed with mixed results. Generally, stem cell therapy enjoys a wide and sometimes over-enthusiastic public profile in terms of clinical therapeutic potential, and these studies should help contextualize the current level of efficacy in traumatic SCI.

Table 8. Bone Marrow Transfer

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Chhabra et al. (2016) India RCT PEDro=7 $N_{Initial}$=21 N_{Final}=21	**Population:** Mean age=52 yr; Gender: male=16, female=6; Level of injury: T1–T12; Severity of injury: AISA A. **Intervention:** Participants were randomized into three groups to determine the safety and feasibility of autologous bone marrow transplantation in individuals with acute SCI. Two groups underwent autologous bone marrow cell transplantation through the intrathecal (n=7) or intralesional group (n=7), whereas the third served as a control (n=7). Outcome measures were assessed at baseline, six and 12 mo post enrollment. **Outcome measures:** Adverse events; Motor score; ASIA score; Walking index of spinal cord injury (WISCI); EMG; Spasticity; Urodynamics; SCIM. **Chronicity:** The range of time from injury to surgery was 24 hr to 5 days.	1. Surgery was well tolerated by all participants. 2. No significant adverse events were attributable to the procedure. 3. There was no significant improvement in the neurological, electrophysiological or urodynamic efficacy variables between groups (p>0.05). 4. A statistically significant improvement in functional scores as measured by SCIM was observed in all groups (p<0.05).
Akbary & Arora (2014) China Pre-Post	**Population:** Mean age: 30.3 yr; Injury etiology: fall=8, struck with object=2; Level of injury:	1. Two individuals showed some improvement in terms of the ASIA scores in but no

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
N=10	lumbar; Level of severity: AIS A; Mean time since injury: 6.1 days. **Intervention:** Individuals who had sustained a traumatic dorsolumbar vertebral fracture with complete paraplegia were recruited for this study. At the beginning of surgery, 100 ml of bone marrow was extracted. After surgical decompression and stabilization, the bone marrow isolate was injected into the site of injury. Outcomes were measured at 6 wk and 3 mo. **Outcome Measures:** American Spinal Injury Association (ASIA) scores, Frankel Grade.	improvements in their Frankel Grade at 6 wk. No improvements were seen at 3 mo. 2. Eight individuals showed no improvement in terms of the ASIA scores or Frankel Grade at 6 wk or 3 mo.

Discussion

One prospective RCT in human subjects has been performed for acute stem cell transplantation after SCI. In their pilot study, Chhabra et al. (2016) recruited 21 individuals who had undergone surgical stabilization and/or decompression for AIS A injuries. They performed either intralesional, intrathecal, or no injection of autologous stem cells. Notably, stem cell transplantation was performed as a second procedure, at 10-14 days post injury, after the primary surgery had been performed. In this study, there was a similar safety profile between groups, with no differences in complications, and similar improvements in functional status measured in each group. There was no difference in neurological recovery, electrophysiological data, functional status or urodynamic profiles between groups at 6 or 12 months.

An additional case series from China (Akbary & Arora, 2014) reported on the simultaneous transplantation of autologous bone marrow at the time of the primary surgery in ten AIS A individuals. At six-week follow-up, two individuals demonstrated some improvement in AIS sensory scores, but no individual demonstrated any motor or functional improvement at 6 weeks or 3 months.

Conclusion

There is level 1b evidence (based on one RCT; (Chhabra et al., 2016), and one pre-post study; (Akbary & Arora, 2014) that autologous bone marrow transfer is not effective in promoting neurological or functional recovery in individuals with traumatic SCI.

> While it appears autologous bone marrow transplant is safe, it is not effective for neurological or functional recovery post SCI.

5.0 Management of Spinal Cord Compression by Metastatic Lesions

5.1 Decompression or Stabilization

The spine is the most common, and most clinically challenging, site of bony metastasis (Abel, Keil, Schlager, & Akbar, 2008). Individual functional status and overall disease prognosis vary considerably, and this leads to significant heterogeneity in the management of the spinal metastasis. In many individuals with symptomatic compression of the spinal cord, the cancer has progressed to a point where surgical intervention is not considered curative. Rather, the rationale for surgery and (neo)adjuvant chemotherapy or radiation is to relieve pain and to prevent or reverse neurologic deficits.

Attempts to decompress the spinal cord or stabilize the spine may employ an anterior, posterior or combined approach. Specifically, the mechanical instability and extent of cord compression caused by the lesion will affect the surgical strategy. While many studies have compared the outcomes of such procedures, unfortunately, most groups include individuals with variable pre-operative neurological deficits and do not provide enough details regarding neurological outcomes. However, as summarized in Table 8, several studies have aimed to determine the possible advantages of different surgical approaches.

Table 9. Decompression or Stabilization for Compression by Metastatic Lesions

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Abel et al. (2008) Germany Pre-Post Test $N_{Initial}$=34, N_{Final}=31	**Population:** Mean age: 60.0 yr; Gender: males=28, females=6; Injury etiology: carcinoma=20, plasmocytoma=5, other=9; Level of injury range: C8-L1. **Intervention:** Participants underwent a posterior decompression and stabilization procedure. Decompression occurred via posterior and posterolateral removal of the compressed intraspinal tumor tissue. Stabilization was achieved with a screw-rod construct above and below the lesion. Standard therapy was provided as needed following the procedure. Outcomes were assessed pre-and postoperatively. **Outcome Measures:** American spinal injury association (ASIA), Functional independence measure (FIM), Pain medication use, Complications.	1. Three participants died post-admission due to complications from the tumor. Post-surgical complications included: deep vein thrombosis (n=2), lung embolism (n=1), gastrointestinal bleeding (n=1), pneumonia associated with lung atelectasis (n=1), and a deep wound infection (n=1). 2. There were no significant differences in ASIA scores from admission to post-surgery on light touch (p=0.07), sensation of pinprick (p>0.05), or motor function (p>0.70). 3. FIM scores significantly improved following surgery compared to admission (p<0.01). 4. Pain medications and dosing were either reduced (n=20), maintained (n=6) or not necessary (n=2). Three participants required more potent pain medications.

Discussion

Bony metastasis in the spine is most commonly encountered in individuals with multiple myeloma, breast or prostate cancer. These lesions may lead to pathologic fractures and usually cause significant pain. Moreover, compression of the spinal cord and the resultant neurologic deterioration is a challenging complication. These findings represent disease progression and usually herald poor survival prognosis.

Numerous groups have proposed treatment strategies and reported the efficacy of surgical and adjuvant therapies (Gokaslan et al. 1998; Rompe et al. 1999; Chong et al. 2012, Abel et al. 2008). Treatment is aimed at preventing further neurologic deficits and for pain control. Surgical options include anterior, posterior or combined approaches for decompression and/or stabilization.

Above, we have summarized several well-designed studies which report surgical outcomes for individuals with metastatic spine lesions. As metastatic lesions most commonly arise within the vertebral body, anterior procedures or combined approaches are usually preferred for decompression. Gokaslan et al. (1998) reported the outcomes for 72 individuals with metastatic lesions who underwent trans-thoracic vertebrectomy. In this series, significant improvements in neurologic status and functionality were noted in 76% of individuals and pain was decreased in 92% of individuals.

While anterior procedures usually allow greater decompression, some individuals may not tolerate the procedure and others may also need posterior stabilization. Abel et al. (2008) report significant improvements in individual pain after posterior decompression and stabilization. They prevented progressive neurologic decline in 87% of individuals and functional status improved significantly in their individuals.

Conclusion

Given the heterogeneity in individual status, lesion characteristics and variations in surgical experience it is likely futile to argue for the superiority of a certain approach for decompression or stabilization for compression by metastatic lesions. Instead, the surgical technique should be individualized to achieve the objectives safely.

There is no evidence that one approach is superior to another with respect to decompression or stabilization for compression by metastatic lesions; all approaches

5.2 Surgery in Combination with Radiotherapy

As mentioned previously, the optimal management of individuals with metastatic spine lesions remains an area of active research. Historically, the standard of care for symptomatic lesions consisted of early radiation therapy along with corticosteroids. In many individuals, this strategy reliably improves pain and prevents neurologic decline in the short term. However, some individuals have better overall prognosis while some lesions are resistant to radiotherapy. In these circumstances, surgical interventions are usually performed. Various groups have studied the efficacy of various treatment approaches. Table 9 summarizes some of the existing literature in this area which aims to determine the utility and cost-effectiveness of decompressive surgery along with varying radiotherapy regimens.

Table 10. Surgery in Combination with Radiotherapy for Compression from Metastatic Lesions

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Patchell et al. (2005) USA RCT PEDro=6	**Population:** Injury etiology: Tumour; Median level of severity: Frankel D. All individuals had metastatic epidural spinal cord compression.	1. Ambulation improved in 84% of individuals in S+RT and 57% in RT. This difference was significant between groups (p<0.001).

N=101	*Surgery and Radiotherapy (S+RT, n=50):* Mean age: 60.0 yr; Gender: males=33, females=17; Level of injury: Cervical=8, T1-T6=20, T7-T12=22; Mean time since injury: 3 mo. *Radiotherapy (RT, n=51):* Median age: 60.0 yr; Gender: males=37, females=14; Level of injury: Cervical=5, T1-T6=18, T7-T12=28; Mean time since injury: 7 mo. **Intervention:** Participants were randomized to S+RT or RT alone. S+RT were operated within 24 hr of admission via spinal cord decompression and tumour stabilization surgery, followed by RT within 14 days. RT was administered within 24 hr at 30 Gy in 10 fractions. All participant received 100 mg of dexamethasone, followed by 24 mg every 6 hr until S+RT/RT. Corticosteroids were reduced after S+RT/RT but continued until study completion. Outcomes were assessed at baseline, during therapy, 1 day post treatment, and every 4wks until end of trial. **Outcome Measures:** Frankel Grade, American Spinal Injury Association Motor Score (AMS), Survival rates, Ambulation status, Urinary continence, Medication use.	2. Individuals in S+RT retained ambulation significantly longer than RT (median 122 versus 13 days, p=0.003). 3. Longer ambulation time was significantly associated with surgery (p=0.0017) and Frankel Grade at pre-treatment (p=0.0008). 4. Ambulatory participants at pre-treatment were able to regain walking ability in 94% in S+RT and 74% (p=0.024) of RT alone. Within this subset, surgery (p=0.0048), Frankel Grade (p=0.016) and breast tumour (p=0.029) were associated with longer ambulation times. 5. Non-ambulatory participants at pre-treatment were able to regain walking ability in 62% of S+RT and 19% of RT (p=0.012). Individuals within this subset walked longer in S+RT compared to RT (median 59 vs 0 days, p=0.04). 6. S+RT significantly improved continence (p=.016), muscle strength on AMS (p=0.001), functional ability on Frankel (p=0.0006) survival time (p=0.033), and reduced use of corticosteroids and opioid analgesics (p=0.0093) compared to RT alone. 7. The trial was stopped early by the data safety and monitoring committee due to proven superiority of the S+RT.
Rades et al. (2010) Germany Case Series N=324	**Population:** *Surgery and Radiotherapy (S+RT, n=108):* Age: ≤63 yr=55, ≥64 yr=53; Gender: males=73, females=35; Injury etiology: Tumor; Level of severity: Eastern Cooperative Oncology Group (ECOG) 1-2=48, 3-4=60. *Radiotherapy (RT, n=216)*: Age: ≤63 yr=55, ≥64 yr=53; Gender: males=146, females=70; Injury etiology: Tumor; Level of severity: ECOG 1-2=97, 3-4=119. **Intervention:** Participants with metastatic spinal cord compression (MSCC) that underwent decompressive surgery followed by RT were retrospectively analyzed. RT was applied a median of 2 wk postoperatively to the midplane or posterior edge of the vertebral body. Some participants also received stabilization of vertebrae (n=70) or a laminectomy (n=38). Each participant was matched to two participants from a cohort treated with RT alone. All participants received 12-32 mg of dexamethasone per day. Outcomes were assessed preoperatively and up to 6 mo after RT. **Outcome Measures:** Local control of MSCC, Motor function, Ambulation rate, Survival rate.	1. Postoperative motor function was associated with ECOG (p<0.001), type of tumor (p<0.001), number of vertebrae involved (p=0.004), presence of visceral metastases during RT (p<0.001), and preoperative ambulatory status (p<0.001). 2. Ambulation rates post intervention were 69% in S+RT, where 30% of previously non-ambulatory individuals regained ability to walk. Within RT alone, 68% were ambulatory post intervention and 26% regained ability to walk. 3. Improvement in local control was significantly associated with absence of visceral metastases (p=0.003). 4. Improved survival rates were significantly associated with females, better ECOG score, one to two vertebral involvement, absence of other bone and visceral metastases, favourable type of tumour, long intervals between diagnosis and compression, preoperative ambulation, slower development of motor deficits, and longer RT administration (all p<0.001).

Kondo et al. (2008) Japan Case Series N=96	**Population:** Median age: 64.0 yr; Gender: males=61, females=35; Injury etiology: Tumor; Level of injury: C1-L1; Level of severity: Frankel A=1, B=18, C=88. **Intervention:** Participants that underwent posterior decompressive surgery followed by intraoperative radiotherapy (IORT) for epidural metastatic spinal tumors were retrospectively reviewed. IORT consisted of a single dose (20-30Gy) of electron beam irradiation to the lesion for 5 min. Total number of surgeries performed was 107. Outcomes were assessed preoperatively, postoperatively, and at a follow-up period ranging from 0.6-107 mo. **Outcome Measures:** Pain, Performance status (PS), Frankel Grade.	1. Pain improved in 46% of cases, and in 60% when drug dose reductions were considered. 2. PS improved by one rank in 88% of surgeries. 3. Neurological status improved by one Frankel Grade in 89% of cases. 4. Postoperatively, 80% of participants were able to walk. At long-term follow-up, abasia returned in 55% of these participants. 5. Participants with preoperative Frankel C classification had postoperative ambulation rate of 88%. Those that did not regain ambulation had worsening PS postoperatively. 6. Of those that survived more than 6 mo (n=60) in Frankel C subgroup, 98% were ambulatory by follow-up. This value was significantly higher than those that did not survive (p<0.001). 7. Postoperative ambulation was significantly associated with preoperative PS and neurological status (p<0.001) and visceral metastasis to vital organs (p=0.0069).
Furlan et al. (2012) Canada Cost-Utility Analysis of Patchell et al. (2005) N=101	**Population:** Injury etiology: Tumour; Median level of severity: Frankel D. All individuals had metastatic epidural spinal cord compression. *Surgery and Radiotherapy (S+RT, n=50):* Mean age: 60.0 yr; Gender: males=33, females=17; Level of injury: Cervical=8, T1-T6=20, T7-T12=22; Mean time since injury: 3 mo. *Radiotherapy (RT, n=51):* Median age: 60.0 yr; Gender: males=37, females=14; Level of injury: Cervical=5, T1-T6=18, T7-T12=28; Mean time since injury: 7 mo. **Intervention:** An analytic decision model was designed to compare cost-utility analyses between S+RT and RT alone for individuals with metastatic spinal cord compression. Costs for both treatment approaches stemmed from physician fees (Ontario Health Insurance Plan) and hospital fees (Ontario Case Costing Initiative). Baseline and sensitivity analyses were performed. **Outcome Measures:** Quality-Adjusted Life Year (QALY), Incremental Cost-Effectiveness Ratio (ICER), Cost-Effectiveness Acceptability Curve (CEAC), Willingness to Pay (WTP).	1. S+RT costed $1,215,514 US per QALY gained whereas RT alone costed $1,017,373 US per QALY.The expected effectiveness for S+RT was 0.57 QALY compared to 0.46 QALY for RT alone. 2. ICER of S+RT compared to RT alone was $250,307 US, but analyses determined that no therapy was dominant. 3. From baseline analyses, RT alone was more cost-effective than S+RT at WTP of $50,000 US. From a one-way sensitivity analysis, S+RT became cost-effective at the threshold of $50,000 US when initial costs of S+RT within first 60 days was less than $29,439 US. 4. Monthly hospice care, from a two-way sensitivity analysis, favoured RT alone. There was a small chance for non-ambulatory individuals with urinary incontinence in S+RT to have higher utility than those in RT alone. 5. Upon Monte Carlo simulation, probabilistic sensitivity analyses revealed that S+RT was more effective than RT alone: S+RT was more cost-effective in 24.02% of the simulations at WTP of $50,000 US. 6. CEAC revealed 55.9% of ICERs were under $100,000 US per additional QALY. 7. Portion of ICERs covered by WTP reached a maximum of 91.1% at

		$1,604,800 US per one additional QALY.

Table 11. Systematic Reviews Examining Surgery with Radiotherapy for Metastatic Lesions

Lee et al. (2014) Korea Meta-analysis of published articles between 2005-2013 AMSTAR=6 N=5 studies	**Methods:** A comprehensive literature search was conducted. Inclusion criteria followed: adults with metastatic epidural spinal cord compression (MESCC), compared radiotherapy (RT) to direct decompressive surgical resection paired with RT (DDSR+RT), and reported ambulation status. **Databases:** MEDLINE, EMBASE, Cochrane Database of Systematic Reviews. Key terms included: epidural, metastasis/metastases, surgery, surgical resection, radiation, and radiotherapy (RT). **Levels of evidence:** *High quality:* RCTs. *Low quality:* observational studies. **Questions/Measures/Hypothesis:** 1. To compare the effects of DDSR+RT to RT alone on ambulation status and survival rates for MESCC. **Outcome measure:** ambulation status, survival rate.	1. A total of 238 participants underwent DDSR+RT therapy and 1137 for RT alone. 2. In DDSR+RT, the mean age was 63.3 yr and the most common site of tumor was lung (28.6%), prostate (12.4%) and breast (10.9%). 3. In RT alone, mean age was 66.8 yr and the most common site of tumor was lung (24.4%), prostate (23.2%), and breast (15.4%). 4. Preoperatively, the rate of participants that could move independently (Frankel Grade D) were 62.2% of DDSR+RT and 74.2% of RT alone. 5. Postoperatively, the DDSR+RT group improved significantly in ambulation status compared to RT alone (p=0.001), with moderate heterogeneity (I^2=57.7%). 6. Ambulation status deteriorated in RT alone compared to DDSR+RT (p=0.002), with low heterogeneity (I^2=7%). 7. Survival rate was significantly prolonged in DDSR+RT compared to RT alone by 6 mo (n=5 studies, p<0.001, small heterogeneity I^2=34.3%) and by 12 mo (n=4 studies, p=0.001, moderate heterogeneity I^2=48.3%).
Kim et al. (2012) USA Systematic review of published articles between 1970-2007 AMSTAR=2 N=33	**Methods:** A literature search of published articles reporting on the use of surgery, radiotherapy (RT), or both for treatment of spine metastasis. Inclusion criteria followed: surgery with stabilization, minimum 25 participants, multiple tumor types, and reported ambulation status. **Databases:** MEDLINE with key terms: metastasis, spinal cord compression, surgery, surgical decompression, radiotherapy, and radiation. **Levels of evidence:** Not reported. **Questions/Measures/Hypothesis:** 1. To compare effectiveness of RT alone or in combination with surgical decompression and stabilization (S+RT) to improve clinical outcomes from pre to post treatment. **Outcome measures:** ambulatory status, pain relief, neurological function, survival rates.	1. In total, 1249 individuals received S+RT and 1246 received RT. Spinal metastasis occurred most often in thoracic (65%), then lumbosacral (25%) and cervical (10%) spine. 2. Prostate cancer was most often treated with RT whereas genitourinary sarcoma was more likely to be treated with S+RT. 3. In non-ambulatory individuals, 64% were able to ambulate following S+RT compared to 29% following RT (p≤0.001). 4. In paraplegic individuals, 42% regained ambulation following S+RT compared to 10% following RT (p≤0.001). 5. Deterioration in ambulation status to pre-treatment levels was not common:1% of S+RT and 9% of RT were non-ambulatory post intervention (p=0.003). 6. In 21 studies, 88% of S+RT compared to 74% of RT were relieved of pain (p≤0.001).

		7. In 20 studies, the 30 day mortality rate for S+RT was 5%; reporting was limited for RT. 8. Lung cancer, melanoma, or tumor of unknown origin had poor survival rates regardless of treatment (1-8 mo). For all tumor types, the median survival rate was higher for S+RT than RT (17 versus 3 mo). 9. Regardless of treatment condition, ambulatory participants had 5-6 times greater survival than non-ambulatory participants.
Klimo et al. (2005) USA Meta-analysis of published articles between 1984-2002 AMSTAR=7 N=28 studies	**Methods:** A literature search of published articles reporting on the use of surgery, radiotherapy (RT), or both for treatment of spine metastasis. Inclusion criteria followed: published in English, retrospective or prospective cohorts, and reported ambulation status. **Databases:** MEDLINE with key terms: spine, metastases, radiation, surgery, treatment, cancer, decompression, and vertebrectomy. **Levels of evidence:** Moderate quality: Prospective cohort studies with internal controls; Low quality: Uncontrolled retrospective and prospective cohort studies. **Questions/Measures/Hypothesis:** 1. To determine the effectiveness of surgery alone or with RT (S±RT) compared to RT alone on ambulation status. **Outcome measures:** Primary outcomes-ambulation status via success rate (maintained/regained) and rescue rate (regained). Secondary outcomes-pain control, sphincter function, survival rates.	1. In S±RT, 999 individuals were treated, average age was 56.4 yr, 52% were male, and the three primary sites (>50%) of tumors were breast, kidney, and lung. 2. In RT, 543 individuals were treated, average age was 62.5 yr, 49% were male, and the three primary sites (>70%) of tumors were breast, lung, and prostate. 3. Thoracic spine (68%) was the most common metastatic location, followed by lumbosacral (21-33%) and cervical spine (6-11%). 4. Surgical approaches to the spine include: anterior (55%), posterior (39%), and combined (6%). RT was delivered in a dose that ranged from 2800-3200cGy for 7-12 days. 5. Success rate for ambulation was greater in S±RT than RT alone, with S±RT having 1.3 times greater chance of being ambulatory ($p<0.001$). 6. Ambulation rescue rate was superior in S±RT than RT, with a 2 times greater chance of regaining ambulation ($p<0.001$). 7. In 21 studies, an improvement in pain was noted in 90% for S±RT and 70% for RT. 8. Sphincter rescue rate was 66% in S±RT and 26% in RT; however this outcome was only reported in 5 studies. 9. One yr survival was an average of 41% in S±RT and 24% in RT, with breast and renal cancer having more favorable survival outcomes across all participants.

Discussion

The overall aim of treatments for symptomatic spinal metastases is to relieve symptoms and, where possible, prevent further neurologic deficits. Three separate systematic reviews (Kim et al., 2012; Klimo et al., 2005; Lee et al., 2014) have summarized the evidence and provided support for surgery and radiotherapy over radiotherapy alone. Numerous studies have confirmed that younger individuals, those with better pre-morbid functional status, or individuals with radio-resistant tumors should be offered surgery to decompress and stabilize the spine. For example, Patchell et al. (2005) conducted an RCT to study the benefit of early surgery in addition to radiotherapy. The trial was discontinued because of the significant benefits within the surgical group which included longer ambulation and improved survival at 3 and 6 months. A study by Furlan et al. (2012) found comparable cost-effectiveness between either approach.

Conclusion

There is level 1b evidence (from several studies) that radiotherapy and steroids, with or without surgery, improves pain from symptomatic metastatic spine compression. Additionally, for individuals younger than 65 years, the addition of surgical decompression to radiotherapy and steroids improves ambulation and survival.

Radiotherapy and surgery for the management of symptomatic metastatic spine compression is effective; early surgical intervention to decompress the spine should be performed after considering tumor features and patient status.

6.0 Laminoplasty and Laminectomy

6.1 Laminectomy and Fusion

The choice of surgical approach in the management of individuals with spinal cord injury is dependent on a myriad of factors. These include individual age and comorbid status, the location of injury, the severity of neurologic injury, the extent of cord compression and any mechanical instability. In general, there is a need to decompress the spine in cases of canal compromise and to stabilize the column. At any level of the spine, one may choose to perform a laminectomy for decompression; this is most commonly accompanied by spinal fusion. In the cervical spine, posterior decompression may be accompanied by the placement of lateral mass screws or with the addition of an anterior cervical discectomy and fusion. Thoracolumbar fractures that cause incomplete injury, ongoing cord compression and instability are most frequently treated by laminectomy and fusion. If there is no need for decompression, one may choose a percutaneous instrumentation technique.

Table 12. Laminectomy and Fusion

Author Year Country Research Design Score Sample Size	**Methods**	**Outcomes**
Boakye et al. (2008) USA Case Series N=31,381	**Population:** 31381 individuals from 1993-2002. **Treatment:** Participants received laminectomy with or without fusion for acute spine trauma. **Outcome Measures:** Clinical status and outcomes while in hospital.	1. Overall mortality was 3.0% 2. Complication rate of 26.3% 3. mean length of stay (LOS) 17 days 4. One postoperative complication doubled the length of stay, increased the mortality rate by fivefold and added over $50,000 to hospital charges. 5. Individuals aged >85 or 65-84 had a 44-and 14-fold greater risk of dying compared with individuals in the 18-44 age group respectively.
Reis (2006) Portugal	**Population:** Mean age: 29.3 yr; Gender: males=20, females=3; Injury etiology:	1. Significant improvements in ASIA scores were evident from baseline to

Author Year Country Research Design Score Sample Size	Methods	Outcomes
Prospective Cohort $N_{Initial}$=23, N_{Final}=20	Syringomyelia=3, microcystic lesions=3, arachnoid cysts=3, tethered cords=14; Level of injury: cervical=4, thoracolumbar=19; Level of severity: AIS A=5, B=8, C=10; Mean time since injury: 5.1 yr. **Intervention:** Participants underwent a laminectomy at four levels to remediate arachnoiditis and altered CSF circulation. Upon opening of dural mater, arachnoiditis and cysts were removed and dentate ligaments were cut. Outcomes were assessed every mo up to 6 mo, then at 9 mo, 1 yr and at a follow-up with an upper limit of 66 mo post-surgery. **Outcome Measures:** American spinal injury association (ASIA) motor, touch and pinprick.	the last follow-up (all p<0.001). Motor improved by 20.6%, touch by 15.6% and pinprick by 14.4%.

Discussion

Cervical or thoracolumbar spinal cord injury is often accompanied by canal compromise or by mechanical instability. In individuals with incomplete injury it is imperative to remove any cord compression and to prevent abnormal movements of the bony elements of the column which may threaten worsening injury. Hence, there is a clear justification for proposing decompressive laminectomies with or without instrumented fusion. In the cervical spine, posterior decompression may be augmented by posterior or anterior fusion while thoracolumbar fractures are often stabilized posteriorly.

An analysis of the National Individual Sample by Boakye et al. (2008) found a low rate of mortality in individuals undergoing these individuals in the US. Moreover, the risk of in-hospital mortality was significantly affected by individual age and existing co-morbidities. This study also found that a single post-operative complication doubled the length of stay and increased risk of mortality 5-fold.

> It is impossible to compare laminectomy and fusion with conservative management in individuals who have ongoing cord compression or column instability. The clinical utility of decompressive laminectomies is obvious; however, in appropriately selected individuals one may elect to perform a percutaneous technique.

6.2 Laminoplasty

In individuals with cervical spine injury who do not appear to have significant instability, the surgeon may choose to perform an expansile laminoplasty instead of a laminectomy. This surgical option has been proposed for individuals with pre-existing cervical stenosis and who may have central cord syndrome after trauma. However, the procedure is far more commonly used in the treatment of chronic cervical myelopathy and especially for individuals with ossification of the posterior longitudinal ligament (OPLL).

Table 13. Laminoplasty

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Uribe et al. (2005) USA Case Control N=69	**Population:** Median age=56 yr, Time between injury and surgery=3 days. **Intervention:** Retrospective review of individuals with acute traumatic central cord syndrome (underlying cervical spondylosis and stenosis) who underwent expansile cervical laminoplasty (n=15; ASIA C=8 and D=7) or not (n=14) **Outcome Measures:** ASIA score preoperatively, postoperatively, and at 3 mo, complications.	1. There were no cases of immediate postoperative deterioration or at 3 mo follow-up. 2. Neurological outcome: 71.4% (10/14) of individuals improved 1 ASIA grade when examined 3 mo post injury.
Ghasemi et al. (2016) Iran Cohort N=41	**Population:** individuals with Cervical Spinal Cord Injury without instability, spinal cord contusion in magnetic resonance image (MRI), spinal cord compression rate more than 20%, neurologic deficit American Spinal Cord Injury Association ([ASIA] scale from A to D), and follow-up of at least 12 mo. **Intervention:** cervical laminoplasty (Hirabayashi Technique) **Outcome Measures:** Preoperative neurological state, clinical outcome, and neurological function were measured using the ASIA impairment scale, Japanese Orthopaedic Association (JOA) grading scale, and Hirabayashi recovering rate	1. Thirty-three (80.4%) individuals showed improvement in ASIA grade at 12-month follow-up. 2. Four (9.7%) individuals in ASIA Grade A and 4 (9.7%) individuals in ASIA Grade D remain unchanged. 3. The mean JOA score improved from 8.4 ± 6.1 points preoperatively to 11.2 ± 5.4 points at 12 mo postoperatively. 4. Improvement in JOA was statistically significant ($P < 0.05$). 5. Those with cervical stenosis had better recovery than those with OPLL
Gu et al. (2014) China Case Series N=60	**Population:** All individuals had ossification of the posterior longitudinal ligament (OPLL). *Group L (n=31):* Mean age: 65.7 yr; Gender: males=25, females=6; Injury etiology: Falls (n=21, 68%), Traffic accident (n=7, 23%), Sports (n=3, 9%); Level of injury: Cervical; Level of severity: ASIA B=9, C=16, D=6; Mean time since injury: 3.3 days. *Group C (n=29)*: Mean age: 66.2 yr; Gender: males=24, females=5; Injury etiology: falls=19, traffic accidents=9, sports=1; Level of injury: Cervical; Level of severity: ASIA B=7, C=15, D=7. **Intervention:** Individuals that underwent laminoplasty (Group L) were compared to those that refused laminoplasty and underwent conservative treatment (Group C). Outcomes were assessed at admission, discharge, 6 mo and final visit (not specified). **Outcome Measures:** American Spinal Injury Association Impairment Scale (AIS), 36-Item Short Form Survey (SF-36), Ossified levels of OPLL, Thickness of OPLL, Canal diameter, Occupation ratio, Lordosis angle, Range of motion (ROM), High signal intensity levels.	1. Motor and sensory scores on AIS were significantly higher in Group L than Group C at all assessments (p<0.05). 2. The only components of SF-36 that significantly improved in Group L at discharge compared to admission were bodily pain and mental health (p<0.05). 3. There were significant differences in all subscales of SF-36 between Group L and Group C at all postoperative assessments (p<0.05). 4. Occupation ratio and canal diameter of OPLL was significantly improved in Group L compared to Group C at all postoperative assessments (p<0.05). 5. High signal intensity levels were significantly better in Group L than Group C from 6 mo onwards (p<0.05). 6. No significant between-group differences were found for OPLL ossification levels, OPLL thickness, lordosis angle, or ROM (p>0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Kawaguci et al. (2014) Japan Case Series $N_{Initial}$=144, N_{Final}=124	**Population:** Mean age: 59.6 yr; Gender: males=102, females=42; Injury etiology: ossification of posterior longitudinal ligament (OPLL); Level of injury: cervical. **Intervention:** Individuals underwent a C3-C7 laminoplasty with posterior decompression surgery (PDS). Anterior decompressive surgery (ADS) was required in 11 cases following PDS. Individuals that received only PDS were compared to those that required ADS following PDS. All individuals used a sternal-occipital-mandibular immobilizer (SOMI) brace or neck collar postoperative for up to 1 mo. Outcomes were assessed preoperatively and postoperatively at the following time points: 1 mo, 6 mo, 1 yr, 3 yr, 5 yr, 10 yr, >10 yr. **Outcome Measures:** Modified Japanese orthopedic association (JOA) score, Rate of recovery, PDS occupying ratio, PDS cervical alignment, Symptoms of ADS.	1. Overall, motor and sensory function of the upper and lower extremities on JOA was significantly improved following laminoplasty (all p<0.001). 2. Bladder function and trunk sensory function on JOA also improved following laminoplasty (both p<0.001). 3. Long term, JOA rapidly improved up until 5 yr follow-up (average 45% to 60%), and then deteriorated slightly by 10 yr (55%). 4. Following ADS, all individuals improved in JOA scores and had a mean recovery rate of 50.9%. 5. Significant differences between those that required ADS following laminoplasty and those that did not were preoperative-PDS occupying ratio of OPLL (p=0.001) and postoperative-PDS cervical alignment (p=0.035). 6. The most common symptoms that preluded ADS were severe unilateral pain in upper extremity (82%) and deterioration of cervical myelopathy (55%). 7. Eight of 11 that required ADS had mixed, 2 had continuous, and 1 had segmental ossification, which was significantly different than the PDS only group (p=0.023).
Acharya et al. (2010) India Case Series $N_{Initial}$=24, N_{Final}=21	**Population:** Mean age: 52.9 yr; Gender: males=21, females=0; Injury etiology: spondylotic myelopathy; Level of injury: cervical; Level of severity: Nurick Scale (difficulty of walking) =3.7 (between 3 (difficulty in walking which prevented full time employment/ability to do house work) and 4 (able to walk only with someone else help or aid of a frame) **Intervention:** Individuals were treated with cervical laminoplasty of C2-C6 using the Hirabayashi technique. Outcomes were assessed preoperative, operative, and postoperative at 2 wk, 6 mo, and 1 yr. **Outcome Measures:** Hoffmann sign, Inverted brachioradialis reflex (IBR), Sustained clonus, Babinski, Hyperreflexia, Modified Japanese orthopedic association (JOA) score, Nurick scale, Recovery rate, t2 hyper-intensity.	1. Preoperative, the sensitivity for detection of myelopathy by provocative signs from greatest to least were Babinski response (95%), IBR (91%), Hoffmann sign (86%), and sustained clonus (48%). 1. The sensitivity for hyperreflexia preoperative were patella (95%), Achilles (90%), biceps (48%) and triceps (5%). 2. At 1 yr, 38% presented with provocative signs (Hoffmann=38%, Babinski=5%, IBR=5%, clonus=5%). 3. In regards to hyperreflexia, the lower limbs retained signs at 1 yr (patella=10%, Achilles=14%) whereas the upper limb did not at all (biceps/triceps=0%). 4. Postoperative, recovery rate improved from 2 wk (28.6%) to 6 mo (60.7%) to 1 yr (61.3%). The mJOA and Nurick scale improved accordingly from 2 wks (10.38, 2.9) to 6 mo (13.29, 1.8) to 1 yr (13.4, 1.7). 5. Of all individuals with radiologic presentation of t2 hyper-intensity on

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		MRI, those with hypo intense cord signal had higher prevalence of Hoffmann sign (100% vs 80%), IBR (100% versus 87%), and Babinski sign (100% versus 93%) compared to normal cord hyper-intensity.

Discussion

Various surgical techniques have been proposed for decompressing the injured spine. As discussed previously, the most common approach is to perform a laminectomy; however, in the cervical spine, another option is to perform a laminoplasty. This technique usually relies upon bone fragments or plate implants to mobilize the spinous processes and thus expand the spinal canal. Various groups have shown that in the appropriately selected individual population, laminoplasty is a reasonable alternative to laminectomy. There are no studies that compare similar subsets of patients undergoing laminoplasty or conservative management. There are no good studies comparing laminectomy to laminoplasty in patients with acute spinal cord injury.

> There are no studies that compare similar subsets of patients undergoing laminoplasty or conservative management. There are no good studies comparing laminectomy to laminoplasty in patients with acute SCI.

7.0 Surgery for Miscellaneous Myelopathies

7.1 Cervical Spondylosis

Cervical spondylosis involves a constellation of chronic degenerative changes that culminate in narrowing of the spinal canal and neural foramen. Due to natural loss of disc height, facet arthropathy, ligamentum flavum hypertrophy and buckling, osteophyte formation, and occasionally ossification of the posterior longitudinal ligament, there is a gradual reduction of available space for the spinal cord throughout the spinal canal including the cervical spine.

Due to the heterogeneity of degenerative processes causing spondylosis, it is not always clear whether decompressive surgery can be best and most safely accomplished from an anterior approach or a posterior approach. This dilemma has been studied and will be summarized here.

Table 14. Cervical Spondylosis

Author Year Country Research Design Score Sample Size	Methods	Outcomes
Luo et al. (2015) China Meta-Analysis AMSTAR=9 N=10 studies	**Objective:** To evaluate the clinical outcomes and complications between anterior and posterior surgical approaches for the intervention of multilevel cervical spondylotic myelopathy (MCSM).	1. All studies were high quality: nine with NOS=8 and one with NOS=7. 2. Clinical outcome was assessed using the Japanese Orthopedic Association Scale (JOA).

Author Year Country Research Design Score Sample Size	Methods	Outcomes
	Methods: Comprehensive literature search of English RCTs of participants with CSM caused by multi-segmental spinal stenosis, excluding trauma, tumors, disc herniation, or previous surgery. Data analysis was performed by calculating standardized/weighted mean difference (SMD/WMD) or odds ratio (OR) and 95% confidence intervals (95%CI). **Databases:** MEDLINE, EMBASE, PubMed, Cochrane. **Evidence:** Studies were assessed for quality using the Newcastle-Ottawa Scale (NOS, 0-10). Statistical significance was defined as p<0.05.	3. In ten studies (n=467), preoperative JOA score was similar in both groups (WMD=0, 95%CI=-0.5 to 0.5, p>0.05). 4. In four studies (n=268), postoperative JOA score was significantly higher in the anterior group than posterior group (WMD=0.79, 95%CI=0.16 to 1.42, p<0.05). 5. In five studies (n=420), recovery rate was similar in both groups (WMD=2.73, 95%CI=-8.69 to 14.15, p>0.05). 6. In nine studies (n=809), complication rate was significantly higher in the anterior group than posterior group (OR=1.65, 95%CI=1.13 to 2.39, p=0.009). 7. In five studies (n=294), reoperation rate was significantly higher in the anterior group than posterior group (OR=8.67, 95%CI=2.85 to 26.34, p=0.0001). 8. In four studies (n=252), blood loss was significantly higher in the anterior group than posterior group (WMD=-40.25, 95%CI=-76.96 to 3.53, p<0.05). 9. In four studies (n=252), operation time was significantly longer in the anterior group than posterior group (WMD=61.3, 95%CI=52.33 to 70.28, p<0.00001). 10. In three studies (n=192), length of stay was significantly shorter in the anterior group than posterior group (WMD=-1.07, 95%CI=-2.23 to -1.17, p<0.00001).
Ghogawala et al. (2011) USA PCT N=50	**Population:** Mean age: 61.6 yr; Gender: males=32, females=18; Level of injury: cervical. **Intervention:** Participants received ventral fusion surgery (n=28) or dorsal fusion surgery (n=22) for cervical spondylotic myelopathy. Outcomes were assessed at baseline, 3 mo, 6 mo, and 12 mo. **Outcome Measures:** Modified Japanese Orthopedic Association Scale (mJOA); Oswestry Neck Disability Index (NDI); EuroQol-5D (EQ-5D); Short-Form 36-Item Health Survey, Physical Component Summary (SF-36 PCS).	1. mJOA mean scores significantly increased in the dorsal (+1.94, p=0.0028) and ventral (+2.04, p<0.001) groups from baseline to 12mo. 2. mJOA mean scores were significantly higher in the ventral group than dorsal group at baseline (13.40 versus 11.60, p=0.009), 6 mo (15.31 versus 13.44, p=0.03), and 12 mo (15.44 versus 13.54, p=0.003). 3. NDI mean scores significantly decreased in the ventral group (-18.4, p<0.001) but not in the dorsal group (-5.89, p=0.22) from baseline to 12 mo. 4. NDI mean scores were significantly lower in the ventral group than dorsal group at 12 mo (17.96 versus 30.13, p=0.03); differences at other time points were not significant. 5. EQ-5D mean scores significantly increased in the dorsal (+0.13, p=0.04) and ventral (+0.16, p<0.001) groups from baseline to 12 mo. 6. EQ-5D mean score at 6 mo was significantly higher in the ventral group than dorsal group (0.77 versus 0.59, p=0.04); differences at other time points were not significant. 7. SF-36 PCS mean scores significantly increased in the dorsal (+5.74, p=0.03) and ventral (+9.92, p<0.001) groups from baseline to 12 mo.

Author Year Country Research Design Score Sample Size	Methods	Outcomes
		8. SF-36 PCS mean score at 6 mo was significantly higher in the ventral group than dorsal group (45.00 versus 38.31, p=0.04); differences at other time points were not significant.
Kong et al. (2015) China Pre-Post N=40	**Population:** Mean age: 57.8 yr; Gender: males=31, females=9; Level of injury: cervical; Mean time since injury: 11.5 mo. **Intervention:** Participants received anterior decompressive surgery for proximal-type cervical spondylotic amyotrophy. **Outcome Measures:** Surgical outcome.	1. Surgical outcome improvement rate was 75%: 16 participants had excellent outcome, 14 had good outcome, and 10 had fair outcome. 2. Surgical outcome improvement rate in participants with spinal cord compression (n=34) was 71%; disease duration was a significant negative predictor of improvement (p<0.01). 1. Surgical outcome improvement rate in participants with nerve root compression (n=6) was 100%.
Liu et al. (2012) China Case Series N=286	**Population:** Mean age: 54 yr; Gender: males=166, females=120; Level of injury: C2-C5=57, C3-C6=75, C4-C7=135. **Intervention:** Participants who received anterior cervical surgery for multilevel cervical spondylotic myelopathy were retrospectively analyzed. Techniques were anterior cervical decompression and fusion (ACDF; n=103), hybrid construct (HC; n=96), and long corpectomy (LC; n=87). **Outcome Measures:** Japanese Orthopedic Association Scale (JOA); Neck Disability Index (NDI); Short-Form 36-Item Health Survey (SF-36); Complications.	1. JOA mean scores improved after intervention in the ACDF group (10.2 to 14.8), HC group (11.3 to 13.9), and LC group (10.7 to 14.5). 2. NDI mean scores improved after intervention in the ACDF group (35.6 to 14.7), HC group (34.9 to 14.3), and LC group (35.2 to 16.0). 3. SF-36 mean scores improved after intervention in the ACDF group (33.2 to 58.5), HC group (35.8 to 52.2), and LC group (34.5 to 49.6). 4. Complication rate was 15.53% in the ACDF group, 22.92% in the HC group, and 26.44% in the LC group, and 21.33% overall.
Liu et al. (2009) China Case Control N=28	**Population:** Mean age: 53.5 yr; Gender: males=19, females=9; Level of injury: C3-C6=17, C4-C7=11. **Intervention:** Participants who received anterior cervical surgery for multilevel cervical spondylotic myelopathy were retrospectively analyzed. Techniques were hybrid decompression (HD; n=12) and two-level corpectomy (TLC; n=16). **Outcome Measures:** Japanese Orthopedic Association Scale (JOA); Neck Disability Index (NDI); Segmental lordosis; Graft fusion.	2. JOA mean scores significantly improved in the HD group (11.2 to 14.3, p<0.05) and TLC group (10.9 to 14.3, p<0.05) after intervention; post-op scores were not significantly different between groups (p=0.964). 3. JOA score improvement rate was not significantly different between the HD and TLC groups (55.8% versus 56.8%, p=0.720). 4. NDI mean scores significantly improved in the HD group (34.3 to 14.9, p<0.05) and TLC group (34.6 to 17.2, p<0.05) after intervention; post-op scores were not significantly different between groups (p=0.053). 5. Segmental lordosis significantly increased in the HD group (3.75 to 10.7, p<0.05) and TLC group (5.06 to 13.0, p<0.05) after intervention; post-op scores were not significantly different between groups (p=0.146). 6. Graft fusion rate was not significantly different between the HD and TLC groups (100% versus 94%, p=0.378).

Discussion

The optimal method of surgical decompression for cervical spondylosis has been studied using several prospective cohorts and summarized via meta-analysis. In a small non-randomized prospective trial, Ghogawala et al. (2011) compared ventral to dorsal decompression and found that both groups demonstrated improvements in disease-specific disability (mJOA and Neck Disability Index) and quality of life compared to baseline. Although improvements in each group were similar, ventral decompression resulted in better change in Neck Disability Index and quality of life measures compared to dorsal decompression. This result is difficult to interpret due to worse neurological status at baseline in the dorsal group as well as small sample size.

Among individuals receiving an anterior/ventral approach for multilevel spondylosis, there are several accepted options for reconstruction/stabilization of the spinal column following decompression. These include adjacent discectomies with fusion, multilevel corpectomy with fusion, or a hybrid combination. The outcomes of these, and their complication profiles, have recently been studied. Liu et al. (2009) report a case control study, again with small numbers, suggesting equivalent and satisfactory clinical outcomes between multilevel corpectomy and a hybrid approach. In an analysis of complication rates, Liu et al. (2012) reported that each of the three anterior approaches showed no difference in neurological or quality of life outcome, despite the multilevel corpectomy group having a higher overall rate of complications, consisting mainly of graft migration, hoarseness, and dysphagia, most of which self-resolved. Among all comers, the approximate rate of surgical complication from anterior decompression was 22%. Also, of note, the more cranially-oriented the construct, the higher rate of postoperative complications, although no differences in neurologic or quality of life outcome were reported.

A similar syndrome to cervical spondylotic myelopathy is cervical spondylotic amytrophy, which describes a pure-motor syndrome thought to be secondary to spondylosis. In this population of individuals, anterior decompression has been described (Kong et al. 2015). In a small series of 40 surgically treated individuals, 75% of individuals experienced an improvement after surgery as defined by manual muscle testing, although it is unclear what threshold constitutes a clinically important difference (Kong et al. 2015).

Finally, Luo et al. (2015) performed a meta-analysis comparing anterior-vs-posterior surgical decompressive approaches. Ten studies were included and consisted of a mix of non-randomized prospective and retrospective studies. Although the anterior approach shows modest evidence of better neurological function postoperatively, the mJOA score and overall clinical outcome generally was deemed clinically nonsignificant between the two groups. This may be due to the higher complication in the anterior approach, especially when treating multilevel disease. Otherwise, statistical equivalence was reported in terms of mJOA score, neurological recovery rate, operative blood loss, and length of hospital stay.

Conclusion

There is level 2 evidence (based on one prospective controlled trial; Ghogawala et al. 2011) that anterior decompression for cervical spondylosis myelopathy may have better neurological recovery, but is also associated with higher complication rates, when compared to posterior decompression. There is no difference in disease-specific disability or quality of life between these two groups.

There is level 3 evidence (based on one case control (Liu et al. 2009), one pre-post (Kong et al. 2015) and one case series (Liu et al. 2012)) that many different reconstructive

options for anterior decompression have been established; however, they are not discernible in terms of quality of life or clinical outcomes.

In the surgical decompression of cervical spondylosis myelopathy, both anterior and posterior approaches are clinically effective. Anterior decompression may have a higher level of neurological recovery but is also subject to more complications and demonstrates no clear superiority in terms of disability or quality of life when compared to posterior

7.2 Degenerative Compressive Myelopathy

There is a relative equipoise with regards to surgical management of degenerative compressive myelopathy. The natural history of this disease is not completely understood and, as such, it is difficult to assess the potential benefit of surgical decompression. As such, any predictive factors that might correlate with outcome are useful.

Table 15. Degenerative Compressive Myelopathy

Author Year Country Research Design Score Sample Size	Methods	Outcomes
Karpova et al. (2013) Canada Systematic Review AMSTAR=7 N=30 studies	**Objective:** To examine the role of magnetic resonance imaging (MRI) in predicting outcomes after surgery for degenerative compressive myelopathy (DCM). **Methods:** Comprehensive literature search of English studies with ≥25 participants aged ≥18 yr after surgical intervention, with symptomatic DCM and detailed preoperative MRI details available. **Databases:** MEDLINE, EMBASE, PubMed. **Evidence:** Studies were assessed for quality using modified Cochrane guidelines (1-2=poor, 3=good, 4-5=excellent). Levels of evidence were assigned using the Sackett Scale.	1. Quality of studies was excellent (n=6), good (n=9), and poor (n=15). 2. Levels of evidence were I (n=2), II (n=3), and IV (n=25). 3. The following surgical outcomes (SO) were evaluated: recovery rate (RR) and post-operative functional score (POFS). 4. Relationship between cord compression and SO was assessed in 14 studies: transverse area (TA, n=5), compression ratio (CR, n=5), antero-posterior (AP, n=1), and qualitative measures (QM, n=3). 5. TA was significantly associated with RR but not POFS. CR, AP, and QM were not significantly associated with RR or POFS. 6. Relationship between signal intensity and SO was assessed in 24 studies: presence, area, and intensity of change on T1/T2-weight imaged (WI). 7. Presence, area, and intensity of SI on T2WI, as well as presence of SI on both T1/T2WI were significantly associated with RR and/or POFS.

Discussion

In a well-designed systematic review, Karpova et al. (2013) assessed magnetic resonance imaging characteristics that might be predictive of outcome in individuals undergoing surgical management of degenerative compressive myelopathy. They identified a mix of excellent and good-quality evidence, including 13 prospective cohort studies, that assessed imaging findings and possible associations with clinical outcomes as judged by common scoring tools included the modified Japanese Orthopedic Assocaiton (mJOA) scale. Overall, they found that transverse area of the spinal cord correlated with postoperative recovery but that other radiological measures were not. In addition, the absence of spinal cord hyperintensity on magnetic resonance imaging was correlated with improved post-surgical outcome as measured by the mJOA and other scales.

Conclusion

There is level 2 evidence (from one studies included in a systematic review; Karpova et al. 2013) that radiological features such as spinal cord transverse area, and absence of spinal cord hyperintensity of MRI, both correlate with improved clinical outcome after decompressive surgery for degenerative compressive myelopathy.

While it is difficult to predict the effectiveness of surgical decompression in degenerative compressive myelopathy, there is good evidence that some MRI findings, including absence of spinal cord hyperintensity on MRI, can predict surgical outcomes.

7.3 Spinal Stenosis

Spinal stenosis, or a narrowing of the central spinal canal, can compromise the integrity of the spinal cord. This may or may not go on to produce a clinical syndrome of myelopathy in select individuals. Generally, the surgical treatment option for symptomatic spinal cord compression involves surgical decompression of the affected level. This section will review indications and methods of decompression for cervical and thoracic myelopathy, as well as outcomes.

Table 16. Spinal Stenosis

Author Year Country Research Design Score Sample Size	Methods	Outcomes
Cao et al. (2018) China Pre-Post N=50	**Population:** Mean age=41.8±6.5 yr; Gender: male=35, female=15; Level of injury: T7/T8=5, T8/T9=11, T9/T10=15, T10/T11=19; Severity of injury: Frankel grade A=0, B=14, C=22, D=14, E=0. **Intervention:** The efficacy of posterolateral decompression combined with interbody fusion and internal fixation for individuals with thoracic spinal stenosis was evaluated. Outcome measures were assessed preoperatively and 1-yr postoperatively. **Outcome measures:** Operation time; Intraoperative blood loss; Postoperative complications; Oswestry disability index (ODI); VAS; Frankel grade. **Chronicity:** The mean time course of disease was 5.5±1.4 mo and the mean operative time was 3.3±0.7 hr.	1. All individuals were operated on successfully. The mean operative time was 3.3±0.7 hr; the mean intraoperative blood loss was 970±110 ml. 2. Postoperative complications included cerebrospinal fluid leak in two cases, transient spinal cord dysfunction in two cases and dural laceration in one case. 3. A significant decrease in the mean ODI and VAS score was observed postoperatively at one yr follow up (p=0.000, p=0.000). 1. A significant improvement in Frankel grade was observed postoperatively (p=0.000).
Wilson et al. (2013) Canada Systematic Review AMSTAR=7 N=5 studies	**Objective:** To assess the frequency, timing, and predictors of symptom development in individuals with radiographical evidence of spinal cord compression (SCC), spinal canal stenosis (SCS), and/or ossification of posterior	2. Quality of studies was II (n=1) and III (n=4). 3. Overall strength of evidence was moderate. 4. Overall strength of recommendations was strong.

	longitudinal ligament (OPLL) but no symptoms of myelopathy. **Methods:** Comprehensive literature search of English longitudinal cohort studies of participants aged ≥18 yr with imaging evidence of SCC, SCN, or OPLL, without symptoms of myelopathy and history of tumor, infection, arthritis, or previous SCI. Data analysis was performed by calculating relative risks (RR) and 95% confidence intervals (95%CI). **Databases:** MEDLINE, Cochrane, Google Scholar. **Evidence:** Studies were assessed for quality using AHRQ guidelines (I, II, or III). Levels of evidence were assigned GRADE criteria (insufficient, low, moderate, or high). Clinical recommendations were made using a modified Delphi approach (weak or strong). Statistical significance was defined as p<0.05.	5. Only three studies (n=355) of the total five (n=832) were included in meta-analysis. 6. In SCC or SCS (n=199), myelopathy development within 44 mo (24-144 mo) was 22.6%. 7. In SCC or SCS, significant predictors of myelopathy development were presence of symptomatic radiculopathy (RR=3.0, 95%CI=2.0-4.4, p=0.007), prolonged somatosensory-evoked potentials (RR=2.9, 95%CI=1.7-5.1, p=0.007), prolonged motor-evoked potentials (RR=3.2, 95%CI=1.9-5.6, p=0.033), and lack of cervical cord MRI hyperintensity (RR=1.7, 95%CI=1.0-2.7, p=0.0036). 8. In OPLL (n=606), myelopathy development within 60-360 mo ranged from 17.0% to 61.5%. 9. In a subset of OPLL (n=156), predictors of myelopathy development were lateral deviation (RR=2.1, 95%CI=1.4-3.1), increased cervical range of motion (p=0.03), and canal stenosis >60%. 10. The authors made a strong recommendation based on moderate evidence: individuals with SCC/SCS secondary to spondylosis, without evidence of myelopathy, and with clinical or electrophysiological evidence of cervical radicular dysfunction or central conduction deficits may be at higher risk for development myelopathy and should be considered for surgical intervention.

Discussion

Cervical canal stenosis is a common radiological finding, especially in older adults, and Wilson et al. (2013) conducted a systematic review to assess the natural history of these individuals, beginning before symptom development. They identified four prospective cohort studies of individuals with cervical cord compression but no clinical evidence of myelopathy. These studies followed individuals prospectively for a mean of between 44-212 months. Overall, they found that approximately 22% originally nonmyelpathic individuals with radiographic spinal cord compression developed myelopathy at 44 months. The risk factors for development of myelopathy included presence of a clinical radiculopathy, as well as SSEP/MEP abnormalities. Among individuals with ossification of the posterior longitidunal ligament (OPLL), no clear risk factors for progression were identified. Based on their systematic review and in conjunction with an international expert survey, their recommendation was that offering decompressive surgery to individuals with a concomitant radiculopathy or electromyographic changes is reasonable, based on likelihood of progression to myelopathy. There was not sufficient evidence to comment on the risk factors for clinical progression or management recommendations in OPLL.

Thoracic spinal stenosis is considerably less common. A pre-post analysis of a surgical cohort by Cao et al. (2018) was reviewed. In 50 individuals treated surgically via posterolateral decompression, they report statistically significant improvement in individual-reported quality of life measures as well as Frankel score at 1 year. A weakness of this study is that the population seems to have been a mix of neurologically intact and myelopathic individuals, and there was no control group for comparison to either non-operative management or an alternative surgical approach (i.e., anterior, or midline posterior). Overall this low-level evidence demonstrates the possibility of thoracic myelopathy from canal stenosis being amenable to surgical decompression.

Conclusion

There is level 2 evidence (from four prospective studies in a systematic review by (Wilson et al., 2013)) that progression from asymptomatic to symptomatic cervical cord compression is low. However, presence of concomitant radiculopathy, or electrophysiological evidence of cord dysfunction puts individuals at a higher risk of such progression.

There is level 3 evidence (one cohort study, (Cao et al., 2018) that decompressive surgery for thoracic spinal cord compression can improve quality of life and Frankel score at 1 year.

Radiological signs of cervical spinal cord are quite common, but risk of progression to symptoms is low overall. Patients with co-existing cervical radiculopathy or electrophysiological changes are at higher risk of progression to clinical myelopathy.

7.4 Syringomyelia and Tethered Spinal Cord

Subsequent to a traumatic SCI, the overarching goal is preservation of residual neurological function and, to the extent possible, reacquisition of previous function. One longer-term pathological process that can interfere with this a spectrum of changes termed spinal cord tethering and post-traumatic syringomyelia.

Over the long term, some scar tissue associates with the injured spinal cord and causes pathological adhesion or tethering to the surrounding dura. This can result in undue traction being placed on the segment of spinal cord cranial to the injury, resulting in new, but delayed, progression of neurological deficit. Similarly, the injured cord can acquire localized atrophy and myelomalacia, resulting in intramedullary cystic cavitation, with the cyst filling with cerebrospinal fluid. If this fluid compartment, or syrinx, develops mass effect, then this can similarly present with delayed worsening of neurological deficit. Both of these processes can have a devastating impact on function depending on the level of injury-for example, an individual with a high thoracic injury can be at risk of losing their upper extremity function if a symptomatic tethered cord or syrinx develops. Because of the significance of this pathology, surgical treatment and/or preventative options have been considered.

Table 17. Syringomyelia and Tethered Spinal Cord

Author Year Country Research Design Score Sample Size	Methods	Outcomes
Bonfield et al., (2010) USA Systematic Review AMSTAR=6	**Objective:** To determine the indications for surgical intervention and optimal surgical intervention technique for post-traumatic syringomyelia (PTS).	1. Strength of evidence was very low (n=16) to low (n=6). 2. Overall recommendations were weak.

N=22 studies	**Methods:** Comprehensive literature search of English articles of all individuals with traumatic syrinx, excluding case reports. **Databases:** MEDLINE, EMBASE, Cochrane, Web of Science. **Evidence:** Levels of evidence were assigned using GRADE criteria (very low, low, moderate, or high). Clinical recommendations were made using a modified Delphi approach (weak or strong).	3. The incidence of PTS was 0.5-4.5% and was twice as common in complete versus incomplete injury. 4. Surgical intervention for PTS was effective at arresting or improving motor deterioration, but not sensory dysfunction or pain syndromes. 5. Spinal cord untethering with expansile duraplasty was the preferred surgical technique. 6. Direct surgical decompression beyond realignment/stabilization of a thoracic complete SCI to reduce the risk of future PTS was not supported. 7. Surgical intervention for incidental, asymptomatic syrinx was not supported.
Falci et al. (2009) USA Case Series N=362	**Population:** Mean age: 40.5 yr; Level of injury: C1-C6=163, C6-T1=83, T1-S5=116; Severity of injury: AIS A=232, AIS B=36, AIS C=41, AIS D=51, AIS E=2; Mean time since injury: 10.7 yr. **Intervention:** Participants who received cord untethering, expansion duraplasty, and cyst shunting for progressive myelopathy were retrospectively analyzed. Outcomes were assessed at pre-op, post-op, and follow-up. **Outcome Measures:** American Spinal Injury Association (ASIA) scores; Clinical status; Complications.	1. At post-op, participants showed significant increases in ASIA light touch score (n=308; +1.39, p=0.029) and pinprick score (n=307; +1.41, p=0.029), and a non-significant decrease in ASIA motor score (n=263; -0.32, p=0.059). 2. At 1 yr follow-up, participants showed non-significant changes in ASIA motor score (n=100; -.128, p=0.102), light touch score (n=110; +0.74, n=0.437), and pinprick score (n=109; +0.58, p=0.633). 3. At last follow-up, participants showed a significant decrease in ASIA motor score (n=134; -1.16, p=0.015) and non-significant changes in light touch score (n=157; -0.76, p=0.391) and pinprick score (n=157; +0.1, p=0.996). 4. Participants reported decreases in neuropathic pain (n=99; 47%), spasticity (n=53; 60%), and hyperhidrosis (n=38; 77%). 5. Participants reported arrest of progressive loss of both motor and sensory function (n=204; 89%), of motor function (n=152; 93%), and of sensory function (n=128; n=97%). 6. Complications were CSF leak/collection (3.8%), DVT/PE (2.35%), wound infection (0.48%), bacterial meningitis (0.48%), myocardial infarction (0.24%), and death (0.48%).
Falci et al. (1999) USA Case Series N=59	**Population:** Mean age: 38 yr; Gender: males=49, females=10; Level of injury: C1-C6=24, C6-T1=20, T1-S5=15; Severity of injury: AIS A=53, AIS B=1, AIS C=3, AIS D=2; Mean time since injury: 12 yr. **Intervention:** Participants who received cord untethering and/or cyst shunting for progressive myelopathy were retrospectively analyzed at 1 yr post-op. **Outcome Measures:** American Spinal Injury Association (ASIA) scores; Clinical status; Complications.	1. Participants showed non-significant increases in ASIA scores when compared to pre-op (p>0.05): light touch (+0.67), pinprick (+1.3), and motor (+0.41). 2. Participants without previous surgery (n=34) showed increases in ASIA scores when compared to pre-op: pinprick (+3.88, p<0.05), light touch (+2.38, p>.05), and motor (+1.47, p>0.05). 3. Participants with previous surgery (n=25) showed non-significant decreases in ASIA scores when compared to pre-op (p>0.05): light touch (-0.7), pinprick (-0.8), and motor (-0.5). 4. Participants showed recovery of lost functional activity (64.3%), substantial improvement in spasticity (62.5%), substantial improvement in neurogenic pain (55.6%), prevention of further neurologic deterioration (95.8%), and improvement in hyperhidrosis (100%).

		5. Complications were CSF leak/collection (8.4%), wound infection (1.7%), cyst recurrence (1.7%), and meningitis (1.7%).

Discussion

The largest case series is that of Falci et al. (2009) who published both early and late follow-up results. They describe 362 individuals surgically treated for tethered cord and/or syringomyelia. Each had delayed neurological decline after traumatic cord injury, attributable to tethering and/or syrinx, and demonstrated statistically significant declines in AIS scores during the first year of assessment. After surgical detethering (and in 20% of individuals, syrinx shunting), AIS scores remained statistically stable over a variable follow-up period from 2 to 12 years. This suggests that in individuals with delayed deterioration, surgical intervention is capable of arresting neurological decline, but not necessarily restoring neurological function. The same individuals responded via questionnaires that their perceptions of spasticity, hyperhidrosis and neuropathic pain had improved post-operatively, but there was no comparator group.

A systematic review of post-traumatic syringomyelia management (Bonfield et al., 2010) found that the incidence of this process is 1-4% among spinal cord injured individuals, and is twice as prevalent in complete, compared to incomplete, injuries. Despite post-traumatic syrinx being more prevalent in individuals with residual kyphosis at the level of injury, their review of low and very low quality retrospective studies found no evidence to prophylactically decompress the injured segment during the index surgical treatment; that is, they advised to not change surgical strategy in hopes of syrinx prevention.

With regard to surgical indications for syrinx, the systematic review by Bonfield et al. (2010) summarized retrospective studies and prospective cohort studies. The authors concluded that surgery was only recommended for progressive motor deterioration, and that progressive pain syndromes, sensory disturbance or other non-motor progression was not recommended. Bonfield et al. (2010) also addressed different methods of syrinx decompression. These range from spinal cord transection, to cerebrospinal fluid shunting to either the subarachnoid or pleural space, pseudomeningocoele creation, to expansile duraplasty. In general, after review of the mostly retrospective literature, there is no clearly superior technique, although a consensus pointed towards cord detethering and expansile duraplasty.

Conclusion

There is level 3 evidence (from one prospective cohort; Falci et al. 2009) that cord detethering with or without syrinx decompression can arrest neurological decline in individuals with delayed progressive myelopathy following spinal cord injury.

There is level 4 evidence (from studies from one systematic review; Bonn et al. 2010) that prophylactic measures for cord tethering and/or syrinx should not be taken, other than what is required to achieve primary spinal realignment / stabilization during the index surgery.

> Post-traumatic tethered cord and syringomyelia has an estimated incidence of 1-4%. Low quality evidence suggests that prophylactic decompression should not be performed, but that patients with progressive motor decline attributable to tethering or syrinx can have an arrest of their decline with surgical management.

8.0 Summary

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9.0 References

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Abbreviations

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