

Odontoid Fractures With Neurologic Deficit Have Higher Mortality and Morbidity

Amar Patel BS, Harvey E. Smith MD,
Kris Radcliff MD, Navin Yadlapalli BS,
Alexander R. Vaccaro MD, PhD

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Abstract

Background Type II odontoid fractures are reportedly increasing in incidence and occur primarily in the elderly. Neurologic deficits (ND) at presentation add to the morbidity of these fractures; however, reports are limited as a result of small case series. It is unclear what specific complications are associated with ND and whether these result in increased incidence of mortality.

Questions/purposes We established the incidence of ND with Type II odontoid fractures and determined if ND are

associated with increased inpatient mortality and morbidity during hospitalization.

Methods Twenty patients with acute Type II odontoid fracture and ND were identified from our institutional database. Baseline presenting characteristics and hospital course data were collected. The cohort was compared with a previously published cohort of 188 patients without ND by age, mechanism of injury, displacement, associated spinal injuries, comorbidities, treatment, mortality, and complications. Patients were only followed during acute-care hospitalization (mean, 11.9 days; range, 0–41 days).

Results The incidence of ND among all Type II odontoid fractures was 9.6%. Ten of 20 patients with Type II odontoid fractures and ND died during hospitalization, and patients with complete cord injuries were 9.33 (95% confidence interval, 1.19–73.0) times more likely to die. Patients with ND experienced more complications and more respiratory complications than those without ND.

Conclusions ND after Type II odontoid fractures is a rare event associated with a high risk of early and rapid clinical decline.

Level of Evidence Level III, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

This work was performed at the Rothman Institute, Thomas Jefferson University Hospital, Philadelphia, PA, USA.

A. Patel, N. Yadlapalli
Jefferson Medical College, Thomas Jefferson University,
Philadelphia, PA, USA

H. E. Smith (✉)
New England Orthopaedic and Spine Surgery, New England
Baptist Hospital, Tufts University, 830 Boylston Street,
Suite 211, Chestnut Hill, Boston, MA 02467, USA
e-mail: harveysmith27@gmail.com

K. Radcliff, A. R. Vaccaro
Department of Orthopaedic Surgery, Thomas Jefferson
University, Philadelphia, PA, USA

K. Radcliff, A. R. Vaccaro
Department of Orthopaedics, Rothman Institute,
Philadelphia, PA, USA

Introduction

Cervical fractures are some of the most frequent spinal injuries in the elderly population today, accounting for 25,000 new hospitalizations every year in the United States [10, 13]. The elderly are particularly predisposed to bony injury as a result of a greater predilection for sustaining low-energy fall injuries coupled with an increased incidence of osteopenia. Compounding the problem is

the increasing number of comorbidities in the elderly population [14].

Approximately 10% to 20% of all cervical fractures occur at the odontoid process [7, 10, 16, 17], and the majority of these are classified as Type II fractures [3, 11]. Originally described by Anderson and D'Alanzo, Type II fractures occur at the junction between the body of the axis and the odontoid process [1]. Substantial displacement of the fractured segment may result in cord compression resulting in spinal cord injury (SCI) with possible neurological deficits (ND) [18]. However, this is a rare event with an occurrence rate ranging from 3% to 25% [2, 15] attributable in large part to the capacious spinal canal at this region.

Previous studies [19–21] of patients with Type II odontoid fractures but without ND suggest these injuries are associated with a mortality rate of 12.8% and a major complication rate of 47.8% after a minimum followup of 0 day (average, 15.1 days; range, 0–161 days). However, there is less literature examining patients with ND. One study of 17 patients suggests odontoid fractures are an infrequent cause of SCI with ND, most often occurring in males with congenital stenosis sustaining high-injuries [7]. Another study of 10 patients with ND after Type II fracture reported that six patients died, and SCI is an increasing finding in geriatric patients [18]. These studies contain too few patients to establish the incidence and determine the morbidity and mortality rates. Larger-scale studies specific to Type II odontoid fractures would help describe the hospital course of such patients to better inform treatment decisions. Specific information on the unique complications and causes of mortality associated with Type II odontoid fractures with ND may ultimately improve patient care and survival.

Our purposes were to (1) establish the incidence of neurological deficits with Type II odontoid fractures; and (2) determine if neurologic deficits were associated with increased in-patient mortality and (3) increased morbidity during hospitalization.

Patients and Methods

We searched our institution's database from June 1985 to July 2008 for patients with Type II odontoid fractures presenting with a ND [19–21]. We included all patients with an American Spinal Injury Association (ASIA) impairment [4] Grade of A, B, C, or D. ASIA A indicates a "complete" SCI in which no motor or sensory function is preserved, ASIA B indicates an "incomplete" SCI in which sensory but not motor function is preserved, ASIA C indicates an "incomplete" SCI in which motor function is preserved and more than half of key muscles below the

neurologic level have a muscle grade of less than 3 (active movement with full range of motion against gravity), and ASIA D indicates an "incomplete" SCI in which motor function is preserved and at least half of the key muscles have a muscle grade of 3 or more. The query returned a total of 116 unique cases with a possible ND after an acute Type II odontoid fracture. One patient's medical record could not be found, and one patient's record was incomplete, thus excluding them from the study. In the remaining 114 patients, we used radiology reports to confirm the presence of an acute Type II odontoid fracture. We defined a ND as an ASIA Grade A, B, C, or D based on consensus between orthopaedics and neurosurgical consult notes. Of the 114 patients whose charts were reviewed, 35 patients did not have a ND and were excluded. Patients were excluded if the radiology report indicated no C2 fracture ($n = 8$), C2 body fracture not involving the dens ($n = 23$), odontoid fractures that were Type I ($n = 2$) or Type III ($n = 19$), and chronic fractures ($n = 7$). These 59 exclusions left 20 patients with an acute Type II odontoid fracture and a ND ("deficit" cohort). Patients were only followed during their acute-care hospitalization (mean, 11.9 days; range, 0–41 days). No patients were recalled specifically for this study; all data were obtained from medical and imaging records. We had prior approval from the Institutional Review Board.

We reviewed the admission records of the 20 patients and extracted the following information: age, date of admission, date of discharge, date of death (if applicable), mechanism of injury (low-energy, high-energy), fracture displacement, comorbidities, associated injuries, ASIA grade, type of treatment (nonoperative or surgical method), estimated blood loss (if surgical treatment), in-hospital complications, and use of traction. Inpatient mortality was defined as a patient death occurring during the course of hospitalization; we did not determine mortality after discharge from our acute-care facility. Comorbidities were quantified using a point system in which one point was assigned for each major organ system (central nervous system, cardiac, respiratory, gastrointestinal, endocrine, vascular, malignancy) with a documented a major comorbidity; this point system was first created and implemented by our institution in a previous study describing Type II odontoid fractures without ND [21]. The data of the 20 patients (Table 1) were compared with data from a previously published cohort of 188 patients with acute Type II odontoid fractures without ND ("intact" cohort) [19–21]. This cohort represents all neurologically intact cases presenting to the same regional SCI center during the same time period serving as a control for this study.

Descriptive statistics were calculated, including frequencies for categorical variables and means and ranges for continuous variables. Univariable analysis was performed

Table 1. Characteristics of patients presenting with neurologic deficits

Category		Number (n = 20)
Gender	Male	13
	Female	7
Mechanism	Low-energy	9
	High-energy	11
Associated spinal injuries	Yes*	14
	No	6
Neurologic deficit	ASIA A	11
	ASIA B	2
	ASIA C	3
	ASIA D	4
Presentation	Quadriplegia	10
	Central cord	9
	Paraplegia	1
Treatment	Nonoperative†	15
	Operative‡	5

* C1 ring (5), C1 anterior arch (2), C1 posterior arch (2), Jefferson (1), C1 lamina fracture (1), C3 (1), C5 (2), C7 (1), T1 (1), T5 (1), T7 (1), L2 (1); †collar without traction (10), collar with traction (1) halo vest without traction (2), halo vest with traction (2); ‡Harms technique (2), Magerl technique (1), anterior odontoid screw fixation (1), C1-C7 posterior fusion (1); ASIA = American Spinal Injury Association.

between the deficit and intact cohorts using the chi-square test for categorical variables and t-test for continuous variables. This demonstrated the presence of ND was associated with younger age ($p < 0.001$), greater percentage of high-energy mechanism of injury ($p < 0.001$), and more associated spinal injuries ($p < 0.001$). There was no difference in the number of comorbidities ($p = 0.10$), treatment ($p = 0.11$), or fracture displacement ($p = 0.33$) between the two cohorts (Table 2). Only the significant ($p < 0.05$) variables from the univariable analysis (age, mechanism of injury, and associated spinal injuries) were used as control parameters for the multivariable analysis. The outcome measures tested were originally inpatient mortality and the number of complications; however, after further review, the most common complication (respiratory distress) was also included. We used a multivariate logistic regression to determine the relationship between the presence of ND and categorical variables (inpatient mortality, the presence of respiratory distress). We used a Poisson distribution with the same parameters to determine the predictors of continuous variables (number of complications). Finally, a multivariate logistic regression was specifically used to determine correlations between mortality and ASIA grade. Because our study is retrospective in nature, data were missing with certain parameters. Specifically, no data were missing in the deficit cohort

Table 2. Comparison of patient characteristics between deficit and intact cohorts

Category	Deficit (n = 20)*	Intact (n = 188)*	p
Age (years)	76.4 (72.2–80.5)	84.3 (83.0–85.8)	< 0.001
Mechanism (low/high energy)	45%/55%	91%/9%	< 0.001
Comorbidity score	1.6 (1.1–2.0)	2.0 (1.9–2.2)	0.10
Displacement (mm)	4.0 (2.5–5.5)	3.3 (2.8–4.0)	0.33
Associated spinal injuries	70%	22%	< 0.001
Length of stay (days)	11.9 (6.2–17.6)	15.1 (12.4–17.4)	0.18
Treatment (operative/nonoperative)	25%/75%	42%/58%	0.11

* Ninety-five percent confidence intervals listed in parentheses.

Table 3. Mortality and complications of deficit and intact cohorts

Category	Deficit (n = 20)*	Intact (n = 188)*	Odds ratio*
Mortality	50%	13%	4.72 (1.35–16.6)
Number of complications	3.2 (2.1–4.0)	1.0 (0.8–1.3)	1.18 (0.54–1.77)
Number of respiratory complications	90%	13%	62.3 (13.9–476.3)

* Ninety-five percent confidence intervals listed in parentheses.

data; however, the intact cohort was missing eight values for displacement and 11 values for comorbidities. We did not attempt to impute missing values, and patients were only excluded in models requiring data to preserve our cohort sizes. All statistics were performed using JMP© 7.02 software (SAS, Cary, NC).

Results

Combining both the deficit and intact cohorts, the incidence of a ND associated with acute Type II odontoid fractures was 9.6% (20 of 208 patients).

Patients with ND were 4.72 (95% confidence interval [CI], 1.35–16.6) times more likely to die than those who were intact (Table 3). Patients presenting with complete spine injuries (ASIA A) were 9.33 (95% CI, 1.19–73.0) times more likely to die than all other patients. Combining both the deficit and intact cohorts, there was a 16.3% (34 of 208 patients) inpatient mortality rate associated with an acute Type II odontoid fracture (Table 4).

Patients with ND had a high number of complications during their hospitalization (Table 5), and the most common complication was respiratory distress. Patients with

Table 4. Mortality rates

	Year of injury	Age (years)	Mechanism of injury	ASIA grade	Treatment	Comment	Course of stay
Deficit cohort	1994	76	Fall	A	Collar	WOC	Cardiopulmonary event
	1994	82	Fall (steps)	A	Collar	WOC	Cardiac arrest, snoxic brain injury
	1999	84	MVA	B	Collar	WOC	Respiratory failure
	2000	78	Fall	B	Collar	WOC	Anoxic brain injury, respiratory failure
	2000	80	Fall	A	Collar	DNR	Septic shock
	2000	81	Fall (steps)	A	Collar	WOC	Neurogenic shock, respiratory failure
	2001	81	Fall (steps)	A	Collar	WOC	Cardiopulmonary event
	2004	81	Fall	A	Collar	WOC	Cardiopulmonary event
	2005	89	MVA	A	Halo	WOC	Neurogenic shock, respiratory failure
	2006	60	Fall (horse)	A	Collar	DNR	Cardiopulmonary event
Intact cohort	1989	86	MVA		Halo	DNR	Pulmonary embolism
	1992	83	Fall		Collar	Unknown	Respiratory failure
	1993	91	Fall		Halo	DNR	Seizure, pneumonia
	1994	92	Fall		Collar	DNR	Cardiopulmonary event
	1996	85	Fall		Halo	Unknown	Respiratory failure
	1996	92	MVA		Halo	Unknown	Respiratory failure
	1997	90	Fall		Halo	Unknown	Cardiopulmonary event
	1997	66	MVA		Collar	Unknown	Acute respiratory distress syndrome
	1997	83	Fall		Collar	DNR	Respiratory failure
	1998	86	Fall		Collar	WOC	Cardiopulmonary event
	1998	88	Fall		Surgery	DNR	Respiratory failure, stroke
	1999	83	Fall		Collar	DNR	Cardiopulmonary event
	1999	83	Fall		Halo	DNR	Unknown
	2000	84	Fall		Surgery	Unknown	Cardiopulmonary event, stroke
	2000	85	Fall		Surgery	DNR	Cardiac arrest
	2000	83	Fall		Halo	DNR	Cardiopulmonary event, stroke
	2002	85	Fall		Collar	Unknown	Unknown
	2002	88	MVA		Surgery	DNR	Cardiac arrest
	2002	84	MVA		Surgery	Unknown	Unknown
	2004	83	Fall		Collar	Unknown	Respiratory failure
2004	89	Fall		Surgery	DNI	Neurogenic shock	
2004	88	Fall		Collar	DNR	Cardiac arrest	
2004	86	Fall		Surgery	Unknown	Unknown	
2005	88	Fall		Collar	Unknown	Anoxic brain injury	

ASIA = American Spinal Injury Association; MVA = motor vehicle accident; WOC = withdrawal of care; DNR = do not resuscitate; DNI = do not intubate.

ND experienced 1.18 (95% CI, 0.54–1.77) times as many complications as those without ND. In the deficit cohort, 18 of 20 (90%) patients experienced respiratory distress and required intubation, of which eight (44%) ultimately required a tracheostomy for respiratory failure. Spine injuries of those who required a tracheostomy were ASIA A (n = 4), ASIA B (n = 1), ASIA C (n = 2), or ASIA D (n = 1). In the intact cohort, 25 (13%) required intubation after respiratory distress, of which 12 (48%) ultimately required a tracheostomy. Patients with ND were 62.3 (95% CI, 13.9–476.3) times more likely to experience respiratory complications.

Discussion

Type II odontoid fractures are one of the most common cervical spine fractures in the elderly. ND associated with odontoid fractures are rare and generally believed to portend a poor prognosis [5, 6, 14]. However, small case series in previous reports have limited the amount of accurate data available for informed treatment decisions to be made. We therefore (1) established the incidence of ND with Type II odontoid fractures. Then we (2) determined if ND were associated with increased in-patient mortality and (3) increased morbidity during hospitalization.

There are several inherent limitations to our study. First, our study was not prospective or randomized. Because this is a retrospective study in which management decision was at the sole discretion of the surgeon, caution must be taken in establishing causality between treatment method and outcomes. Second, inclusion bias may have existed when classifying patients. Patients were categorized into each cohort based on the presence of a ND, largely determined by the ASIA grade on admission. The ASIA classification

is subject to interobserver variance [13]; therefore, we only included patients who had a consensus on neurologic status between the orthopaedic and neurosurgery consult notes. Classification of the type of odontoid fracture in each patient was determined by radiographic reports, and any uncertainty or ambiguity in fracture classification resulted in exclusion of the patient. Third, we had a small number of patients, therefore limiting the power of our study and possibly introducing the risk of Type II error. However, the injuries studied are relatively uncommon with a high rate of early expiration; thus, it is difficult to obtain large single-institution cohorts, even one that is a regional SCI center. Moreover, our multivariable analysis allowed us to control for important variables that may have otherwise confounded our findings. Fourth, our followup was limited to inpatient hospitalization only; therefore, our results may have not captured all mortality or morbidity that would have normally been attained from long-term followup.

We found an incidence of ND among all Type II odontoid fractures of 9.6%. One previous study of 35 cases reported an incidence of 29% with Type II odontoid fractures [18]. Other studies reported an incidence of 7.5% to 13% with all odontoid fractures [7, 15] and 6.9% to 29% [6, 14] with all cervical fractures. Our observations are consistent with the values reported in the literature (Table 6) and represent the largest study specifically observing ND associated with Type II odontoid fractures.

Patients with ND experienced high inpatient mortality. Reported mortality has varied extensively in the literature with fracture type and outcome times (Table 7). One study described a 60% mortality rate associated with Type II fractures with a 21-month followup [18], and another

Table 5. Complications

Complication	Patients (n = 20)
Respiratory distress*	18
Feeding tube	7
Atrial fibrillation	4
Pneumonia	4
Neurogenic bowel/bladder	3
Neurogenic shock	3
Hypertension	3
Systemic infection	3
Gastrointestinal bleed	3
Cardiac arrest	3
Nasogastric tube	2
Anoxic brain injury	2
Deep vein thrombosis	2
Urinary tract infection	2
Electrolyte imbalance	2
Congestive heart failure	2
Dysphagia	1

* Eight patients had tracheostomies.

Table 6. Comparison of the incidence of neurologic deficits

Author	Population	Fracture site	Years	Incidence
Harris et al. [6]	Older than 65 years	All cervical	1991–2006 (26 years)	6.9% (44/639)
Harrop et al. [7]	All ages (range, 29–89 years)	All odontoid	1991–2000 (10 years)	7.5% (17/226)
Malik et al. [14]	Older than 65 years	All cervical	1994–2002 (9 years)	29% (31/107)
Muller et al. [15]	Older than 70 years	All odontoid	1984–1993 (10 years)	13% (3/13)
Ryan and Taylor [18]	Older than 60 years of age	Type II odontoid	1963–1985 (23 years)	29% (10/35)
Patel et al. (current study)	All ages (range, 42–89 years)	Type II odontoid	1985–2006 (22 years)	9.6% (20/208)

Table 7. Comparison of mortality with neurologic deficits

Author	Population	Fracture site	Outcome time	Mortality
Harris et al. [6]	Older than 65 years	All cervical	3 months	32% (14/44)
Harrop et al. [7]	All ages (range, 29–89 years)	All odontoid	Inpatient (range, 0–365 days)	53% (9/17)
Ryan and Taylor [18]	Older than 60 years	Type II odontoid	21 months	60% (6/10)
Varma et al. [22]	All ages (range, 1–97 years)	All cervical	Inpatient (range, 0–172 days)	14.9% (168/1129)
Patel et al. (current study)	All ages (range, 42–89 years)	Type II odontoid	Inpatient (range, 0–41 days)	50% (10/20)

described a 32% mortality rate of cervical fractures with a 3-month followup [6]. Two other studies reported inpatient mortality rates of 14.9% to 53% without followup after discharge [7, 22]. We determined that 10 of 20 patients with a Type II fracture and an associated ND died during inpatient hospitalization. Moreover, patients with deficits had the greatest probability of death with complete injuries (ASIA A). Severe injuries to the spinal cord after trauma have been associated with autonomic dysregulation, oftentimes leading to cardiopulmonary complications [12, 22]. Similarly, all 10 mortalities in the deficit cohort involved cardiac and/or respiratory events during the course of hospitalization.

When compared with the intact cohort, the deficit cohort had more complications with stay, in particular respiratory complications. There are several proposed reasons for this finding. Harrop et al. described the pathogenesis of respiratory decompensation as an effect of upper airway obstruction secondary to retropharyngeal edema from soft tissue injury after trauma and unintentional manipulation (ie, positioning for imaging, traction, intubation) [9]. In the deficit cohort, 18 patients were intubated and 10 ultimately were taken off of mechanical ventilation, consistent with the observations of Harrop et al. Conversely, it is important to note that eight patients eventually required tracheostomies. One previous study determined that high cervical injuries normally portend poor respiratory status with all C2 ASIA A patients requiring eventual tracheostomy placement [8]. In our cohort, there was no correlation between ventilator status and the severity of spine injury, and only three of 11 (27%) ASIA A patients required tracheostomies. This finding suggests that in addition to transient airway swelling, there may be a unique feature to the biomechanics of C1–2 injuries that differs from other high-level cervical injuries and merits further study. These results indicate respiratory distress is an extremely common complication of ND in patients with Type II odontoid fractures.

ND with Type II odontoid fractures is a rare event, and it is associated with high inpatient mortality and morbidity. With a growing geriatric population, there may be an increased incidence of this difficult clinical presentation. This study is useful in that it offers valuable prognostic data for the small but formidable population that may present with SCI and possible ND after a Type II odontoid fracture. Odontoid fractures with ND are clinically distinct from neurologically intact fractures and are associated with a high risk of early and rapid clinical decline.

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References

- Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Joint Surg Am.* 1974;56:1663–1674.
- Crockard HA, Heilman AE, Stevens JM. Progressive myelopathy secondary to odontoid fractures: clinical, radiological, and surgical features. *J Neurosurg.* 1993;78:579–586.
- Dickman CA, Hadeley MN, Browner C, Sonntag VKH. Neurosurgical management of acute atlas-axis combination fractures. *J Neurosurg.* 1989;70:45–49.
- Ditunno JF Jr, Young W, Donovan WH, Creasey G. The international standards booklet for neurological and functional classification of spinal cord injury. *Paraplegia.* 1994;32:70–80.
- Fassett DR, Harrop JS, Maltenfort M, Jeyamohan SB, Ratliff JD, Anderson DG, Hilibrand AS, Albert TJ, Vaccaro AR, Sharan AD. Mortality rates in geriatric patients with spinal cord injuries. *J Neurosurg Spine.* 2007;7:277–281.
- Harris MB, Reichmann WM, Bono CM, Bouchard K, Corbett KL, Warholic N, Simon JB, Schoenfeld AJ, Maciolek L, Corsello P, Losina E, Katz JN. Mortality in elderly patients after cervical spine fractures. *J Bone Joint Surg Am.* 2010;92:567–574.
- Harrop JS, Sharan AD, Przybylski GJ. Epidemiology of spinal cord injury after acute odontoid fractures. *Neurosurg Focus.* 2000;8:e4.
- Harrop JS, Sharan AD, Scheid EH, Vaccaro AR, Przybylski GJ. Tracheostomy placement in patients with complete cervical spinal cord injuries: American Spinal Injury Association Grade A. *J Neurosurg.* 2004;100(Suppl):20–23.
- Harrop JS, Vaccaro A, Przybylski GJ. Acute respiratory compromise associated with flexed cervical traction after C2 fractures. *Spine.* 2001;26:E50–E54.
- Kirankumar MV, Behari S, Salunke P, Banerji D, Chhabra DK, Jain VK. Surgical management of remote, isolated Type II odontoid fractures with atlantoaxial dislocation causing cervical compressive myelopathy. *Neurosurgery.* 2005;56:1004–1012; discussion 1004–1012.
- Koech F, Ackland HM, Varma DK, Williamson OD, Malham GM. Nonoperative management of Type II odontoid fractures in the elderly. *Spine.* 2008;33:2881–2886.
- Krassioukov A. Autonomic function following cervical spinal cord injury. *Respir Physiol Neurobiol.* 2009;169:157–164.
- Lasfargues JE, Custis D, Morrone F, Carswell J, Nguyen T. A model for estimating spinal cord injury prevalence in the United States. *Paraplegia.* 1995;33:62.
- Malik SA, Murphy M, Connolly P, O'Byrne J. Evaluation of morbidity, mortality and outcome following cervical spine injuries in elderly patients. *Eur Spine J.* 2008;17:585–591.
- Müller EJ, Wick M, Russe O, Muhr G. Management of odontoid fractures in the elderly. *Eur Spine J.* 1999;8:360–365.
- Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. *Clin Orthop Relat Res.* 1985;193:178–183.
- Ryan MD, Taylor TK. Odontoid fractures. A rational approach to treatment. *J Bone Joint Surg Br.* 1982;64:416–421.
- Ryan MD, Taylor TK. Odontoid fractures in the elderly. *J Spinal Disord.* 1993;6:397–401.
- Smith HE, Fehlings M, Chapman J, Maltenfort M, Zaslavsky J, Kerr S, Harris E, Albert T, Harrop J, Hilibrand A, Anderson DG, Vaccaro AR. Trends in epidemiology and management of Type II odontoid fractures: 20 year experience at a model system spine injury tertiary referral center. *J Spinal Disord Tech.* 2010;23:501–505.
- Smith HE, Kerr SM, Maltenfort M, Chaudhry S, Norton R, Albert TJ, Harrop J, Hilibrand AS, Anderson DG, Kopjar B, Brodke DS, Wang JC, Fehlings MG, Chapman JR, Patel A, Arnold PM,

- Vaccaro AR. Early complications of surgical versus conservative treatment of isolated Type II odontoid fractures in octogenarians: a retrospective cohort study. *J Spinal Disord Tech.* 2008;21:535–539.
21. Smith HE, Vaccaro AR, Maltenfort M, Albert TJ, Hilibrand AS, Anderson DG, Harrop J, Fehlings MG, Kopjar B, Brodke DS, Arnold PM, Shaffrey CI. Trends in surgical management for Type II odontoid fracture: 20 years of experience at a regional spinal cord injury center. *Orthopedics.* 2008;31:650.
22. Varma A, Hill EG, Nicholas J, Selassie A. Predictors of early mortality after traumatic spinal cord injury: a population-based study. *Spine.* 2010;35:778–783.