The Spine Journal 19 (2019) 687−694

THE SPINE JOURNAL

Clinical Study

The impact of stenosis and translation on spinal cord injuries in traumatic cervical facet dislocations

David M. Glassman, MD[a,*], Erik Magnusson, MD[b], Julie Agel, MA[b], Carlo Bellabarba, MD[b], Richard J. Bransford, MD[b]

[a] Orthopaedic Department, Naval Medical Center, 34800 Bob Wilson Drive, San Diego, CA 92134, USA

[b] Department of Orthopaedic Surgery and Sports Medicine, Harborview Medical Center, 325 Ninth Avenue, Box 359798, Seattle, WA 98104, USA

Received 29 January 2018; revised 21 October 2018; accepted 22 October 2018

Abstract

BACKGROUND CONTEXT: Although facet dislocations account for only 6% of cervical trauma, the consequences are often devastating. Cervical facet dislocations are associated with a disproportionate amount of spinal cord injuries; however, neurologic examination of patients is often difficult, as patients commonly present with reduced levels of consciousness. There are limited studies that have investigated the impact of spinal canal diameter and translation on neurologic injury following facet dislocations.

PURPOSE: Review a consecutive series of patients with facet dislocations to assess the impact of sagittal diameter and translation on Spinal Cord Injury (SCI).

STUDY DESIGN: Retrospective review at a level I trauma center identified 97 patients with facet dislocations.

METHODS: Between 2004 and 2014, a retrospective review at a level I trauma center identified patients with traumatic facet dislocation. Demographic data, neurologic exams, and radiographic findings were reviewed. We assessed sagittal diameter at the injury level, as well as above and below, and translation. This study has no funding source and its authors have no potential conflicts of interest-associated biases.

RESULTS: Ninety-seven patients presented with facet dislocations. Fifty-nine (61%) presented with a SCI. Those with ASIA A averaged 8.0 mm of injury level canal diameter, and ASIA E averaged 12.6 mm ($p < .001$). Additionally, those with ASIA A averaged 8.0 mm of translation, and ASIA E averaged 4.2 mm ($p < 0.001$). Two groups were created based on their general motor function. Those with ASIA A−C averaged 8.4 mm of injury level canal diameter, and ASIA D−E averaged 12.3 mm ($p < .001$). Those with ASIA A−C averaged 7.8 mm of translation, and ASIA D−E averaged 4.4 mm ($p < .001$). Receiver operating characteristic (ROC) curves demonstrated that translation was a good predictor of ASIA A−C and canal diameter was an almost perfect predictor of ASIA D−E.

CONCLUSIONS: Our data indicate that patients with greater translation and/or a smaller canal diameter at the injury level have a higher rate of SCI. Adjacent canal diameter did not correlate with neurologic injury. Published by Elsevier Inc.

Keywords: Cervical facet dislocation; Diagnostic imaging; Recovery of function/prognosis; Spinal canal diameter/translation; Spinal canal stenosis; Spinal cord injury.

FDA device/drug status: Not applicable.

Author disclosures: ***DMG:*** Nothing to disclose. ***EM:*** Nothing to disclose. ***JA:*** Nothing to disclose. ***CB:*** Nothing to disclose. ***RJB:*** Fellowship Support: AO Spine (E, Paid directly to institution/employer), Depuy Synthes (E, Paid directly to institution/employer); Speaking and/or Teaching Arrangements: AOSpine North America (B), Globus (B).

* Corresponding author. Orthopaedic Department, Naval Medical Center, 34800 Bob Wilson Drive, San Diego, CA 92134, USA. Tel.: 858-229-3816.

E-mail addresses: david.m.glassman.mil@mail.mil (D.M. Glassman), rbransfo@uw.edu (R.J. Bransford).

https://doi.org/10.1016/j.spinee.2018.10.015
1529-9430/Published by Elsevier Inc.

Introduction

Cervical facet dislocations represent about 6% of cervical spine fractures. There is a bimodal distribution. Younger patients present after high-energy mechanisms of injury, and older patients present after low-energy mechanisms of injury [1,2]. Cervical facet dislocations are associated with a disproportionate amount of spinal cord injuries; however, neurologic examination is often difficult, as patients commonly present with reduced levels of consciousness. The neurologic deficits seen after such injuries are thought to be attributable to the narrow cervical spinal canal and resultant compression of the spinal cord by the dislocated and anteriorly translated superior vertebral body [3,4]. Seventy-five percent of all cervical spine dislocations occur between C3 and C7, with the highest incidence at C5−6 [5].

There are limited studies that have investigated the impact of spinal canal diameter and translation on neurologic injury following facet dislocations. Previous studies investigated the impact of lateral canal diameter and Torg ratio [6] on neurologic outcomes in patients with cervical spine fractures and dislocations [7−9]. Another study investigated the role of anterior vertebral translation on clinical outcomes following cervical facet dislocations [10]. These studies used lateral cervical spine radiographs and included small cohorts of heterogeneous patient populations.

The purpose of this study was to investigate the impact of sagittal canal diameter and vertebral body translation on neurologic injuries following cervical facet dislocations using CT imaging. We hypothesized that the amount of residual canal diameter and vertebral body anterolisthesis would correlate with neurologic injury. We also hypothesized that smaller preinjury cervical canal diameter would correlate with greater neurologic injury.

Materials and methods

After obtaining Institutional IRB approval, we retrospectively identified all patients presenting to a level 1 trauma center with unilateral or bilateral cervical facet dislocations between 2004 and 2014. All patients with a prereduction cervical spine CT scan were included in our analysis. We excluded four patients who presented with facet dislocations associated with ankylosing spondylitis or diffuse idiopathic skeletal hyperostosis. We also excluded patients in

Fig. 1. Illustration demonstrating the technique to measure canal diameter at the injury level using midsagittal CT reconstruction. Canal diameters were measured posteriorly from the vertebral body perpendicular to the spinolaminar line. Line A, above the injury level. Line B, at the injury level. Line C, below the injury level. Line D, spinolaminar level. This was assessed with cross-reference to the axial CT cut.

which the mechanism was more consistent with an extension-translation type injury.

Patient demographic data including age, gender, and mechanism of injury were gathered from the medical record. We recorded the initial neurologic exam as an American Spinal Injury Association (ASIA) grade, which was determined in accordance with the International Standards for Neurological Classification of Spinal Cord Injury. Orthopedic surgery residents performed this examination, which was verified by an orthopedic spine fellow and an orthopedic spine attending. Fracture-specific data were also collected and included the following: level of facet dislocation, unilateral vs. bilateral facet dislocation, and presence of facet fractures.

Residual canal diameter at the level of injury and amount of anterolisthesis was measured on immediate post-injury and prereduction cervical CT scans. Canal diameter was measured on the midsagittal CT reconstructions. Canal diameter at the injury level was measured from the posterior superior body of the caudal vertebral body perpendicular to the spinolaminar line (Fig. 1). The canal diameters of adjacent levels were measured from the mid-vertebral body to the spinolaminar line.

Anterior translation was measured from the midsagittal CT reconstruction for bilateral and unilateral dislocations. Anterior translation was measured from a line indicating the posterior aspect of the dislocated vertebral body to the posterior margin of the adjacent caudal vertebral body (Fig. 2). All measurements were recorded by an orthopedic spine attending, orthopedic spine fellow, and an orthopedic surgery resident. All analyses were completed using the average of these measures.

There may be benefit from measurements done on both CT and MRI imaging. This study focuses on CT to compare prereduction measurements. Though controversial, MRI scans are not always performed prior to closed reduction.

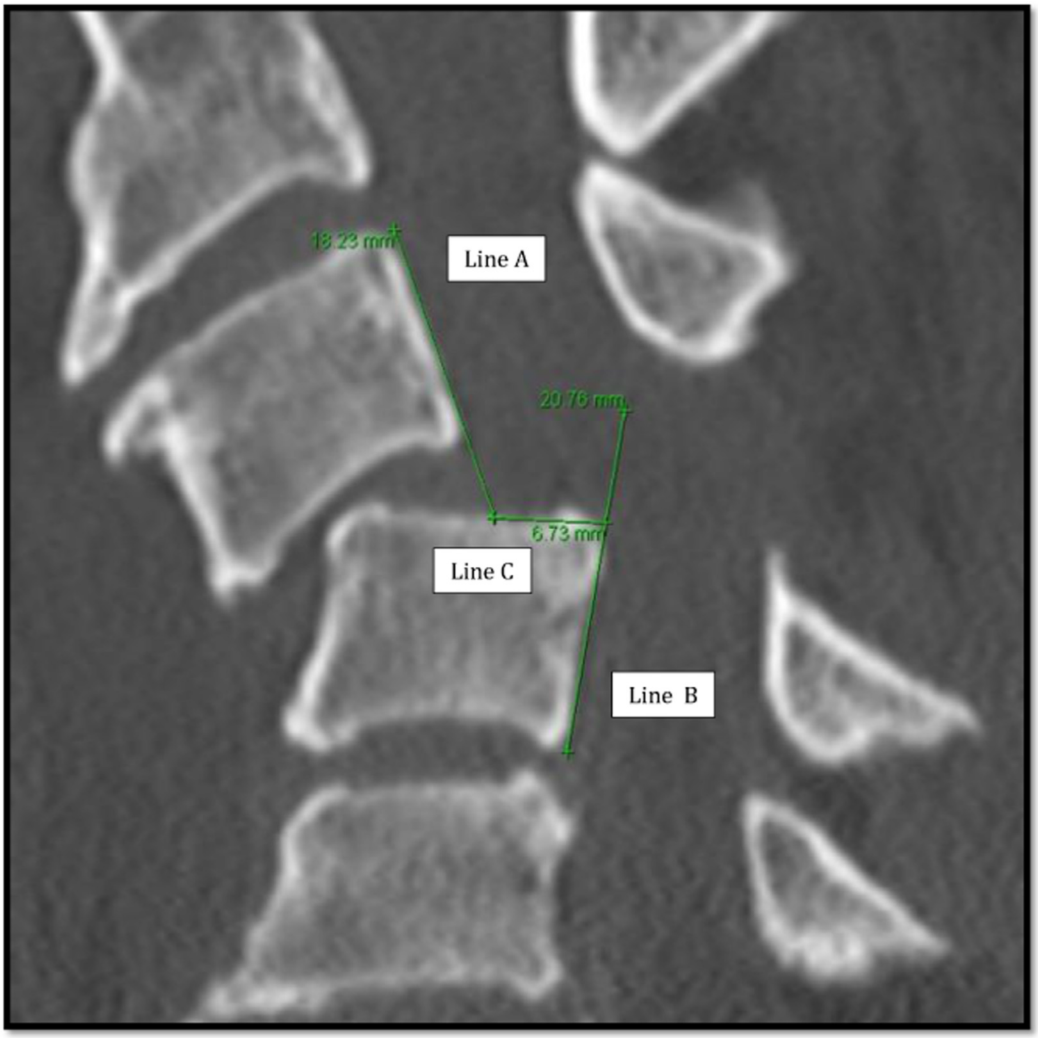

Fig. 2. Illustration demonstrating the technique to measure translation at the injury level using midsagittal CT reconstruction. Anterior translations were measured posteriorly from the dislocated vertebral body to the posterior margin of the caudal vertebral body. Line A, posterior margin of the dislocated vertebral body. Line B, posterior margin of the caudal vertebral body. Line C, anterior translation measured from the intersection of Line A and the superior margin of the caudal vertebral body to Line B.

Our institutional protocol is that for awake, cooperative patients, we do not do a prereduction MRI prior to reduction and therefore do not have MRI data for most of our patients.

Patients were then grouped into two cohorts for additional statistical analysis. One cohort included those patients who presented with ASIA grades of A−C (nonfunctional motor strength), and the other cohort consisted of patients who presented with ASIA D−E (functional motor strength).

Statistics

All analyses were done using SPSS v23@IBM. Descriptive analysis was done for all variables. One-way ANOVA was performed to determine differences across the ASIA grades. Receiver operating characteristic (ROC) curves were created to determine the predictive ability of the outcome variables. This provides a graphical demonstration of the sensitivity and specificity of the different measurements by measuring the area under the curve.

To assess the sensitivity and specificity of stenosis and translation to spinal cord injury, we used ROC curves. Assessing translation of each point on the ROC curve represents a sensitivity/specificity pair corresponding to a particular decision threshold. A test with perfect discrimination (no overlap in the two distributions) has a ROC curve that passes through the upper left corner (100% sensitivity, 100% specificity) with an area under the curve (AUC) = 1 [11].

Results

Between January 1, 2004 and December 31, 2014, we identified 97 patients admitted to our level 1 trauma center for treatment of unilateral or bilateral cervical facet dislocations that met inclusion criteria (Table 1). There were 67 males and 30 females. The average patient age at presentation was 42 years and ranged between 16 and 88 years of age. Most patients were involved in a high-speed motor vehicle collision (52%). Other sources of injury included diving accidents (24%) and ground-level falls (13%). The remainder of injuries was attributed to assault or recreational accidents.

The most common level of injury was C6−7 (41%), followed by C5−6 (24%) and C4−5 (22%). Fifty-eight were bilateral dislocations, and 39 were unilateral dislocations. Facet fractures were common. Thirty-two patients (33%) presented with unilateral left-sided facet fractures, 31 patients (32%) presented with unilateral right-sided facet fractures, 11 patients (11%) presented with bilateral facet fractures. Twenty-three patients (24%) presented without an associated facet fracture.

The neurologic status at presentation was bimodal. Most patients presented with either intact neurologic function (ASIA E) or complete spinal cord injuries (ASIA A). Thirty-eight patients presented with neurologic injuries classified as ASIA A (39%), 4 as ASIA B (4%), 4 as ASIA C (4%), 13 as ASIA D (13%), and 38 as ASIA E (39%).

The average residual canal diameter of all patients at the level of injury was 10.5 mm, and ranged between 4 and 18.4 mm. The average diameter at adjacent levels of all patients was 14.6 mm (range 11.1−20.6 mm) cranially and 14.3 mm (range 9.8−19.5 mm) caudally. There was no correlation between the mean canal diameters at adjacent levels and ASIA status (Table 2). Adjacent level diameter can be considered a proxy for preinjury canal diameter at the dislocated level. This presumption compensates for multilevel degenerative spinal stenosis and has been applied in previous literature [8,12].

There was a direct relationship between mean canal diameter and ASIA grade at presentation. Patients presenting with ASIA A had a mean canal diameter at the level of injury of 8 mm (95% confidence interval [CI] 7.49−8.49), whereas patients presenting with ASIA E had a mean canal diameter of 12.6 mm (95% CI 11.8 −13.4, $p < .0001$). Patients with incomplete spinal cord injuries had means of 11.4 mm for ASIA D, 11.7 mm ASIA C, and for 8.9 mm ASIA B. These measurements were not statistically different.

The average anterior translation at the level of injury was 6.0 mm. There was a direct relationship between amount of translation and ASIA grade at presentation. Patients who presented with complete spinal cord injury, ASIA A, had an average anterolisthesis of 8.0 mm (95% CI 7.2−8.9), whereas patients with ASIA E had average translation of 6.0 mm (95% CI 5.4−6.6, $p < .001$). The average translation of ASIA B, C, and D patients were not statistically different (Table 3).

We then analyzed our two cohorts: ASIA A−C and ASIA D−E. The average canal diameter at the level of injury for patients with ASIA A−C was significantly smaller than patients with ASIA D−E. The average diameter for ASIA A−C was 8.4 mm (range 7.8−9.0 mm) compared with 12.3 mm (range 11.6−13.0 mm) for patients with ASIA D−E ($p < .001$). A similar correlation was found when comparing anterolisthesis between these groups. The average anterolisthesis for patients with ASIA A−C was 7.8 mm (range 7−8.5 mm) compared with 4.4 mm (range 3.8−5 mm) for patients with ASIA D−E ($p < .001$; Table 4).

The cohort data were plotted on a ROC curve (Table 5). Canal diameter was an almost perfect predictor of ASIA D−E SCI, with the area under the curve = 0.905 (Fig. 3). Translation was a good predictor of ASIA A−C SCI, with the area under the curve = 0.850 (Fig. 4).

Canal diameter of 9.2 mm demonstrated a sensitivity (true positive) of 90% and a specificity (true negative) of 79% in predicting ASIA D−E, which leaves a 21% false positive rate. A canal diameter of 8.4 mm increased the sensitivity of the prediction of ASIA D−E to 96%. However, this decreased the specificity of the prediction to 46%, which leaves a 54% false positive rate.

Table 1
Demographics of study group population

Patient demographics		N
Sex	Male	67
	Female	30
Age	Minimum	16
	Maximum	88
	Mean	42.5
Mechanism of injury	MVC	51
	Diving injury	23
	Ground level Fall	13
	Fall from height	7
	Assault	3
Level of injury	C2−3	2
	C3−4	5
	C4−5	21
	C5−6	23
	C6−7	40
	C7−8	6
Dislocation	Unilateral	39
	Bilateral	58
Facet fracture	Unilateral left	32
	Unilateral right	31
	Bilateral	11
	None	23
ASIA grade at presentation	A	38
	B	4
	C	4
	D	13
	E	38

So, if a canal diameter of 9.2 mm is used as a cutoff, then 90% of subjects predicted to be ASIA D−E will actually be ASIA D−E. Alternatively, 21% of those predicted to be ASIA A−C will actually be ASIA D−E.

If a canal diameter of 9.8 mm is used as a cutoff, then 80% of patients will be correctly predicted to be ASIA D−E. Alternatively, 15% of patients classified as ASIA A−C will actually be ASIA D−E.

Using a translation of 3.7 mm as a cutoff demonstrated a sensitivity (true positive) of 91% confirming those who were ASIA A−C. However, this resulted in a specificity of 38% in predicting ASIA D−E, leaving a false positive rate of 63%. So, if the translation measures greater than 3.7 mm, 91% of those you predict to be ASIA A−C will actually be ASIA A−C, and 63% of those who you predict to be ASIA D−E will actually be ASIA A−C.

If you increase the translation cutoff to 5.2 mm, then the sensitivity becomes 78%. This results in 33% of those you predict to be ASIA D−E will actually be ASIA A−C.

A translation cutoff of 2.9 mm demonstrated a sensitivity (true positive) of 96% and a specificity of 30% in predicting ASIA A−C. Sixty-three percent of the ASIA D−E would be incorrectly predicted to be ASIA A−C.

Discussion

Cervical facet dislocations are uncommon injuries, but they have the potential to cause significant neurologic effects. The incidence, evaluation, and management of cervical facet dislocations have been extensively studied. Despite this breadth of literature, there have been relatively few studies investigating the importance of cervical spine canal diameter on neurologic outcomes [7,8]. Our goal was to test our hypotheses that smaller spinal canal diameters and increasing anterolisthesis are associated with worsening neurologic injury.

Table 2
Canal diameter (mm) in 97 patients by ASIA grade

	ASIA grade	N	Mean (Std. deviation)	95% CI	Minimum	Maximum
Injury level	A	38	8.0 (1.5)	7.5−8.5	4	10.7
	B	4	8.9 (1.8)	6.1−11.7	7.7	11.5
	C	4	11.7 (2.8)	7.2−16.1	8.85	15.3
	D	13	11.4 (2.3)	10.0−12.8	8.15	15
	E	38	12.6 (2.5)	11.8−13.4	7.3	18.4
	Total	97	10.5 (3.0)	9.9−11.1	4	18.4
Cranial level	A	38	14.0 (1.7)	13.4−14.5	11.3	19.1
	B	4	13.9 (2.1)	10.6−17.3	11.9	16.9
	C	4	15.3 (3.7)	9.4−21.2	12.0	20.6
	D	13	14.6 (2.3)	13.2−16.0	11.1	19.2
	E	38	15.2 (1.9)	14.6−15.8	11.7	18.7
	Total	97	14.6 (2.0)	14.2−15.0	11.1	20.6
Caudal level	A	38	14.3 (1.5)	13.8−14.7	11.4	18.1
	B	4	12.9 (2.0)	9.7−16.2	10.7	15.5
	C	4	14.8 (3.2)	9.7−19.8	12.5	19.5
	D	13	13.6 (2.1)	12.3−14.8	9.8	17.8
	E	38	14.8 (1.4)	14.35−15.3	12.3	17.9
	Total	97	14.3 (1.7)	14.4−14.7	9.8	19.5

Table 3
Translation (mm) in 97 patients by ASIA grade

	ASIA	N	Mean	Std. deviation	Std. error	95% confidence interval for mean: Lower bound	95% confidence interval for mean: Upper bound	Minimum	Maximum
Anterolisthesis	A	38	8.0	2.5	0.4	7.2	8.9	2.6	14.8
	B	4	5.9	2.0	1.0	2.7	9.1	2.9	7.1
	C	4	7.2	3.0	1.5	2.5	11.9	2.9	9.3
	D	13	4.9	2.0	0.6	3.7	6.1	0.0	7.9
	E	38	4.2	2.2	0.4	3.5	5.0	0.0	10.2
	Total	97	6.0	2.9	0.3	5.4	6.6	0.0	14.8

Given the small number of patients with incomplete spinal cord injuries, we grouped patients into two cohorts for additional statistical analysis. The groups indicate a clinical level of functionality, as patients who present with ASIA grades of D−E are far more likely to have functional motor strength following cervical spinal cord injuries. One cohort included those patients who presented with ASIA grades of A−C (nonfunctional motor strength), and the other cohort consisted of patients who presented with ASIA D−E (functional motor strength).

We found a strong association between the canal diameter at the level of injury and neurologic status at presentation. Our hypothesis that smaller residual canal diameter at the level of injury correlated with worsening neurologic status was supported. There was a direct and statistically significant correlation between injury canal diameter and ASIA grade at presentation. We found no significant difference between adjacent level canal diameters. This disproved our hypothesis that preinjury canal diameter would correlate with greater neurologic injury.

Eismont et al. in 1984 were the first to publish results investigating canal diameter and neurologic injuries in all forms of cervical spine trauma [7]. They found a correlation between preinjury canal size and neurologic outcome. Patients without neurologic injury had larger canal diameters compared with patients with incomplete injuries, and those with incomplete injuries had larger canal diameters than those with complete injuries. They concluded that a larger canal diameter was protective against neurologic injury. The conclusions reached in that study are tempered by relying solely on radiographs, extrapolating data from postreduction images, and combining a mixed presentation of cervical spine injuries that included various types of fractures and dislocations. Dailey et al. demonstrated that the use of CT images allows spine surgeons to more accurately diagnose cervical trauma [13].

Lintner et al. investigated the relationship between preinjury canal diameter and neurologic injury in a small cohort of patients (n=33) with cervical facet dislocations [8]. They found no relationship between preinjury canal diameter or Torg ratio and neurologic injury. They concluded that preinjury canal diameter and Torg ratio are not prognostic, as facet dislocations result in both bony and soft tissue compression of the spinal cord. They recommended additional avenues to assess the risk of neurologic injury following facet dislocations. These included using CT or MRI to investigate the soft tissue component of cord compression and measuring the spinal canal diameter at the time of injury. Their study was limited by relying solely on radiographs, extrapolating data from postreduction images,

Table 4
Canal diameter and translation (mm) in 97 patients by ASIA A−C vs. D−E

ASIA		N	Mean	Std. deviation	Std. error	95% confidence interval for mean: Lower bound	95% confidence interval for mean: Upper bound	Minimum	Maximum
Injury level	A−C	46	8.4	1.9	0.3	7.8	9.0	4.0	15.3
	D−E	51	12.3	2.5	0.3	11.6	13.0	7.3	18.4
	Total	97	10.5	3.0	0.3	9.9	11.1	4.0	18.4
Cranial level	A−C	46	14.1	1.9	0.3	13.5	14.7	11.3	20.6
	D−E	51	15.1	2.0	0.3	14.5	15.6	11.1	19.2
	Total	97	14.6	2.0	0.2	14.2	15.0	11.1	20.6
Caudal level	A−C	46	14.2	1.7	0.3	13.7	14.7	10.7	19.5
	D−E	51	14.5	1.7	0.2	14.0	15.0	9.8	17.9
	Total	97	14.3	1.7	0.2	14.0	14.7	9.8	19.5
Anterolisthesis/ translation	A−C	46	7.8	2.6	0.4	7.0	8.5	2.6	14.8
	D−E	51	4.4	2.2	0.3	3.8	5.0	0.0	10.2
	Total	97	6.0	2.9	0.3	5.4	6.6	0.0	14.8

Table 5
Specificity and sensitivity values from ROC curves for diameter and translation

	Diameter	
	Sensitivity	Specificity
8.1 mm	98%	67%
8.4 mm	96%	54%
9.3 mm	90%	20%
10.0 mm	77%	89%
11.4 mm	63%	94%
12.5 mm	51%	98%
	Translation	
Translation	Sensitivity	Specificity
2.7 mm	98%	28%
3.0 mm	94%	29%
4.3 mm	89%	51%
6.6 mm	67%	90%
8.6 mm	35%	96%
9.9 mm	15%	98%

and having a small sample size. Our study supports these conclusions.

More recently, Quarrington et al. reviewed a group of patients who sustained both facet dislocations and subluxations. A combination of modalities including radiographs, CT, and/or MRI was used to collect their data. Though the patients were not stratified according to specific ASIA grade, they were able to conclude that greater spinal occlusion led to spinal cord injury. Further, they determined that CT-derived values of spinal canal occlusion and MRI-derived values of spinal cord compression are equivalent at predicting spinal cord injury [14].

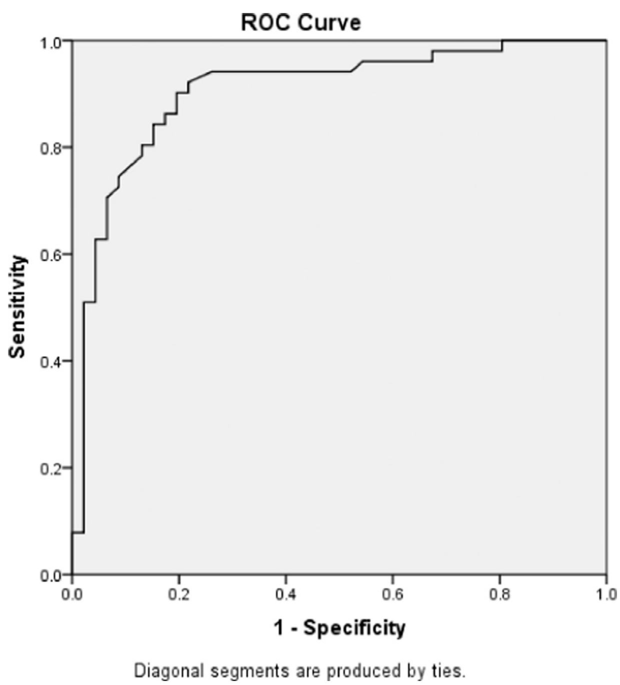

Fig. 3. ROC curve for injury level canal diameter/ASIA D−E with area under the curve = 0.91.

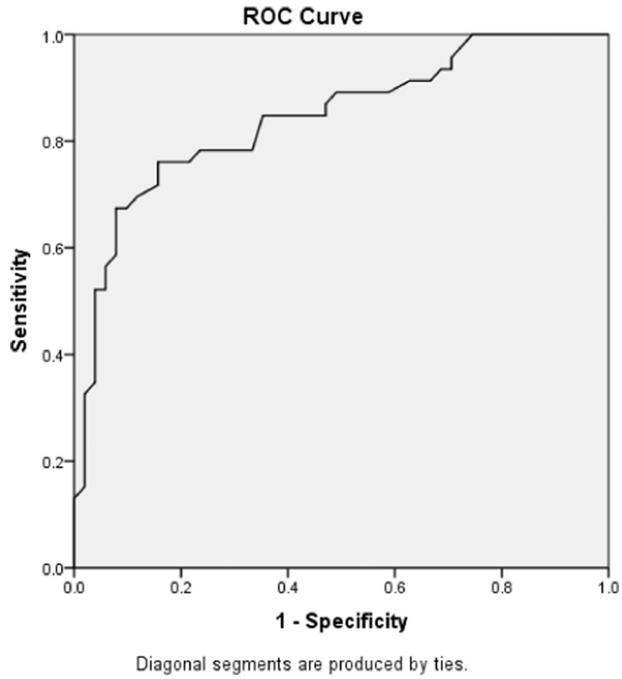

Fig. 4. ROC curve for translation/ASIA A−C with area under the curve = 0.85.

We were able to confirm our hypothesis that increasing anterolisthesis correlates with worsening neurologic injury. There was a direct correlation between mean translation and ASIA grade at presentation. Patients who presented with complete spinal cord injury had an average anterolisthesis of 8 mm, whereas patients with no spinal cord injury sustained an average translation of 4.2 mm. The average anterolisthesis for patients with ASIA grades A−C was 7.8 mm, compared with 4.4 mm for patients with ASIA grades D−E.

The effect of anterolisthesis on neurologic injury has been less studied. O'Connnor et al. investigated the effect of anterolisthesis and neurologic injury in patients with cervical facet dislocations [10]. They measured the ratio of anterior displacement of the cranial vertebral body to the midsagittal diameter of the caudal nondisplaced body. This result was then compared with the patient's presenting ASIA classification. They identified a significant correlation between anterolisthesis and worsening ASIA grades. Their analysis was limited due to its small sample size of 33 patients. Our larger sample size confirmed this clinically significant correlation.

There were several weaknesses to our study. This was a retrospective cohort review which introduces multiple forms of bias. The research team was not blinded to the ASIA grade at presentation, which may have introduced detection bias. We did not use validated ratios, including Torg ratios, and instead relied upon CT calibration to limit magnification artifact. We believe this is justified, as most trauma patients are currently worked up with CT imaging as opposed to plain radiographs.

Despite our large cohort of patients, there was an insufficient number of patients with incomplete spinal cord injuries (ASIA B−D) to perform adequate subgroup statistical analyses. We managed this by grouping incomplete injuries into two functional groups, those with potential to have functional motor strength following their injury (ASIA D and E) and those who would most likely not have functional motor strength (ASIA A, B, and C). Additionally, this study only compared CT imaging with a patient's neurologic status. Future studies intend to compare ASIA grade with MRI data describing spinal cord diameter and indication of injury.

Our study indicates that patients with a smaller injury level diameter and/or greater translation have a higher rate of SCI. We found an average canal diameter of 8.4 mm and translation of 7.8 mm in those with ASIA A−C injuries compared with a diameter of 12.3 mm and translation of 4.4 mm in those with ASIA D−E injuries. Diameter was a better predictor of ASIA D−E, and translation was a better predictor of ASIA A−C. Adjacent canal diameter did not correlate with neurologic injury. Predicting motor recovery based on initial CT imaging can guide expectations for patient goals and planning of care.

Ethical review committee statement

This study was reviewed and approved by the institutional review board of Harborview Medical Center where this study was performed.

Conflicts of interest and source of funding

None declared.

References

[1] Lowery DW, Wald MM, Browne BJ, Tigges S, Hoffman JR, Mower WR, et al. Epidemiology of cervical spine injury victims. Ann Emerg Med 2001;38:12–6.

[2] Hadley MN, Fitzpatrick BC, Sonntag VK, Browner CM. Facet fracture-dislocation injuries of the cervical spine. Neurosurgery 1992;30:661–6.

[3] Ivancic PC, Pearson AM, Tominaga Y, Simpson AK, Yue JJ, Panjabi MM, et al. Mechanism of cervical spinal cord injury during bilateral facet dislocation. Spine 2007;32:2467–73.

[4] Robertson PA, Ryan MD. Neurological deterioration after reduction of cervical subluxation. Mechanical compression by disc tissue. J Bone Joint Surg Br 1992;74:224–7.

[5] Goldberg W, Mueller C, Panacek E, Tigges S, Hoffman JR, Mower WR, et al. Distribution and patterns of blunt traumatic cervical spine injury. Ann Emerg Med 2001;38:17–21.

[6] Torg JS, Pavlov H, Genuario SE, Sennett B, Wisneski RJ, Robie BH, et al. Neuropraxia of the cervical spinal cord with transient quadriplegia. J Bone Joint Surg Am 1986;68:1354–70.

[7] Eismont FJ, Clifford S, Goldbert M, Green B. Cervical sagittal spinal canal size in spine injury. Spine 1984;9:663–6.

[8] Lintner DM, Knight RQ, Cullen JP. The neurologic sequelae of cervical spine facet injuries. Spine 1993;8:725–9.

[9] Aebli N, Wicki AG, Rüegg TB, Petrou N, Eisenlohr H, Krebs J, et al. The Torg-Pavlov ratio for the prediction of acute spinal cord injury after a minor trauma to the cervical spine. Spine J 2013;13:605–12.

[10] O'Connor PA, McCormack O, Noël J, McCormack D, O'Byrne J. Anterior displacement correlates with neurological impairment in cervical facet dislocations. Int Orthop 2003;27:190–3.

[11] Zweig MH, Campbell G. Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. Clin Chem 1993;39:561–77.

[12] Kang JD, Figgie MP, Bohlman HH. Sagittal measurements of the cervical spine in subaxial fractures and dislocations. J Bone Joint Surg 1994;76-A:1617–28.

[13] Dailey AT, Shaffrey CI, Rampersaud R, Lee J, Brodke DS, Arnold P, et al. Utility of helical computed tomography in differentiating unilateral and bilateral facet dislocations. J Spinal Cord Med 2009;321:43–8.

[14] Quarrington RD, Jones CF, Tcherveniakov P, Clark JM , Sandler SJI, Lee YC, et al. Traumatic subaxial cervical facet subluxation and dislocation: epidemiology, radiographic analyses, and risk factors for spinal cord injury. Spine J 2018;18:387–98.