Spinal Cord Injury Associated with Spinal Stenosis: Outcomes and Prognostic Features.

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ABSTRACT

Spinal cord injury (SCI) is gradually considered to be a health priority worldwide, due to its ever-growing occurrence in the recent years. When associated with spinal stenosis, it results in substantial pain and disability and becomes the most prevalent reason for spinal surgery in individuals exceeding the 50 years of age. The aim of this review is to examine and compare functional outcomes and define the prognostic features for patients suffering from spinal cord injury (SCI) associated with spinal stenosis. A search in PubMed, ScienceDirect, EMBASE and AMED was conducted, using keywords such as, "Spinal Cord injury" and "Spinal Stenosis". Our literature research was completed in April 2022 and the review was carried out according to the guidelines of the PRISMA. 23 studies were included. Approximately 7,900 patients were observed in 20 studies and a considerable number of those were followed for time period ranging from 1 to 4 years. Study's outcomes indicate that best prognostic factors lie with patients suffering from incomplete CSCI without major fracture or pre-existing CSCS when undergoing early surgery. Age is a good prognostic factor. Studies are contradictory whether early surgical treatment determines positive outcomes.

Keywords: spinal cord injury (SCI); spinal canal stenosis; lumbar spinal stenosis, cervical spinal stenosis.

Introduction

Spinal Stenosis interprets the narrowing of the spinal canal or the intervertebral foramina at various anatomic levels, secondary to pathologic processes of the vertebral elements. Lumbar spinal stenosis (LSS), Cervical spinal stenosis (CSS) and Central canal stenosis are classified under the label of Spinal Stenosis.

Spinal Stenosis is a degenerative chronic condition in which the spaces around the neurovascular structures of the spine become narrower, usually in the cervical or lumbar spine, mostly due to aging process. It evokes pain in the lower parts of the body, instability, impaired ambulation, neurological deterioration in the case of LSS or pain in the neck and upper ligaments, cervical radiculopathy, cervical myelopathy in the case of CSS [1,2]. Spinal Stenosis may also be related to spi-

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nal cord injury (SCI). The yearly incidence of spinal cord injury (SCI) in the United States is estimated to amount to approximately 17.810 new cases [3]. Yet, it is growingly regarded as a health priority globally [4-6]. Motor and sensory impairment, pain, respiratory and cardiovascular alterations, loss of bladder and bowel function, tetraplegia are some of its direct complications [7,8]. Given the impact of Spinal Stenosis in the mobility, autonomy and quality of life of a considerable amount of people worldwide, it is the most common reason for spinal surgical treatment [5,6.9-11] . This study aims to review outcomes and prognostic factors for patients suffering from SCI associated with spinal stenosis.

PubMed databases, MEDLINE, Embase and AMED were searched for studies published between 1990 and 2022 employing keywords such as, "Spinal Cord injury" and "Spinal Stenosis". Our literature research was completed in March 2022 and the review was conducted in accordance with the guidelines of the PRISMA [12].

Eligibility criteria: Studies providing information on outcome measures and prognostic factors about recovery from Spinal Cord injury associated with Spinal Stenosis. The articles had to be either written or translated into English. Access to full text was essential.

Study exclusion criteria: Articles that were not written or translated in English or German were excluded. Articles that were impossible to be accessed in full text were excluded as well. Articles that failed to associate spinal cord injury with spinal stenosis or lacked prognostic factors were not included either. We decided to also exclude studies that examined a specific age group, omitting large ratios of the general population and studies that involved a single patient. Three studies were conducted on animals and therefore were excluded, too.

Each record that fulfilled the inclusion criteria was fully read. 27 reports were retrieved by the reviewer (Figure 1). No automation tools were used in the process.

Discussion

The initial electronic database search produced an overall of 52 articles of these, 23 were considered for inclusion in this review (Figure 1). Approximately 7,900 patients were observed in 20 studies and a considerable number of those was followed for a period of time ranging from 1 to 4 years.

Torg et al. examined 117 footballers suffering from cervical spinal stenosis with cord neurapraxia and transient quadriplegia. No correlation was found between stenosis of the spinal canal and irreversible sequelae [13]. It is advisable that patients with cord neurapraxia resulting from transient, reversible compression deformation of the spinal cord refrain from contact activities. Kirshblum & O'Connor (1998) assembled studies that focused on prognosis following traumatic SCI. They concluded that comprehensive physical examination is the most precise method in order to predict neurologic recovery [14].

Several studies have reported that age[15-19]plays an important part in successful recovery, especially when incomplete spinal cord injury is involved [17]. However, race, gender and injury mechanics bear no influence to neurologic recovery [15].

Yale et al. state that neurologic outcome depends on the diameter of the residual spinal canal. In their study involving 200 patients suffering from trauma in cervical spine, the authors reported that those with residual cervical spinal canal diameter <10 mm presented neurologic deterioration, whereas the group with residual cervical spinal canal diameter >10 mm had neurologic recovery [20].

AArabi et al, studied 42 patients with ATCCS due to spinal stenosis. They had a follow up for a year and examined ASIA motor score, midsagittal diameter at the point of maximum compression, MCC, length of parenchymal damage on T2-weighted MR imaging. They also conducted a 10 independent variable gradual regression analysis. Measurements revealed that mean admission ASIA motor score was 63.8, compression was in most cases observed at skeletal segments C3-4 & C4-5 of the spinal cord (71%), mean midsagittal diameter was 5.6 mm in the area of the spinal cord where compression was maximized, maximum canal compromise (MCC) rated 50.5%, spinal cord compression was 16.5% at its maximum point, length of parenchymal damage on T2-weighted MR imaging was 29.4 mm. The period between injury and surgery did not exceed 24 hours in 9 patients. 10 patients were operated within 2 days at most from injury time, 23 patients underwent surgery later than 2 days since the injury. At the 1-year follow-up, measurements read: mean ASIA motor score 94.1, FIM 111.1, manual dexterity 64.4% of baseline, pain level 3.5. Regression analysis indicated that ASIA motor score at follow-up and admission ASIA motor score ($p = 0.003$) were considerably connected. The same applied between MCC ($p = 0.02$), and midsagittal diameter ($p = 0.02$). FIM and admission ASIA motor score ($p = 0.03$), MCC ($p = 0.02$), and age ($p = 0.02$) were linked. Manual dexterity and admission ASIA motor score ($p = 0.0002$) as well as length of parenchymal damage on T2-weighted MR imaging ($p = 0.002$) were related. Relationship was observed between pain level and age ($p = 0.02$) and length of parenchymal lesion on T2-weighted MR imaging ($p = 0.04$), as well [21].

In the study of Alpízar-Aguirre et al., 195 patients with cervical stenosis were followed. Female patients at the ages between 46 and 55 were predominant. C5-C6 were the points that suffered at the majority of the cases. Following surgery, they had remarkable improvement of the neck disability. Surgery was demonstrated to be better treatment than physical therapy in other studies, too [22-24].

Kwon et al. (2015) examined 246 patients enduring cervical cord injury. A 1-year follow-up was conducted and a second one was performed at a mean period of 42.2 months. Measurements showed Mean American Spinal Injury Association (ASIA) motor score 38.4 ± 21.9 (range, 2-70) when patients were admitted, ameliorated to 67.7 ± 19.1 (range, 8-94) at the last follow-up ($p < 0.05$). Mean recovery rate of motor score 55.8 ± 19.9%. SI grade 0 was observed in 5 patients, SI grade 1 was recorded in 20 patients, whereas 13 subjects were found with SI grade 2. Age, initial ASIA motor grade, intramedullary SI grade, and SAC bore remarkable relationship with the neurological outcome. The neurological outcome did not seem to be affected by initial cervical alignment, canal diameter, length of SI, period between injury-operation, and OPLL type [25].

In the study of Bonavita et al., 168 patients with Traumatic Spinal Cord Injury and 72 patients with incomplete Spinal Cord Injury were monitored. Patients with an ISCI were older and had fewer cervical lesions than subjects enduring TSCI. Etiology and lesion features were pinpointed as predictors of functional (SCIM improvement and SCIM at discharge) outcome when linear and logistic regression were conducted. Traumatic patients when compared to ischemic ones were found to have greater results. Occurrence of complications, time spent in hospital & discharge dispositions were found to be associated with AIS level, lesion level and age of patients [26].

Park et al. examined 73 patients with cervical spinal cord injury who were treated with one-level decompression and fusion surgery. Of the 73 patients suffering SCI, 27 showed ≥1 grade of AIS immediate improvement and 35 subjects had the same improvement 3 months after surgery. Multivariate analysis revealed that mean arterial blood pressure (MAP) played an important role in recovery of SCI patients during the immediate post-operative period. In the late recovery period at 3 months after surgery, recovery was associated with AIS before surgery and the MAP [27]. On the other hand, Shigematsu et al., in their study, followed 32 patients with cervical spinal canal stenosis. 17 of them underwent decompression and 15 received conservative treatment. At the final follow-up, 3 patients (9.3%) had returned to their pre-injury Frankel grade. 26 patients (83.3%) lost one or more neurological grades. 3 patients (9.3%) passed away. However, in Lee et al. study (29), a 2-year follow-up period was utilized to reveal higher percentages in patients that had undergone surgery than in patients that had received conservative treatment ≥1 grade (90.9% vs. 57.1%, $P=0.0051$) and 2 grade (30.3% vs. 9.5%) improvements in ASIA grade. In multivariate analysis, solely early surgical treatment resulted in ASIA grade improvement after 2 years ($P=0.0044$) [28].

Khorasanizadeh, et al. [30] conducted a random pooled effect analysis as well as meta-regression analysis in 114. It was concluded that the injury level was related to recovery; recovery rates formed a sequence: lumbar > cervical and thoracolumbar > thoracic. There was high probability that complete injury would be the aftereffect of thoracic SCI and penetrating SCI. Penetrating TSCI showed lower recovery rate than blunt injury (OR 0.76, 95% CI 0.62-0.92; $p = 0.006$). Follow-up duration had a positive relation to recovery rate ($p = 0.001$). Injury factors, namely, the severity, the level and the mechanism of injury affect post TSCI neurological recovery regardless what treatment is followed or country of origin of the patients. A follow-up of at least one year period is essential for TSCI studies when patients with neurologically incomplete injury are included.

The most important prognostic factor relating to neurologic recovery in spinal cord injury is contusion plenum. Incomplete cervical spinal cord lesions in younger patients and those with either a central cord or Brown-Sequard syndrome are more likely to recover[15]. SCI clinical syndromes manifest a considerable number of admissions to acute SCI rehabilitation. CCS most frequently occurring, especially in older ages, displays poor admission functional level in comparison with other SCI clinical syndromes. Individuals enduring cervical BSS obtain higher functional improvement, when discharged, as to individuals suffering CCS. The functional outcomes regarding patients with CMS and CES have been proven to be equal. Individuals diagnosed with ACS manifest the longest LOS of the SCI clinical syndromes while inpatient rehabilitation is recommended [16].

According to Rüegg et al., MR measurements of the cord-canal-area ratio (> 0.8) or the space available for the cord (< 1.2 mm) enable reliable identification of patients susceptible to acute CSCI following a minor trauma to the cervical spine. Yet, spinal canal imaging characteristics are not likely to relate to the severity of or recovery from CSCI subsequent to minor trauma [31]. Patients in peril of acute SCI following a minor trauma to the cervical spine are detectable when applying a disc-level canal diameter cutoff value (measured on MR images) of 8 mm. Radiological characteristics of the spinal canal may also determine the severity of acute SCI after a minor trauma to the cervical spine [32]. In the study of Eismond et al., the authors stated that a larger sagittal diameter of the cervical spine is protective of the neural elements [33]. On the other hand, as far as thoracolumbar spine is concerned, Vacaro et al. reported that thoracolumbar spine dimensions do not provide an explanation for the neurologic injury degree subsequent to burst fracture. The authors reported that contrary to what would be inferred, larger canals do not defend neural elements [34].

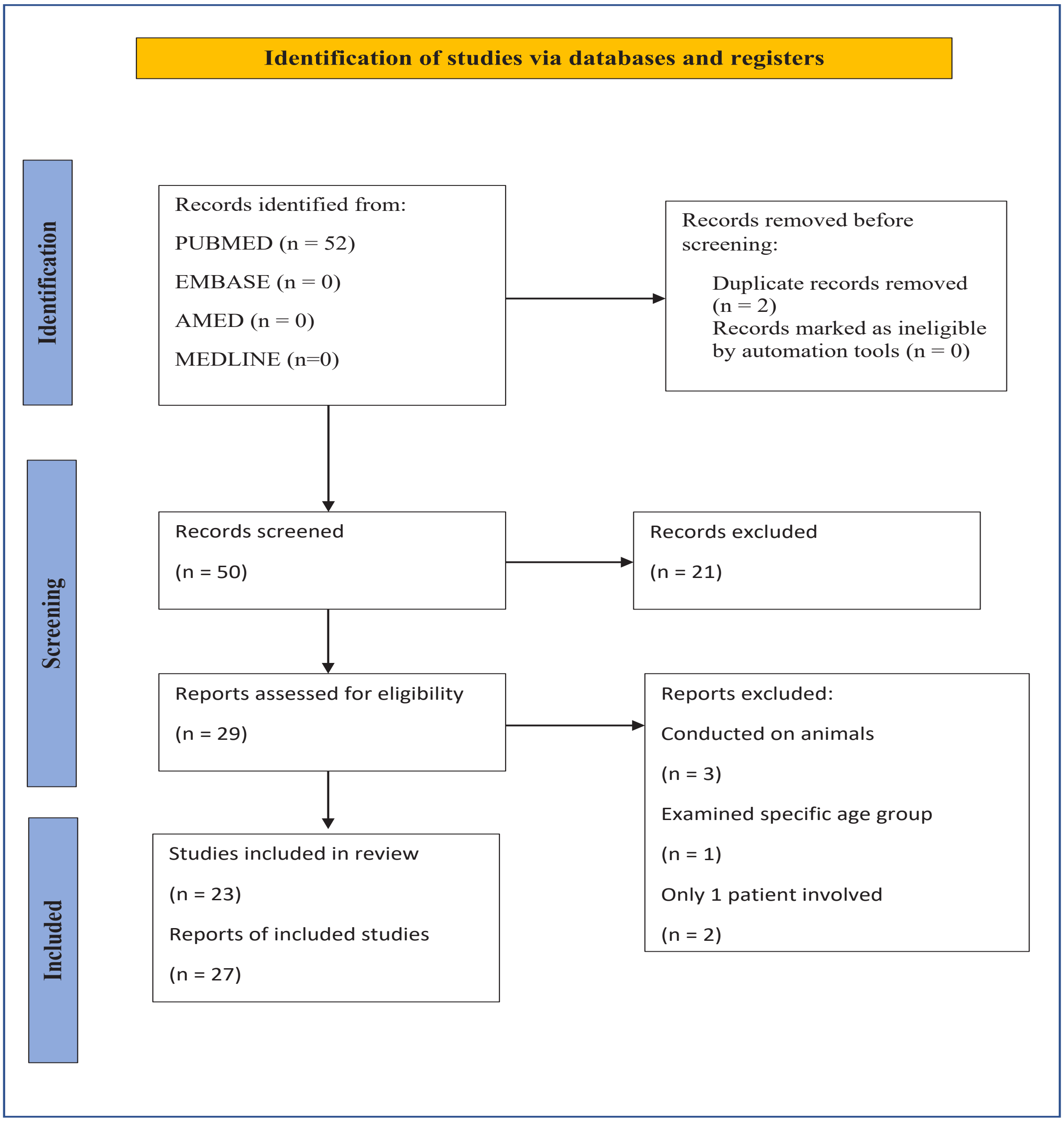
Neurological recovery after TSCI is definitely reliant on injury factors (i.e., severity, level, and mechanism of injury), yet not affected by type of treatment or country of origin [30]. Marked stenosis of the cervical spinal canal might result in irreversible changes in the spinal cord when combined with indirect minor trauma. It is, therefore, advisable to verify with lateral radiograph of the cervical for early detection of cervical spinal stenosis [20].

Poor neurological recovery is noticed in patients suffering complete thoracic SCI, when levels are above T10. A high SI grade on preoperative T2WI negatively affects neurological outcome. Consequently, the severity of SI change, cord compression ratio, and preoperative neurological status are considered to be important prognostic factors when relation between SCI and OPLL is detected [25].

Age at the time of injury, also, determines prognosis as young patients have better chances to functional recovery. Conversion to a better AIS grade enabled patients to ameliorate concerning self-care and mobility in 12 months [17]. On the other hand, MSCC, spinal cord hemorrhage and cord swelling are prognostic factors for small neurologic recovery. Extent of MSCC is more reliable than presence of canal stenosis for predicting the neurologic outcome after SCI [35].

While preoperative neurological status, cord compression ratio, SI grade and hemodynamic MAP at admission serve for prognosis of recovery [25,27] the MR imaging diagnosis before operation may not always correspond to the intraoperative discoveries, thus failing to provide a comprehensive and accurate diagnosis. Emphasis should be laid on clinical symptoms [36]. It is advisable that acute SCI patients undergo comprehensive physical examination in order to detect the initial level and classification of the injury and predict neurologic recovery. Clinical examination combined with somatosensory evoked potentials, magnetic resonance imaging, transcranial magnetic stimulation and similar tests are likely to define the outcome [14]. Additionally, diagnosis of ischemia and trauma may assist in functional recovery in SCI patients [26].

Samuel et al. (2015) suggest that the majority of patients with SCI do not undergo surgery within the first 24 hours after injury, and the majority of delays occur after inpatient admission which affects the recovery rate later [25]. Early surgery proved to provide better neurological outcomes when compared to conserva-



tive treatment received by individuals who suffer from incomplete CSCI without major fracture or dislocation and pre-existing CSCS in the Lee et al. (2021) study as well [22,29]. However, in the Pollard & Apple study, high-dose steroid administration, routine early surgical intervention, or surgical decompression in stenotic patients without fracture were not detected as determinants of the outcome [15]. Park et al. (2017) also state that the interval between decompression surgery and trauma is irrelevant to the neurological outcome [27]. Admission ASIA motor score, midsagittal diameter, MCC, length of parenchymal damage on T2-weighted MR imaging, and age revealed long-term ASIA motor score, FIM, manual dexterity, and dysesthetic pain [27].

According to Shigematsu et al. (2017) "silent" CSCS when combined with cervical cord injuries does not permit return to pre-injury neurological status [21].

No conclusions could be drawn from the review regarding physical therapy treatment[24]. Physiothera-

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TABLE 1.

Description of included studies

No	Study	Population	Intervention	Outcome measures	Results
1	Torg J. S. (1995). Cervical spinal stenosis with cord neurapraxia and transient quadriplegia.	Footballers 117 quadriplegics 45 patients in transient cohort		Ratio Method	No correlation between developmental narrowing (stenosis) of the spinal canal & irreversible sequelae in a spine rendered unstable by football induced trauma. Manifestations of cord neurapraxia resulting from transient, reversible compression deformation of the spinal cord. Athletes with documented episode of cervical cord neurapraxia associated with: • ligamentous instability • intervertebral disc disease with cord compression • significant degenerative changes • magnetic resonance imaging evidence of cord defects or swelling • symptoms of positive neurological findings lasting more than 36 hours • more than one recurrence should avoid continued participation in contact activities
2	Kirshblum, S. C., & O'Connor, K. C. (1998). Predicting neurologic recovery in traumatic cervical spinal cord injury. Review.	Selection of studies in English language that discussed prognosis after traumatic SCI.			Comprehensive physical examination of the acute SCI patient is essential in determining the initial level and classification of the injury and the most accurate method to predict neurologic recovery. Somatosensory evoked potentials, magnetic resonance imaging, and transcranial magnetic stimulation, may be helpful in further determining outcome when used in association with the clinical examination
3	Witzmann A. (2000). Akupunktur und andere Therapieformen beim Patienten mit chronischen Wirbelsäulenschmerzen [Acupuncture and other forms of treatment for patients with chronic back pain]. Review.		Manual therapeutic strategies, application of local anesthetics, Acupuncture. X-ray conducted periradicular infiltration, epidural blockades with local anesthetics and steroids, hiatus sacralis blockade, percutaneous radiofrequency denervation of the facet joint and percutaneous lumbar radiofrequency sympathicotomy	Symptomatology	Pain-producing spinal structures recognized & treatment offered to patients with manual therapeutic strategies. Pain-producing spinal sites treated with local anesthetics. Acupuncture is treatment option for pain relief & has effect upon physical and psychological disturbances.

					X-ray conducted periradicular infiltration, epidural blockades with local anesthetics and steroids, hiatus sacralis blockade, percutaneous radiofrequency denervation of the facet joint and percutaneous lumbar radiofrequency sympathicotomy preferable when the aforementioned methods fail. Disc herniation with radicular symptoms, spinal canal stenosis, cervical stenotic myelopathy and degenerative spinal instability may be indications for surgical intervention.
4	Pollard, M. E., & Apple, D. F. (2003). Factors associated with improved neurologic outcomes in patients with incomplete tetraplegia.	412 patients with traumatic, incomplete, cervical spinal cord injuries.	intravenous steroids (NASCIS II protocol), early definitive surgery (<24 hours after injury), early anterior decompression for burst fractures or disc herniations (<24 hours after injury), and surgical decompression for stenosis without fracture.	change in motor score, change in sensory score, final motor score, and final sensory score data recorded at the time of injury, on admission to rehabilitation, on discharge from rehabilitation, and at 1, 2, and final year of follow-up evaluation.	Neurologic recovery not related to the following factors: gender, race, type of fracture, or mechanism of injury. Neurologic recovery also not related to the following interventions: high-dose methylprednisolone administration, early definitive surgery, early anterior decompression for burst fractures or disc herniations, or decompression of stenotic canals without fracture. Improved neurologic outcomes noted in younger patients (= 0.002), and those with either a central cord or Brown-Sequard syndrome (= 0.019).
5	McKinley, W., Santos, K., Meade, M., & Brooke, K. (2007). Incidence and outcomes of spinal cord injury clinical syndromes.	839 consecutive admissions with acute SCIs.	Tertiary care, level 1 trauma center inpatient rehabilitation unit.	Functional independence measure (FIM), FIM subgroups (motor, self-care, sphincter control), length of stay (LOS), and discharge disposition	175 patients (20.9%) diagnosed with SCI clinical syndromes. CCS the most common (44.0%), followed by CES (25.1%) and BSS (17.1%). Significant differences (P < or = 0.01) found between groups with regard to age, race, etiology, total admission FIM, motor admission FIM, self-care admission and discharge FIM, and LOS. Statistical analysis between tetraplegic BSS and CCS revealed significant differences (P < or = 0.01) with respect to age (39.7 vs 53.2 years) and a trend toward significance (P < or = 0.05) with regard to self-care admission and discharge FIM. No significant differences (P < or = 0.01) were found when comparing CMS to CES.

6	Miyanji, F., Furlan, J. C., Aarabi, B., Arnold, P. M., & Fehlings, M. G. (2007). Acute cervical traumatic spinal cord injury: MR imaging findings correlated with neurologic outcome--prospective study with 100 consecutive patients.	100 patients (79 male, 21 female; mean age, 45 years; age range, 17-96 years) with traumatic cervical SCI.		American Spinal Injury Association (ASIA) motor score at admission and follow-up ASIA impairment scale for injury severity classification. 3 quantitative (maximum spinal cord compression [MSCC], maximum canal compromise [MCC], and lesion length) and 6 qualitative (intramedullary hemorrhage, edema, cord swelling, soft-tissue injury [STI], canal stenosis, & disk herniation) imaging parameters. Data analyzed with Fisher exact test, the Mantel-Haenszel chi(2) test, analysis of variance, analysis of covariance, stepwise multivariable linear regression.	Patients with complete motor and sensory SCIs had more substantial MCC (P=.005), MSCC (P=.002), and lesion length (P=.005) than did patients with incomplete SCIs and those with no SCIs. Patients with complete SCIs also had higher frequencies of hemorrhage (P<.001), edema (P<.001), cord swelling (P=.001), stenosis (P=.01), and STI (P=.001). MCC (P=.012), MSCC (P=.014), and cord swelling (P<.001) correlated with baseline ASIA motor scores. MSCC (P=.028), hemorrhage (P<.001), and cord swelling (P=.029) predictive of the neurologic outcome at follow-up. Hemorrhage (P<.001) and cord swelling (P=.002) correlated significantly with follow-up ASIA score after controlling for the baseline neurologic assessment.
7	Cao, J., Wang, Q., Wang, G., Lv, F., & Zhong, D. (2009). [Diagnostic value of MR imaging in cervical spinal canal stenosis combined with spinal cord injury]	41 patients with cervical spinal canal stenosis and spinal cord injury: 34 males and 7 females aged 32-71 years (average 53.4 years, 27 patients older than 60 years). 12 cases of anterior spinal cord injury syndrome, 23 of central spinal cord syndrome and 6 of Brown-Sequard syndrome.	operation	MRI data, JOA score of spinal cord function	MR imaging diagnosis before operation showed abnormal signal changes within the spinal cord in 37 cases (41 sites), anterior and posterior longitudinal ligaments and discs (APLLD) injury in 28 cases (30 sites) and signal of edema and hematoma signals in anterior surface of cervical spines (EBC) in 34 cases (36 sites). Diagnosis during operation revealed edemas raises, contusions tears of posterior soft tissue in 18 cases (20 sites), appendix fracture in 6 cases (7 sites), formation of EBC in 20 cases (23 sites), APLLD injury in 34 cases (44 sites), intervertebral instability without the rupture of ligament and intervertebral disc in 7 cases (10 sites). Significant difference between MRI diagnosis before operation and intraoperative discoveries (P < 0.05).

8	Yoo, D. S., Lee, S. B., Huh, P. W., Kang, S. G., & Cho, K. S. (2010). Spinal cord injury in cervical spinal stenosis by minor trauma.	200 cases (98 cervical OPLLs and 102 CSMs) of cervical spinal stenosis for 8 years. 63 (33.5%) minor trauma cases to the cervical spine in 200 patients. Patients divided into 2 groups according to the residual cervical spinal canal diameter: group I (<10 mm cervical spinal canal) and group II (> or =10 mm cervical spinal canal).	surgical decompression	Neurologic status assessed by JOA score.	Neurologic outcome depended on the diameter of the residual spinal canal; 22 of 25 patients in group I developed neurologic deterioration, that occurred in 8 of the 38 patients in group II (P < .05). After surgical decompression, 8 patients in group I and 30 patients in group II came out with an improved JOA score of more than 50% (P < .05).
9	Aarabi, B., Alexander, M., Mirvis, S. E., Shanmuganathan, K., Chesler, D., Maulucci, C., Iguchi, M., Aresco, C., & Blacklock, T. (2011). Predictors of outcome in acute traumatic central cord syndrome due to spinal stenosis.	42 patients treated for ATCCS due to spinal stenosis	surgical decompression	follow-up for at least 12 months, ASIA motor score, midsagittal diameter at the point of maximum compression, MCC, length of parenchymal damage on T2-weighted MR imaging. Stepwise regression analysis of 10 independent variables.	Mean admission ASIA motor score 63.8, spinal cord most frequently compressed at skeletal segments C3-4 & C4-5 (71%), mean midsagittal diameter at the point of maximum compression 5.6 mm, maximum canal compromise (MCC) 50.5%, maximum spinal cord compression 16.5%, length of parenchymal damage on T2-weighted MR imaging 29.4 mm. Time after injury until surgery: within 24 hours in 9 patients, 24-48 hours in 10 patients, more than 48 hours in 23 patients. At the 1-year follow-up, mean ASIA motor score 94.1, FIM 111.1, manual dexterity 64.4% of baseline, pain level 3.5. Regression analysis indicated significant relationships between ASIA motor score at follow-up and admission ASIA motor score (p = 0.003), MCC (p = 0.02), and midsagittal diameter (p = 0.02); FIM and admission ASIA motor score (p = 0.03), MCC (p = 0.02), and age (p = 0.02); manual dexterity and admission ASIA motor score (p = 0.0002) and length of parenchymal damage on T2-weighted MR imaging (p = 0.002); and pain level and age (p = 0.02) and length of parenchymal lesion on T2-weighted MR imaging (p = 0.04).

10	Aebli, N., Rüegg, T. B., Wicki, A. G., Petrou, N., & Krebs, J. (2013). Predicting the risk and severity of acute spinal cord injury after a minor trauma to the cervical spine.	52 patients suffering from acute cervical SCI & 131 patients showing no neurologic deficits after minor trauma to cervical spine.		On sagittal MR images: vertebral body diameter, midvertebral canal diameter, disc-level canal diameter, and spinal cord diameter. On lateral conventional radiographs: vertebral body diameter and midvertebral canal diameter.	All investigated MR image parameters in the SCI group significantly (p<.001) smaller compared to control group. No significant (p>.9) difference in any parameter among the different American Spinal Injury Association impairment score groups. A cutoff value of 8.0 mm for the minimal sagittal disc-level canal diameter yielded the largest positive predictive value and likelihood ratio for predicting SCI.
11	Alpízar-Aguirre, A., Solano-Vargas, J. D., Zárate-Kalfopulus, B., Rosales-Olivares, L. M., Sánchez-Bringas, G., & Reyes-Sánchez, A. A. (2013). Resultados funcionales de la cirugía del conducto cervical estrecho [Functional results of surgery for cervical stenosis].	195 patients with cervical stenosis	surgical treatment	neck disability index questionnaire, the Nurick scale. Descriptive statistics.	Females were predominant. The most affected age group was 46-55 years. The most frequently affected level was C5-C6. A significant improvement was seen in the neck disability index due to pain and the Nurick scale.
12	Macedo, L. G., Hum, A., Kuleba, L., Mo, J., Truong, L., Yeung, M., & Battié, M. C. (2013). Physical therapy interventions for degenerative lumbar spinal stenosis: a systematic review.	Ten studies included: 5 RCTs, 2 controlled trials, 2 mixed-design studies, and 1 longitudinal cohort study.			Pooled effects of 2 studies revealed that addition of physical therapy modality to exercise had no statistically significant effect on outcome. Pooled effects results of RCTs evaluating surgery versus physical therapy demonstrated surgery better than physical therapy for pain and disability at long term (2 years) only. Exercise is significantly better than no exercise, cycling and body-weight-supported treadmill walking have similar effects, and corsets are better than no corsets.
13	Kwon, S. Y., Shin, J. J., Lee, J. H., & Cho, W. H. (2015). Prognostic factors for surgical outcome in spinal cord injury associated with ossification of the posterior longitudinal ligament (OPLL).	246 patients with cervical cord injury.	cervical laminoplasty (8) and cervical decompression and fixation (30).	1-year follow-up, with mean follow-up period 42.2 months. OPLL type, cause of injury, cervical sagittal angle, cervical spine stenosis, cord compression ratio (space available for the spinal cord (SAC)), grade of intramedullary SI (grade 0, none; grade 1, light; grade 2, intense T2WI) were assessed.	Mean American Spinal Injury Association (ASIA) motor score at admission 38.4 ± 21.9 (range, 2-70) and improved to 67.7 ± 19.1 (range, 8-94) at last follow-up (p < 0.05). Mean recovery rate of motor score 55.8 ± 19.9%. Five patients had SI grade 0, 20 patients SI grade 1, and 13 patients SI grade 2. Age, initial ASIA motor grade, intramedullary SI grade, and SAC significantly related to neurological outcome.

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					Initial cervical alignment, canal diameter, length of SI, time interval between injury and operation, and OPLL type had no significant effect on neurological outcome.
14	Rüegg, T. B., Wicki, A. G., Aebli, N., Wisianowsky, C., & Krebs, J. (2015). The diagnostic value of magnetic resonance imaging measurements for assessing cervical spinal canal stenosis.	52 CSCI patients & 77 control patients	single-center retrospective radiological case-control study of patients with CSCI after a minor trauma to the cervical spine from 2000 to 2010	axial T2-weighted MR images, motor index scores of 10 key muscles at different time points (initially, 1, 3, and 12 months after injury), Receiver operating characteristic curves.	The intra- and interobserver reliability regarding the MRI measurements ranged from good (0.72) to perfect (0.99). Significant differences between CSCI group and control group ($p < 0.001$) for all parameters, except for cord area. Prominent differences between the groups for the spinal canal area, cord-canal-area ratio, and space available for the cord. Classification accuracy best for cord-canal-area ratio and space available for the cord; areas under the curve were 0.99 (95% CI 0.97-1.0) and 0.98 (95% CI 0.95-0.99), respectively. No significant ($p > 0.05$) correlation between any of the imaging parameters and the motor index score at any time point.
15	Samuel, A. M., Bohl, D. D., Basques, B. A., Diaz-Collado, P. J., Lukasiewicz, A. M., Webb, M. L., & Grauer, J. N. (2015). Analysis of Delays to Surgery for Cervical Spinal Cord Injuries.	2636 patients with cervical SCI: 803 with complete SCI, 950 with incomplete SCI, and 883 with central SCI.	surgery	Relationships between surgical timing and patient and injury characteristics	Average time to surgery was 51.1 hours for patients with complete SCI, 55.3 hours for patients with incomplete SCI, and 83.1 hours for patients with central SCI. Only 44% of patients with SCI underwent surgery within the first 24 hours after injury, including only 49% of patients with incomplete SCI. The vast majority of time between injury and surgery was after admission, rather than in the emergency department or in the field. Upper cervical SCIs and greater Charlson Comorbidity Index were associated with later surgery in all 3 SCI subpopulations.
16	Burns, S. P., Weaver, F., Chin, A., Svircev, J., & Carbone, L. (2016). Cervical stenosis in spinal cord injury and disorders.	1954 Veterans with onset of traumatic or non-traumatic tetraplegia during FY 1999-2007		Demographics, etiologies of SCI/D and comorbidities by CSS status.	Veterans with SCI/D and CSS were older, more likely to have incomplete injuries and more likely to be Black than those with SCI/D and no CSS.

					Of patients with traumatic etiologies for SCI, 35.1% had a diagnosis of CSS at the time of or in the 2 years prior to SCI onset. Of those with tetraplegia due to falls, 40.0% had CSS. For other traumatic etiologies the percentages with CSS were lower: vehicular (25.0%); sports (16.1%); and acts of violence (10.2%). Total comorbidity scores measured by the Charlson co morbidity index and CMS Hierarchical Condition Category (CMS-HCC) were higher in those with CSS and SCI/D compared to those with SCI/D without CSS ($P < 0.0001$ respectively).
17	Harvey L. A. (2016). Physiotherapy rehabilitation for people with spinal cord injuries.	60 clinical trials	Physiotherapy		Absence of high-quality trials involving people with SCI to guide treatment, lack of high-quality direct evidence, extensive scope of practice Physiotherapy interventions to increase strength, treat and prevent contractures, improve performance of motor tasks Physiotherapists need to resort to previous knowledge from other areas of physiotherapy to decide upon treatment.
18	Lee, B. A., Leiby, B. E., & Marino, R. J. (2016). Neurological and functional recovery after thoracic spinal cord injury.	661patients enrolled in Spinal Cord Injury Model Systems database, injured between 2000 and 2011, with initial neurological level of injury from T2-12. 265 patients had second neurological exams & 400 patients had Functional Independence Measure (FIM) scores ≥6 months after injury.	Retrospective analysis of longitudinal database	American Spinal Injury Association Impairment Scale (AIS) grade, sensory level (SL), lower extremity motor scores (LEMS), and FIM.	At baseline, 73% of subjects were AIS A, of them, 15.5% converted to motor incomplete. The mean SL increase for subjects with an AIS A grade was 0.33 ± 0.21; 86% remained within two levels of baseline. Subjects with low thoracic paraplegia (T10-12) demonstrated greater LEMS gain than high paraplegia (T2-9), and had higher 1-year FIM scores. Better FIM scores were correlated with better AIS grades, younger age and increase in AIS grade. Ability to walk at 1 year associated with low thoracic injury, higher initial LEMS, incomplete injury and increase in AIS grade.

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19	Bonavita, J., Torre, M., Capirossi, R., Baroncini, I., Brunelli, E., Chiarottini, G., Maietti, E., Olivi, S., Molinari, M., & Scivoletto, G. (2017). Outcomes Following Ischemic Myelopathies and Traumatic Spinal Injury.	168 patients with a TSCI and 72 with an ISCI.	-	American Spinal Injury Association Impairment Scale (AIS) standards and Spinal Cord Independence Measure (SCIM). Linear and logistic regression models to analyze the effects of the etiology of the lesion, AIS level at admission, and level of the lesion.	Patients with an ISCI were older and had fewer cervical lesions and fewer complete lesions than patients with TSCI. By linear and logistic regression, etiology was a predictor (together with lesion features) of functional (SCIM improvement and SCIM at discharge) outcome. Traumatic patients had better outcome than ischemic ones. Age, AIS level, and lesion level were chief predictors of length of stay, occurrence of complications & discharge dispositions.
20	Park, J. H., Kim, J. H., Roh, S. W., Rhim, S. C., & Jeon, S. R. (2017). Prognostic factor analysis after surgical decompression and stabilization for cervical spinal-cord injury.	73 patients with cervical SCI.	one-level decompression and fusion surgery	American Spinal Injury Association Impairment scale (AIS) before surgery, blood pressure at admission, the amount of cord compression, surgical time, estimated blood loss during surgery, and steroid use. Considered improvement if AIS improvement ≥1 grade.	Of 73 patients with SCI, 27 and 35 showed ≥1 grade of AIS improvement immediately and 3 months after surgery, respectively. In multivariate analysis, the mean arterial blood pressure (MAP) was a significant prognostic factor affecting recovery in the SCI patients during the immediate post-operative period. In the late recovery period at 3 months after surgery, the AIS before surgery and the MAP were significant prognostic factors affecting recovery.
21	Shigematsu, H., Cheung, J. P., Mak, K. C., Bruzzone, M., & Luk, K. D. (2017). Cervical spinal canal stenosis first presenting after spinal cord injury due to minor trauma: An insight into the value of preventive decompression.	32 patients with CSCS 47 asymptomatic individuals from general population	Decompression in 17 patients & conservative treatment in 15.	MRI measurements, Frankel classification,	At the final follow-up, 3 patients (9.3%) returned to their pre-injury Frankel grade, whereas 26 patients (83.3%) lost one or more neurological grade. 3 patients (9.3%) died.
22	Khorasanizadeh, M., Yousefifard, M., Eskian, M., Lu, Y., Chalangari, M., Harrop, J. S., Jazayeri, S. B., Seyedpour, S., Khodaei, B., Hosseini, M., & Rahimi-Movaghar, V. (2019). Neurological recovery following traumatic spinal cord injury: a systematic review and meta-analysis.	114 studies		random pooled effect analysis, meta-regression analysis.	Level of injury was a significant predictor of recovery; recovery rates followed this pattern: lumbar > cervical and thoracolumbar > thoracic. Thoracic SCI and penetrating SCI were significantly more likely to result in complete injury. Penetrating TSCI had a significantly lower recovery rate compared to blunt injury (OR 0.76, 95% CI 0.62-0.92; $p = 0.006$). Recovery rate was positively correlated with longer follow-up duration ($p = 0.001$).

					Neurological recovery after TSCI is significantly dependent on injury factors (i.e., severity, level, and mechanism of injury), but is not associated with type of treatment or country of origin. A minimum follow-up of 12 months is recommended for TSCI studies that include patients with neurologically incomplete injury.
23	Lee, S., Kim, C., Ha, J. K., Jung, S. K., & Park, J. H. (2021). Comparison of Early Surgical Treatment with Conservative Treatment of Incomplete Cervical Spinal Cord Injury Without Major Fracture or Dislocation in Patients with Pre-existing Cervical Spinal Stenosis.	54 patients	early surgical treatment (<24 h) (S group), conservative treatment (C group)	degree of improvement in ASIA grade after 2 years, medical records and radiographic data.	During the 2-year follow-up period, higher percentages of patients in the S group than in the C group showed ≥1 grade (90.9% vs. 57.1%, P=0.0051) and 2 grade (30.3% vs. 9.5%) improvements in ASIA grade. Multivariate analysis showed that early surgical treatment, was the only factor significantly associated with ASIA grade improvement after 2 years (P=0.0044).

py interventions tend to improve strength, treat and protect from contractures, raise performance of motor tasks, however, physiotherapists need to resort to previous knowledge from other areas of physiotherapy to decide upon treatment [37].

Conclusion

According to Table 1, which successfully summarizes the data presented in the 23 articles included in this research, it is clearly indicated that a comprehensive physical examination of an acute SCI patient is of the outmost importance in defining initial level and classification of the injury. The aforementioned method is the most accurate available to predict a possible neurologic recovery using immediate surgical treatment. An invaluable tool, which can be used as a prognostic criterium towards neurological recovery, is the level of completion of the lesion caused by a spinal cord injury. Even though several studies have already indicated that age, race and other similar demographic statistics may not be indicative of the success of the neurological recovery, younger patients with an incomplete lesion bear better chances to recover.

Spinal cord hemorrhage and cord swelling are associated with a poor prognosis for neurologic recovery since they inhibit the comprehensive physical examination prior to an invasive surgery treatment. Unfortunately, the literature review has already demonstrated that MR imaging diagnosis before operation do not correspond to the intraoperative discoveries, indicating that MRI diagnosis fails to make a relatively comprehensive and accurate diagnosis. Therefore, a clinical diagnosis is imperative, which in turn corroborates further with the previous assessment.

Although the waiting time between the inflicted injury and the surgery is not a crucial factor for a successful surgery and neurological rehabilitation - at least not as crucial as the physical examination and diagnosis itself - the majority of patients with SCI do not undergo surgery within the first 24 hours after injury. In fact, most delays are observed after inpatient admission.

Several studies have illustrated that subjects with pre-existing canal stenosis may present a lower threshold for surgery due to the poor neurological outcome of CSCS. Patients that have considerably good preoperative neurological status, are more likely to neurologically recover after surgery.

Incomplete cervical spinal cord lesions when inflicted on patients young at age are most likely to result in neurologic recovery.

No conclusions could be drawn from the review regarding the most appropriate physical therapy treatment for LSS. Despite not playing an important part in rehabilitation, exercise and corsets contribute to the patient's recovery.

The best prognostic factors lie with patients suffering incomplete CSCI without major fracture or pre-existing CSCS when undergoing early surgery.

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