



Universiteit
Leiden
The Netherlands

Complete traumatic spinal cord injury: current insights regarding timing of surgery and level of injury

Wengel, P.V. ter; Haan, Y. de; Feller, R.E.; Oner, F.C.; Vandertop, W.P.

Citation

Wengel, P. V. ter, Haan, Y. de, Feller, R. E., Oner, F. C., & Vandertop, W. P. (2019). Complete traumatic spinal cord injury: current insights regarding timing of surgery and level of injury. *Global Spine Journal*, 10(3), 324-331. doi:10.1177/2192568219844990

Version: Publisher's Version

License: [Creative Commons CC BY-NC-ND 4.0 license](#)

Downloaded from: <https://hdl.handle.net/1887/3184581>

Note: To cite this publication please use the final published version (if applicable).

Complete Traumatic Spinal Cord Injury: Current Insights Regarding Timing of Surgery and Level of Injury

Global Spine Journal
2020, Vol. 10(3) 324-331
© The Author(s) 2019
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2192568219844990
journals.sagepub.com/home/gsj



Paula Valerie ter Wengel, MD^{1,2}, Yvette De Haan, MD¹,
Ricardo E. Feller, MD¹, F. Cumhur Oner, MD, PhD³,
and William Peter Vandertop, MD, PhD^{1,4}

Abstract

Study Design: A narrative literature review.

Objectives: To review the neurological recovery patterns in traumatic spinal cord injury (tSCI) patients with a complete lack of motor and sensory function below the level of injury (ie, ASIA A [American Spinal Injury Association scale]), as well as the impact of level of injury and timing of surgical intervention.

Results: Spontaneous neurological recovery in patients with complete tSCI differs per level of injury: patients with cervical and thoracolumbar tSCI recover ≥ 1 ASIA grade in 17.3% to 34.0% 1 year after injury, compared with 10.7% to 18.6% in thoracic tSCI. Surgical decompression within 24 hours has a beneficial effect on neurological recovery in patients with complete cervical tSCI, whereas this effect is less clear for thoracic and thoracolumbar tSCI. A 1- or 2-grade improvement in the ASIA scale does not necessarily result in functional recovery.

Conclusion: In complete tSCI, the level of injury as well as surgical timing affect neurological recovery. There appears to be a beneficial effect of early surgical decompression in patients with complete cervical tSCI, more so than for thoracic and thoracolumbar tSCI. Frequently, the effect of surgical intervention is evaluated by an improvement in ASIA grade, but it is unclear whether this scale is sensitive enough to evaluate meaningful effectiveness of the intervention and desired outcome for patients with tSCI.

Keywords

spinal cord injuries, surgical decompression, spinal fusion, outcome assessment, complete spinal cord injury

Introduction

Traumatic spinal cord injury (tSCI) is a devastating event that can lead to death or lifelong disability. Since it usually occurs in younger individuals, the loss of productive life years has an enormous economic and social impact. The annual incidence is estimated at 10.4 to 83 cases per million per year, with wide variations between regions and countries.^{1,2} The cervical spinal cord is the most commonly affected level, followed by the thoracic and lumbar.³ Around 30% to 55% of patients with tSCI will present with complete neurological injury.^{1,3-6} In particular, younger individuals more often present with complete tSCI compared to older patients.¹

Surgical intervention aims to restore the mechanical integrity of the spinal column, as well as to potentiate neurological

recovery. The neurological outcome is affected by the initial severity, as well as the level, of neurological injury.⁷⁻¹⁰ Nevertheless, current guidelines recommend performing surgical decompression in tSCI within 24 hours, regardless of the level and severity of injury.¹¹ Although these guidelines are based on

¹ VU University Medical Center, Amsterdam, Netherlands

² Leiden University Medical Center, Leiden, Netherlands

³ University Medical Center Utrecht, Utrecht, Netherlands

⁴ Academic Medical Center, Amsterdam, Netherlands

Corresponding Author:

Paula Valerie ter Wengel, De Boelelaan 1117, Amsterdam 1081 HV, Netherlands.

Email: valerieterwengel@hotmail.com



Creative Commons Non Commercial No Derivs CC BY-NC-ND: This article is distributed under the terms of the Creative Commons Attribution-Non Commercial-NoDerivs 4.0 License (<https://creativecommons.org/licenses/by-nc-nd/4.0/>) which permits non-commercial use, reproduction and distribution of the work as published without adaptation or alteration, without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

Table 1. The Natural Neurological Recovery Patterns in Complete tSCI.^{9,22,23,44}

		Percentage of ASIA Conversion 1 Year After Trauma				
	Baseline ASIA	A	B	C	D	E
Cervical tSCI	A	70.2-70.9	12.5-14.6	8.0-9.4	4.5-7.2	0
Thoracic tSCI	A	84.1-87.4	4.1-5.9	4.4-7.9	0-4.8	0
Thoracolumbar tSCI	A	70.8	15.3	5.6	6.3-8.3	0

Abbreviations: ASIA, American Spinal Injury Association; tSCI, traumatic spinal cord injury.

the results of studies including both patients with complete and incomplete tSCI,¹²⁻¹⁵ in daily practice a distinction in surgical urgency is usually still made on the basis of the severity of initial neurological injury, such that patients with incomplete tSCI are treated more urgently than patients with complete tSCI.¹⁶⁻²⁴

This study reviews the current body of evidence on level of injury and timing of surgical intervention in tSCI patients with a complete lack of motor and sensory function below the level of injury and no preservation of the sacral segments (ie, grade A on the ASIA [American Spinal Injury Association] Impairment Scale [AIS]).

Cervical tSCI

Natural History

Approximately 17.3% to 34.0% of patients with cervical tSCI will present with a complete injury.^{20,21} In polytrauma patients with cervical spine injuries, the incidence of complete tSCI is much higher—65.4%.³ After 1 year, patients with an initial ASIA A injury will remain ASIA A in 70.2% to 70.9% of the cases, implying that approximately 30% will show some signs of recovery. Around 12.5% to 14.6% will improve to ASIA B, 8.0% to 9.4% to ASIA C, 4.5% to 7.2% to ASIA D, and 0% to ASIA E (Table 1).^{9,22,23} In contrast, patients with incomplete tSCI have a much higher spontaneous recovery compared with complete tSCI (Supplement 1, available online).²⁷ Motor recovery is evaluated for each muscle group below the level of injury and calculated into a motor score (ranging from 0 to 5 per muscle group) according to ASIA standards.²⁴ Patients with complete cervical tSCI show a mean recovery of 9.0 to 14 motor score points below the level of injury 1 year after injury.^{9,22,25,26} Neurological recovery most commonly occurs within the first 3 months and will enter a plateau phase thereafter.⁹ However, 9.1% of the patients who have not recovered the first year postinjury can still exhibit some neurological recovery even 5 years after injury.²⁷

Impact of Timing of Surgical Intervention

The majority of studies in patients with cervical tSCI have investigated the effect of early surgery in cohorts with complete and incomplete tSCI (Table 2).^{12,28-40} Two studies have investigated the effect of surgery in patients with complete tSCI.^{41,42} Bourassa-Moreau et al addressed the effect of surgical timing in patients with complete tSCI and observed a

significant ($P = .008$) benefit of surgical decompression within 24 hours on ≥ 1 ASIA grade improvement.⁴¹ Nine (64.3%) out of 14 patients in the early group improved at least one grade, compared to none out of 6 in the late group. Another study by Hansebout and Hansebout in 20 complete tSCI patients evaluated the effect of early surgical decompression in combination with perioperative regional epidural cooling within 8 hours of injury.⁴² Fourteen of these patients had cervical injuries. Nine (64.3%) out of 14 patients with complete cervical tSCI improved at least one ASIA grade.

A recent meta-analysis demonstrated a significant beneficial effect of early surgery within 24 hours in patients with complete cervical tSCI.⁴³ In 422 patients with complete cervical tSCI, the impact of surgical timing on neurological recovery was investigated. An increase of ≥ 2 ASIA grades was regarded as successful. Improvement in the early surgery group was 22.6% (95% confidence interval [CI] = 16.6% to 28.7% in 248 patients from 11 studies) compared to 10.4% (95% CI = 5.6% to 15.8% in 174 patients from 6 studies) in the late surgery group. The odds ratio for neurological improvement of early versus late surgery with complete cervical tSCI was 2.6 (95% CI = 1.4 to 5.1).⁴³ This result would indicate a paradigm shift in the surgical treatment of patients with traumatic cervical spinal cord injury in the sense that patients with complete tSCI should not be treated less urgently than patients with incomplete tSCI.

Thoracic tSCI

Natural History

Approximately 16.2% to 73.0% of patients with thoracic tSCI will present with complete neurological injury.^{20,21} In polytrauma patients with thoracic injuries, the incidence of complete tSCI is much higher—69.4%.³ Within 1 year (Table 1), 10.7% to 18.6% of the patients with an initial ASIA A injury will improve ≥ 1 ASIA grade compared with 84.6% in patients with an initial ASIA B injury.^{9,23,44} The mean motor point recovery in thoracic tSCI is 0.1 to 4.5 one year after injury, which is substantially less than in cervical or thoracolumbar tSCI.^{9,26,44} Patients with thoracic tSCI who remained ASIA A 1 year after injury can still show neurological recovery up till 5 years in 3.6%.²⁷

Impact of Timing of Surgical Intervention

The impact of early surgery in patients with thoracic tSCI is less clear, and therefore, urgent surgery in patients with

Table 2. Neurological Recovery After Early (<24 Hours) or Late (>24 Hours) Surgery in Cervical tSCI.

					Percentage of ASIA Conversion in Follow-up				
	Follow-up Mean	Age Mean ^a	Number of Patients With Baseline ASIA A		A	B	C	D	E
Early and late studies									
Fehlings ¹²	6 months ^b	45	Early	44	56.8	25.0	13.6	4.5	0
		50.7	Late	27	63.0	25.9	11.1	0	0
Levi ³²	11.4 months	25.5	Early	21	23.8	52.4	19.0	4.8	0
		27	Late	14	57.1	14.3	7.1	21.4	0
Umerani ³⁹	6 months ^b	37.5	Early	11	54.5	18.2	18.2	9.1	0
		40.1	Late	18	77.8	11.1	5.6	5.6	0
Newton ³⁵	3-6 months	22	Early	24	58.3	12.5	4.2	4.2	20.8
			Late	8	100	0	0	0	0
Randle ³⁸	10.8 months	28.9	Early	20	50.0	35.0	15.0	0	0
		29.4	Late	12	75.0	16.7	0	8.3	0
Bourassa ⁴¹	163.2 days	37.3	Early	14	35.7	35.7	7.1	21.4	0
		47.1	Late	6	100	0	0	0	0
Cotler ²⁹	19.7 months	n.a.	Early	7	57.1	0	28.6	14.3	0
			Late	4	0	100	0	0	0
Late studies									
Liu ³³	24.9 months	41.9	Late	66	63.6	24.2	10.6	1.5	0
Benzel ²⁸	2-3 months ^c	n.a.	Late	35	100	0	0	0	0
Early studies									
Papadopoulos ³⁶	31.6 months	32	Early	38	44.7	34.2	13.2	7.9	0
Jug ³¹	6 months	n.a.	Early	26	65.4	19.2	3.8	11.5	0
Shen ⁴⁰	3.1 years	39.9	Early	2	50	50	0	0	0
Mattiassich ³⁴	2.6 years	50	Early	20	50.0	25.0	15.0	10.0	0
Hansebout ⁴²	55.2 months	22.6	Early	14	35.7	35.7	21.4	7.1	0
Grassner ³⁰	12 months ^d	51.9	Early	14	28.6	35.7	7.1	28.6	0

Abbreviations: ASIA, American Spinal Injury Association; tSCI, traumatic spinal cord injury.

^aMean age for the cohort (including complete and incomplete tSCI patients).

^bAll patients had at least 6 months of follow-up.

^cAll patients had at least 2 to 3 months of follow-up.

^dAll patients had at least 12 months of follow-up.

complete thoracic tSCI is still a subject of debate.^{41,45-50} Most studies on neurological outcome include patients with both complete and incomplete thoracic and thoracolumbar tSCI (Table 3).^{13,16,41,51,52} Two studies evaluated the effect of surgical timing in thoracic tSCI specifically.^{52,53} One study in 12 complete thoracic tSCI patients evaluated the efficacy of surgery.⁵³ Two patients had an undocumented surgical timing, one was decompressed in 1 day and 9 had surgical decompression between 2 to 36 days after injury. Only 2 (16.7%) patients improved neurologically. One patient who underwent surgery at 2 days improved to ASIA C, another patient underwent surgery at 25 days and improved to ASIA B. The second study evaluated the neurological recovery after surgery within 24 hours in 8 patients with thoracic tSCI (T4-T9).⁵² After 1 year, 2 (37.5%) improved to ASIA B and 1 to ASIA D.

description of the level of spinal injury for conus medullaris and cauda equina injury.⁵⁵ Studies have described medullary injury from T8-L2 and cauda equina injury caudal from L1-L2.^{55,56} Conus medullaris syndrome (CMS) and cauda equina syndrome (CES) may be difficult to distinguish. CMS is often defined by a symmetric sensory deficits, paralytic bladder incontinence, bowel incontinence, and mild lower extremity weakness. CES is often characterized by asymmetric sensory-motor deficits. Approximately 21.0% of patients will present with a complete lack of motor and sensory function below the level of injury.²¹ The rate of neurological recovery in thoracolumbar tSCI is similar to the recovery in complete cervical tSCI (Table 1).⁴⁴ After 1 year, patients will have a median recovery of 3.6 to 5.3 motor score points below the level of injury.^{26,44}

Thoracolumbar tSCI

Natural History

Isolated conus medullaris injury from thoracolumbar fractures without concomitant dysfunction of the cauda equina is rare.⁵⁴ There is a variance in the literature regarding the

Impact of Timing of Surgical Intervention

There is paucity of literature concerning the surgical timing and neurological outcome in patients with conus medullaris (CM) and cauda equina (CE) injury (Table 3).^{52,56-60} Although the natural course of conus medullaris injury differs considerably

Table 3. Neurological Recovery After Early (<24 Hours) or Late (>24 Hours) Surgery in Thoracic and Thoracolumbar tSCI.

	Follow-up Mean	Mean Age ^a	Level of Injury	Number of Patients With Baseline ASIA A	Percentage of ASIA Conversion in Follow-up					
					A	B	C	D	E	
Thoracic										
Rahimi ⁵³	47.9 months	40.4	Early	T5-T11	1	100	0	0	0	0
			Late	T5-T11	9	77.8	11.1	11.1	0	0
Dobran ⁵²	12 months ^b	47.5	Early	T4-9	8	62.5	25.0	0	12.5	0
Rahimi ¹³	12 months ^b	31.7	Early	T5-T12	7	80.0	20.0	0	0	0
		37.8	Late	T5-T12	9	88.9	11.1	0	0	0
Thoracic and thoracolumbar										
Wiberg ¹⁶	8 months to 6 years	29	Early	T4-L1	2	0	50.0	50.0	0	0
			Late	T4-L1	4	100	0	0	0	0
Bourassa-Moreau ⁴¹	145.8 days	40.9	Early	T2-L2	24	83.3	8.3	0	8.3	0
		51.2	Late	T2-L2	9	77.8	0	11.1	11.1	0
Ramirez-Villaescusa ⁵¹	>2 years	36.8	Early	T1-L2	2	100	0	0	0	0
Thoracolumbar										
Cengiz ⁵⁶	14.5 months	39.7	Early	T8-L2	6	33.3	16.7	16.7	33.3	0
		41.4	Late	T8-L2	7	85.7	14.3	0		0
Rath ⁵⁸	14.2 months	44.3	Early	T10-L1	3	0	0	66.7	33.3	0
			Late	T12	3	100	0	0	0	0
Dobran ⁵²	12 months ^b	47.5	Early	T10-L2	8	62.5	12.5	25.0	0	0
			Early	L1-S1	1	100	0	0	0	0
Rahimi ⁵⁷	32 months	32.3	Early	T12-L2	2	0	0	100	0	0
		23.6	Late	T12-L1	11	27.3	0	45.5	18.2	9.1
Payer ⁶⁰	24 months	36	Early	T11-L2	6	16.7	16.7	16.7	50	0
Clohisy ⁵⁹	42 months	36.3	Late	T12	1	0	0	0	100	0

Abbreviations: ASIA, American Spinal Injury Association; tSCI, traumatic spinal cord injury.

^aMean age for the cohort (including complete and incomplete tSCI patients).^bAll patients had at least 12 months of follow-up.

from higher thoracic spinal cord injury, a large number of studies are based on cohorts containing both thoracic and thoracolumbar tSCI patients.^{41,56,58,61} Evidence for optimal surgical timing in cauda equina injury is primarily based on lumbar disc herniation series.⁶² However, 3 studies did specifically evaluate thoracolumbar tSCI.^{52,57,60} One study in patients with thoracolumbar tSCI evaluated the effect of surgery within 8 hours.⁶⁰ Five (83.3%) of 6 patients with complete (ASIA A) thoracolumbar tSCI improved neurologically: 1 improved to ASIA B, 1 to ASIA C, and 3 to ASIA D. Another study in patients with thoracolumbar tSCI evaluated the efficacy of surgery.⁵⁷ There were 17 patients who had complete thoracolumbar tSCI, 4 of whom had undocumented surgical timing, 2 were decompressed within 24 hours, and 11 had surgical decompression after 24 hours. Both patients who underwent surgery within 24 hours improved from an ASIA A to an ASIA C at follow-up. Eight (72.7%) patients who underwent surgery after 24 hours improved neurologically: 5 improved to ASIA C, 2 to ASIA D, and 1 to ASIA E. The third study evaluated neurological recovery when patients underwent surgery within 24 hours.⁵² Eight patients had thoracolumbar tSCI (T10-T12). Three (37.5%) patients with thoracolumbar tSCI improved neurologically after 1 year: 1 to an ASIA B and 2 to ASIA C.

Severity of Injury and Interpretation of Recovery

The severity of injury is generally categorized according to international standards for neurological classification of spinal cord injury of the American Spine Injury Association in conjunction with the International Spinal Cord Society: the ASIA Impairment Scale (AIS).²⁴ The consistency of the initial neurological assessment in patients with complete tSCI depends on numerous factors hampering its reliability.⁶³ Such factors include closed head injury, drug effects, language barriers, psychological disorders, or ventilator dependency. Burns et al assessed the consistency of the ASIA scale in the acute phase directly after injury and on reexamination within 7 days after injury. When an initial neurological examination was performed reliably, that is, without any of the aforementioned factors, and showed ASIA grade A, only 1 (2.6%) of 38 patients converted to ASIA B on reevaluation within 7 days. When there was concern regarding the reliability of the initial examination, 4 (9.3%) of 43 patients converted to ASIA B on reexamination within 7 days.⁶³ In contrast, 2 (15.4%) of 13 patients with an initially reliable ASIA B improved to ASIA C on reexamination within 7 days and 1 (7.7%) to ASIA D. In patients where the initial ASIA B was unreliable at first

examination, none improved within the first week after injury. Thus 5 (6.2%) of all 81 patients with ASIA A at initial examination converted to ASIA B, whereas 3 (13.6%) of 22 patients with ASIA B at presentation improved ≥ 1 ASIA grade. When evaluating the effect of any intervention in patients with tSCI it is important to distinguish whether the initial neurological assessment was performed reliably, since this can affect the rate of spontaneous neurological improvement.

The effect of surgical timing is often evaluated with improvement by either 1 or 2 ASIA grades.^{12,33,41,56,64} An improvement in ASIA grade is considered to be a clinically meaningful outcome in evaluating the effect of surgical interventions in patients with tSCI.^{12,43} It is, however, unknown whether this improvement in ASIA grade translates to meaningful functional recovery and thus what this increase means in regard to a patient's quality of life.⁶⁵ Therefore, the question arises whether the ASIA classification is sensitive enough to capture the functional meaningful improvement for patients with tSCI. Several studies show that regaining the ability to walk is the greatest desirable outcome in patients with tSCI, followed by self-care, enhanced mobility, independent transfers, and sphincter management.⁶⁶⁻⁷⁰ However, an improvement in ASIA grade does not ensure the ability to walk. One study in patients with cervical and thoracic tSCI evaluated the relation of ASIA conversion and the ability to walk.⁷¹ From the 161 ASIA A patients, 23 improved to ASIA B, 9 to ASIA C, and 10 to ASIA D. Only 6 patients regained the ability to walk, all of which improved to ASIA D.⁷¹ In addition, the priorities of neurological improvement differ for patients with tetraplegia and paraplegia. Patients with paraplegia have a higher priority of regaining locomotion and sexual function compared to patients with tetraplegia.^{66,70} Conversely, patients with tetraplegia have a high priority of regaining hand function, which does not necessarily has to coincide with an improvement in ASIA grade but could also occur with a decrease in the level of injury. Future studies should not only focus on an improvement in ASIA scale but also on lowering of tSCI level and its perceived effect on meaningful recovery in tSCI patients.

Conclusion

There appear to be different patterns for spontaneous recovery in cervical, thoracic, and thoracolumbar tSCI. To promote neurological recovery, surgical decompression of the spinal cord within 24 hours seems particularly beneficial in patients with complete cervical tSCI. This effect is less clear for patients with thoracic and thoracolumbar tSCI. The efficacy of surgical timing in tSCI is often evaluated with an improvement in ASIA grade. It is important to evaluate the reliability of the first neurological examination, since this can affect the spontaneous neurological improvement within the first week after injury. The effect of ASIA grade improvement on meaningful neurological recovery remains unclear.

Acknowledgments

We would like to thank E. Martin and Ir. G. E. Sierra Vargas for their constructive support and cooperation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Paula Valerie ter Wengel, MD  <https://orcid.org/0000-0003-1073-8239>

Supplemental Material

The supplemental material is available in the online version of the article.

References

1. Thompson C, Mutch J, Parent S, Mac-Thiong JM. The changing demographics of traumatic spinal cord injury: an 11-year study of 831 patients. *J Spinal Cord Med.* 2015;38:214-223. doi:10.1179/2045772314Y.0000000233
2. van den Berg MEL, Castellote JM, Mahillo-Fernandez I, de Pedro-Cuesta J. Incidence of spinal cord injury worldwide: a systematic review. *Neuroepidemiology.* 2010;34:184-192. doi:10.1159/000279335
3. Stephan K, Huber S, Häberle S, et al; TraumaRegister DGU. Spinal cord injury—incidence, prognosis, and outcome: an analysis of the TraumaRegister DGU. *Spine J.* 2015;15:1994-2001. doi:10.1016/j.spinee.2015.04.041
4. Devivo MJ. Epidemiology of traumatic spinal cord injury: trends and future implications. *Spinal Cord.* 2012;50:365-372. doi:10.1038/sc.2011.178
5. Chen Y, He Y, DeVivo MJ. Changing demographics and injury profile of new traumatic spinal cord injuries in the United States, 1972-2014. *Arch Phys Med Rehabil.* 2016;97:1610-1619. doi:10.1016/j.apmr.2016.03.017
6. McCaughey EJ, Purcell M, Mclean AN, et al. Changing demographics of spinal cord injury over a 20-year period: a longitudinal population-based study in Scotland. *Spinal Cord.* 2016;54:270-276. doi:10.1038/sc.2015.167
7. Wilson JR, Cadotte DW, Fehlings MG. Clinical predictors of neurological outcome, functional status, and survival after traumatic spinal cord injury: a systematic review. *J Neurosurg Spine.* 2012;17(suppl 1):11-26. doi:10.3171/2012.4.AOSpine1245
8. El Tecle NE, Dahdaleh NS, Bydon M, Ray WZ, Torner JC, Hitchon PW. The natural history of complete spinal cord injury: a pooled analysis of 1162 patients and a meta-analysis of modern data. *J Neurosurg Spine.* 2018;28:436-443. doi:10.3171/2017.7.SPINE17107
9. Fawcett JW, Curt A, Steeves JD, et al. Guidelines for the conduct of clinical trials for spinal cord injury as developed by the ICCP panel: spontaneous recovery after spinal cord injury and statistical

- power needed for therapeutic clinical trials. *Spinal Cord*. 2007;45: 190-205. doi:10.1038/sj.sc.3102007
10. Geisler FH, Coleman WP, Grieco G, Poonian D; Sygen Study Group. Measurements and recovery patterns in a multicenter study of acute spinal cord injury. *Spine (Phila Pa 1976)*. 2001; 26(24 suppl):S68-S86.
 11. Fehlings MG, Tetreault LA, Wilson JR, et al. A clinical practice guideline for the management of patients with acute spinal cord injury and central cord syndrome: recommendations on the timing (≤ 24 hours versus >24 hours) of decompressive surgery. *Glob Spine J*. 2017;7(3 suppl):195S-202S. doi:10.1177/2192568217706367
 12. Fehlings MG, Vaccaro A, Wilson JR, et al. Early versus delayed decompression for traumatic cervical spinal cord injury: results of the surgical timing in acute spinal cord injury study (STASCIS). *PLoS One*. 2012;7:e32037. doi:10.1371/journal.pone.0032037
 13. Rahimi-Movaghar V, Niakan A, Haghnegahdar A, Shahlaee A, Saadat S, Barzideh E. Early versus late surgical decompression for traumatic thoracic/thoracolumbar (T1-L1) spinal cord injured patients. Primary results of a randomized controlled trial at one year follow-up. *Neurosciences (Riyadh)*. 2014;19:183-191.
 14. Dvorak MF, Noonan VK, Fallah N, et al; RHSCIR Network. The influence of time from injury to surgery on motor recovery and length of hospital stay in acute traumatic spinal cord injury: an observational Canadian Cohort Study. *J Neurotrauma*. 2015;32: 645-654. doi:10.1089/neu.2014.3632
 15. Wilson JR, Singh A, Craven C, et al. Early versus late surgery for traumatic spinal cord injury: the results of a prospective Canadian cohort study. *Spinal Cord*. 2012;50:840-843. doi:10.1038/sc.2012.59
 16. Wiberg J, Hauge HN. Neurological outcome after surgery for thoracic and lumbar spine injuries. *Acta Neurochir (Wien)*. 1988;91:106-112.
 17. Agostinello J, Battistuzzo CR, Skeers P, Bernard S, Batchelor PE. Early spinal surgery following thoracolumbar spinal cord injury. *Spine (Phila Pa 1976)*. 2017;42: E617-E623. doi:10.1097/BRS.0000000000001903
 18. Ter Wengel PV, Feller RE, Stadhouder A, et al. Timing of surgery in traumatic spinal cord injury: a national, multidisciplinary survey. *Eur Spine J*. 2018;27:1831-1838. doi:10.1007/s00586-018-5551-y
 19. Werndle MC, Zoumprouli A, Sedgwick P, Papadopoulos MC. Variability in the treatment of acute spinal cord injury in the United Kingdom: results of a national survey. *J Neurotrauma*. 2012;29:880-888. doi:10.1089/neu.2011.2038
 20. Nijendijk JHB, Post MWM, van Asbeck FWA. Epidemiology of traumatic spinal cord injuries in the Netherlands in 2010. *Spinal Cord*. 2014;52:258-263. doi:10.1038/sc.2013.180
 21. Pickett GE, Campos-Benitez M, Keller JL, Duggal N. Epidemiology of traumatic spinal cord injury in Canada. *Spine (Phila Pa 1976)*. 2006;31:799-805. doi:10.1097/01.brs.0000207258.80129.03
 22. Marino RJ, Burns S, Graves DE, Leiby BE, Kirshblum S, Lammertse DP. Upper- and lower-extremity motor recovery after traumatic cervical spinal cord injury: an update from the national spinal cord injury database. *Arch Phys Med Rehabil*. 2011;92: 369-375. doi:10.1016/j.apmr.2010.09.027
 23. Zariffa J, Curt A; EMSCI Syudy Group, Steeves JD. Functional motor preservation below the level of injury in subjects with American Spinal Injury Association Impairment Scale grade A spinal cord injuries. *Arch Phys Med Rehabil*. 2012;93:905-907. doi:10.1016/j.apmr.2011.10.024
 24. Maynard FM Jr, Bracken MB, Creasey G, et al. International standards for neurological and functional classification of spinal cord injury. American Spinal Injury Association. *Spinal Cord*. 1997;35:266-274.
 25. Marino RJ, Ditunno JF Jr, Donovan WH, Maynard F Jr. Neurologic recovery after traumatic spinal cord injury: data from the Model Spinal Cord Injury Systems. *Arch Phys Med Rehabil*. 1999;80:1391-1396.
 26. Dvorak MF, Noonan VK, Fallah N, et al. Minimizing errors in acute traumatic spinal cord injury trials by acknowledging the heterogeneity of spinal cord anatomy and injury severity: an observational Canadian cohort analysis. *J Neurotrauma*. 2014; 31:1540-1547. doi:10.1089/neu.2013.3278
 27. Kirshblum S, Millis S, McKinley W, Tulskey D. Late neurologic recovery after traumatic spinal cord injury. *Arch Phys Med Rehabil*. 2004;85:1811-1817. doi:10.1016/j.apmr.2004.03.015
 28. Benzel EC, Larson SJ. Functional recovery after decompressive spine operation for cervical spine fractures. *Neurosurgery*. 1987; 20:742-746. doi:10.1097/00006123-198705000-00012
 29. Cotler JM, Herbison GJ, Nasuti JF, Ditunno JF Jr, An H, Wolff BE. Closed reduction of traumatic cervical spine dislocation using traction weights up to 140 pounds. *Spine (Phila Pa 1976)*. 1993; 18:386-390. doi:10.1097/00007632-199303000-00015
 30. Grassner L, Wutte C, Klein B, et al. Early decompression (<8 h) after traumatic cervical spinal cord injury improves functional outcome as assessed by spinal cord independence measure after one year. *J Neurotrauma*. 2016;33:1658-1666. doi:10.1089/neu.2015.4325
 31. Jug M, Kežar N, Vesel M, et al. Neurological recovery after traumatic cervical spinal cord injury is superior if surgical decompression and instrumented fusion are performed within 8 hours versus 8 to 24 hours after injury: a single center experience. *J Neurotrauma*. 2015;32:1385-1392. doi:10.1089/neu.2014.3767
 32. Levi L, Wolf A, Rigamonti D, Ragheb J, Mirvis S, Robinson W. Anterior decompression in cervical spine trauma: does the timing of surgery affect the outcome? *Neurosurgery*. 1991;29:216-222.
 33. Liu Y, Shi CG, Wang XW, et al. Timing of surgical decompression for traumatic cervical spinal cord injury. *Int Orthop*. 2015; 39:2457-2463. doi:10.1007/s00264-014-2652-z
 34. Mattiassich G, Gollwitzer M, Gaderer F, et al. Functional outcomes in individuals undergoing very early (<5 h) and early (5-24 h) surgical decompression in traumatic cervical spinal cord injury: analysis of neurological improvement from the Austrian Spinal Cord Injury Study. *J Neurotrauma*. 2017;34:3326-3371. doi:10.1089/neu.2017.5132
 35. Newton D, England M, Doll H, Gardner BP. The case for early treatment of dislocations of the cervical spine with cord involvement sustained playing rugby. *J Bone Joint Surg Br*. 2011;93: 1646-1652. doi:10.1302/0301-620X.93B12.27048

36. Papadopoulos SM, Selden NR, Quint DJ, Patel N, Gillespie B, Grube S. Immediate spinal cord decompression for cervical spinal cord injury: feasibility and outcome. *J Trauma*. 2002;52:323-332. doi:10.1097/00005373-200202000-00019
37. Payer M. Immediate open anterior reduction and antero-posterior fixation/fusion for bilateral cervical locked facets. *Acta Neurochir (Wien)*. 2005;147:509-514. doi:10.1007/s00701-004-0462-6
38. Randle MJ, Wolf A, Levi L, et al. The use of anterior Caspar plate fixation in acute cervical spine injury. *Surg Neurol*. 1991;36:181-189. doi:10.1016/0090-3019(91)90110-U
39. Umerani MS, Abbas A, Sharif S. Clinical outcome in patients with early versus delayed decompression in cervical spine trauma. *Asian Spine J*. 2014;8:427-434. doi:10.4184/asj.2014.8.4.427
40. Shen Y, Shen HL, Feng ML, Zhang WB. Immediate reduction under general anesthesia and single-staged anteroposterior spinal reconstruction for fracture-dislocation of lower cervical spine. *J Spinal Disord Tech*. 2015;28:E1-E8. doi:10.1097/BSD.0000000000000065
41. Bourassa-Moreau É, Mac-Thiong JM, Li A, et al. Do patients with complete spinal cord injury benefit from early surgical decompression? Analysis of neurological improvement in a prospective cohort study. *J Neurotrauma*. 2016;33:301-306. doi:10.1089/neu.2015.3957
42. Hansebout RR, Hansebout CR. Local cooling for traumatic spinal cord injury: outcomes in 20 patients and review of the literature. *J Neurosurg Spine*. 2014;20:550-561. doi:10.3171/2014.2.SPINE13318
43. Ter Wengel PV, De Witt Hamer PC, Pauptit JC, van der Gaag NA, Oner FC, Vandertop WP. Early surgical decompression improves neurological outcome after complete traumatic cervical spinal cord injury: a meta-analysis. *J Neurotrauma*. 2019;36:835-844. doi:10.1089/neu.2018.5974
44. Zariffa J, Kramer JLK, Fawcett JW, et al. Characterization of neurological recovery following traumatic sensorimotor complete thoracic spinal cord injury. *Spinal Cord*. 2011;49:463-471. doi:10.1038/sc.2010.140
45. Charles YP, Steib JP. Management of thoracolumbar spine fractures with neurologic disorder. *Orthop Traumatol Surg Res*. 2015;101:S31-S40. doi:10.1016/j.otsr.2014.06.024
46. Launay O, Charles YP, Steib JP. Should post-traumatic thoracolumbar Frankel A paraplegia be operated as an emergency? Report of three cases and review of the literature. *Orthop Traumatol Surg Res*. 2012;98:352-358. doi:10.1016/j.otsr.2011.08.019
47. Vaccaro AR, Lim MR, Hurlbert RJ, et al. Surgical decision making for unstable thoracolumbar spine injuries: results of a consensus panel review by the Spine Trauma Study Group. *J Spinal Disord Tech*. 2006;19:1-10. doi:10.1097/01.bsd.0000180080.59559.45
48. Rutges JPHJ, Oner FC, Leenen LPH. Timing of thoracic and lumbar fracture fixation in spinal injuries: a systematic review of neurological and clinical outcome. *Eur Spine J*. 2007;16:579-587. doi:10.1007/s00586-006-0224-7
49. Kato S, Murray JC, Kwon BK, Schroeder GD, Vaccaro AR, Fehlings MG. Does surgical intervention or timing of surgery have an effect on neurological recovery in the setting of a thoracolumbar burst fracture? *J Orthop Trauma*. 2017;31(suppl 4):S38-S43. doi:10.1097/BOT.0000000000000946
50. Eichholz KM, Rabb CH, Anderson PA, et al. Congress of neurological surgeons systematic review and evidence-based guidelines on the evaluation and treatment of patients with thoracolumbar spine trauma: timing of surgical intervention. *Neurosurgery*. 2019;84:E35-E55. doi:10.1093/neuros/nyy362
51. Ramírez-Villaescusa J, Hidalgo JLT, Ruiz-Picazo D, Martin-Benlloch A, Torres-Lozano P, Portero-Martinez E. The impact of urgent intervention on the neurologic recovery in patients with thoracolumbar fractures. *J Spine Surg*. 2018;4:388-396. doi:10.21037/jss.2018.06.07
52. Dobran M, Iacoangeli M, Di Somma LG, et al. Neurological outcome in a series of 58 patients operated for traumatic thoracolumbar spinal cord injuries. *Surg Neurol Int*. 2014;5(Suppl 7):S329-S332. doi:10.4103/2152-7806.139645
53. Rahimi-Movaghar V. Efficacy of surgical decompression in the setting of complete thoracic spinal cord injury. *J Spinal Cord Med*. 2005;28:415-420. doi:10.1080/10790268.2005.11753841
54. Doherty JG, Burns AS, O'Ferrall DM, Ditunno JF Jr. Prevalence of upper motor neuron vs lower motor neuron lesions in complete lower thoracic and lumbar spinal cord injuries. *J Spinal Cord Med*. 2002;25:289-292. doi:10.1080/10790268.2002.11753630
55. Brouwers E, van de Meent H, Curt A, Starremans B, Hosman A, Bartels R. Definitions of traumatic conus medullaris and cauda equina syndrome: a systematic literature review. *Spinal Cord*. 2017;55:886-890. doi:10.1038/sc.2017.54
56. Cengiz ŞL, Kalkan E, Bayir A, Ilik K, Basefer A. Timing of thoracolumbar spine stabilization in trauma patients; impact on neurological outcome and clinical course. A real prospective (RCT) randomized controlled study. *Arch Orthop Trauma Surg*. 2008;128:959-966. doi:10.1007/s00402-007-0518-1
57. Rahimi-Movaghar V, Vaccaro AR, Mohammadi M. Efficacy of surgical decompression in regard to motor recovery in the setting of conus medullaris injury. *J Spinal Cord Med*. 2006;29:32-38. doi:10.1080/10790268.2006.11753854
58. Rath SA, Kahamba JF, Kretschmer T, Neff U, Richter HP, Antoniadis G. Neurological recovery and its influencing factors in thoracic and lumbar spine fractures after surgical decompression and stabilization. *Neurosurg Rev*. 2005;28:44-52. doi:10.1007/s10143-004-0356-3
59. Clohisy JC, Akbarnia BA, Bucholz RD, Burkus JK, Backer RJ. Neurologic recovery associated with anterior decompression of spine fractures at the thoracolumbar junction (T12-L1). *Spine (Phila Pa 1976)*. 1992;17(8 suppl):S325-S330. doi:10.1097/00007632-199208001-00019
60. Payer M. Unstable burst fractures of the thoraco-lumbar junction: treatment by posterior bisegmental correction/fixation and staged anterior corpectomy and titanium cage implantation. *Acta Neurochir (Wien)*. 2006;148:299-306. doi:10.1007/s00701-005-0681-5
61. Wang L, Li J, Wang H, et al. Posterior short segment pedicle screw fixation and TLIF for the treatment of unstable thoracolumbar/lumbar fracture. *BMC Musculoskelet Disord*. 2014;15:40. doi:10.1186/1471-2474-15-40

62. Radcliff KE, Kepler CK, Delasotta LA, et al. Current management review of thoracolumbar cord syndromes. *Spine J*. 2011;11:884-892. doi:10.1016/j.spinee.2011.07.022
63. Burns AS, Lee BS, Ditunno JF Jr, Tessler A. Patient selection for clinical trials: the reliability of the early spinal cord injury examination. *J Neurotrauma*. 2003;20:477-482. doi:10.1089/089771503765355540
64. Du JP, Fan Y, Liu JJ, et al. Decompression for traumatic thoracic/thoracolumbar incomplete spinal cord injury: application of AO Spine Injury Classification System to identify the timing of operation. *World Neurosurg*. 2018;116:e867-e873. doi:10.1016/j.wneu.2018.05.118
65. Wu X, Liu J, Tanadini LG, et al. Challenges for defining minimal clinically important difference (MCID) after spinal cord injury. *Spinal Cord*. 2015;53:84-91. doi:10.1038/sc.2014.232
66. Anderson KD. Targeting recovery: priorities of the spinal cord-injured population. *J Neurotrauma*. 2004;21:1371-1383. doi:10.1089/neu.2004.21.1371
67. Donnelly C, Eng JJ, Hall J, et al. Client-centered assessment and the identification of meaningful treatment goals for individuals with a spinal cord injury. *Spinal Cord*. 2004;42:302-307. doi:10.1038/sj.sc.3101589
68. Estores IM. The consumers perspective and the professional literature: what do persons with spinal cord injury want? *J Rehabil Res Dev*. 2003;40(4 suppl 1):93-98. doi:10.1682/JRRD.2003.08.0093
69. Goulet J, Richard-Denis A, Thompson C, Mac-Thiong JM. Relationships between specific functional abilities and health-related quality of life in chronic traumatic spinal cord injury. *Am J Phys Med Rehabil*. 2019;98:14-19. doi:10.1097/PHM.0000000000001006
70. Ditunno PL, Patrick M, Stineman M, Ditunno JF. Who wants to walk? Preferences for recovery after SCI: a longitudinal and cross-sectional study. *Spinal Cord*. 2008;46:500-506. doi:10.1038/sj.sc.3102172
71. van Middendorp JJ, Hosman AJF, Pouw MH; EM-SCI Study Group. Van de Meent H. ASIA impairment scale conversion in traumatic SCI: is it related with the ability to walk? A descriptive comparison with functional ambulation outcome measures in 273 patients. *Spinal Cord*. 2009;47:555-560. doi:10.1038/sc.2008.162