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Surgery Decreases Nonunion, Myelopathy, and Mortality for Patients With Traumatic Odontoid Fractures: A Propensity Score Matched Analysis

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BACKGROUND: Existing literature suggests that surgical intervention for odontoid fractures is beneficial but often does not control for known confounding factors.

OBJECTIVE: To examine the effect of surgical fixation on myelopathy, fracture nonunion, and mortality after traumatic odontoid fractures.

METHODS: We analyzed all traumatic odontoid fractures managed at our institution between 2010 and 2020. Ordinal multivariable logistic regression was used to identify factors associated with myelopathy severity at follow-up. Propensity score analysis was used to test the treatment effect of surgery on nonunion and mortality.

RESULTS: Three hundred and three patients with traumatic odontoid fracture were identified, of whom 21.6% underwent surgical stabilization. After propensity score matching, populations were well balanced across all analyses (Rubin's B < 25.0, 0.5 < Rubin's R < 2.0). Controlling for age and fracture angulation, type, comminution, and displacement, the overall rate of nonunion was lower in the surgical group (39.7% vs 57.3%, average treatment effect [ATE] = −0.153 [−0.279, −0.028], *P* = .017). Controlling for age, sex, Nurick score, Charlson Comorbidity Index, Injury Severity Score, and selection for intensive care unit admission, the mortality rate was lower for the surgical group at 30 days (1.7% vs 13.8%, ATE = −0.101 [−0.172, −0.030], *P* = .005) and at 1 year was 7.0% vs 23.7%, ATE = −0.099 [−0.181, −0.017], *P* = .018. Cox proportional hazards analysis also demonstrated a mortality benefit for surgery (hazard ratio = 0.587 [0.426, 0.799], *P* = .0009). Patients who underwent surgery were less likely to have worse myelopathy scores at follow-up (odds ratio = 0.48 [0.25, 0.93], *P* = .029).

CONCLUSION: Surgical stabilization is associated with better myelopathy scores at follow-up and causes lower rates of fracture nonunion, 30-day mortality, and 1-year mortality.

KEY WORDS: Odontoid, Dens, Odontoid fracture, Dens fracture, Axis fracture, Spine fracture, Spine trauma

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Odontoid fractures are the most common traumatic cervical fracture of the older patients.[1] Surgical intervention is risky in this population,[1] but conservative management is associated with high rates of fracture nonunion.[2-5] Moreover, existing literature suggests a substantial rate of delayed morbidity associated with nonoperative management.[6-9] Indeed, a recent meta-analysis showed a trend toward significance for a mortality benefit with surgical stabilization.[10] However, there is significant selection bias in the existing literature because many series identify differences between surgical and nonoperative groups, but do not control or adjust for them.[5,8,10-18]

In the trauma context, 30-day mortality may be driven by associated injuries other than the odontoid fracture itself. The Injury Severity Score (ISS) is a well validated measure of mortality

ABBREVIATIONS: AUROC, area under the receiver operator curve; **ATE,** average treatment effect; **CCI,** Charlson Comorbidity Index; **EBL,** estimated blood loss; **ESRD,** end stage renal disease; **HR,** hazard ratio; **ICH,** intracranial hemorrhage; **ISS,** Injury Severity Score; **med,** median; **OC,** occipito-cervical.

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in the trauma literature but remains underused in the traumatic odontoid fracture literature.[19] Moreover, spine patients selected for intensive care unit (ICU) admission are known to represent a high-risk patient subgroup; therefore, a providers' clinical judgment to select a patient for ICU admission is likely to be clinically relevant.[20,21] In addition, neurological impairment may spur the decision to pursue surgery and which may affect a patient's long-term function and prognosis. Without controlling for these factors, any calculated survival benefit associated with surgery is highly confounded.

Here, we examine the effect of surgical stabilization on mortality in the odontoid fracture population at 30 days and 1 year using propensity score matched analysis. We do so while controlling for age, sex, comorbid disease burden, neurological status, ISS, and selection for ICU admission. We similarly assess the effect of surgery on fracture nonunion, controlling for multiple relevant features including age,[1,22,23] Anderson-D'Alonzo fracture type,[24] fracture angulation,[25] comminution,[26] and displacement. Moreover, we use ordinal multivariable logistic regression to examine the effect of surgical stabilization on myelopathy as measured by the Nurick score.

METHODS

Data Source

All patients with odontoid fractures who presented to Northwestern Memorial Hospital between January 1st, 2010, and December 31st, 2020, were identified using the Northwestern University Electronic Data Warehouse, an institutional data repository. The study was approved by the Northwestern University Institutional Review Board, and patient consent was waived given the study design.

Demographic and Clinical Data

We collected data on patients' age, sex, Charlson Comorbidity Index (CCI), ISS, any history of osteoporosis, and presenting Nurick score.[19,27] Odontoid fractures were excluded from the ISS calculations, ie, calculated ISSs reflected the severity of all injuries the patient sustained other than their odontoid fracture. By convention, an ISS ≥15 was considered severe.[28] Age was treated as a continuous variable scaled by 10, so calculated odds ratios for age reflect the odds associated with a change in age of 10 years.

Odontoid fractures were classified using the Anderson-D'Alonzo classification system into Types I, II, and III.[24] Comminution, angulation, and displacement ≥3 mm were screened for from attending radiology reports and notes from treating providers, and then, diagnostic studies were reviewed for confirmation of accuracy. Bony healing was defined as osseous bridging between the fracture fragment and the axis.

Data Management

Microsoft Excel version 16.661 (Microsoft) was used to manage data. Statistical analysis was performed using and Stata 12.0 (StataCorp) and Prism 9.4.0 (GraphPad Software, Inc.).

Outcomes

Mortality rates were assessed at 30 days and 1 year. Rates of fracture nonunion were assessed after 26 weeks of follow-up and overall including the total duration of follow-up. Myelopathy was assessed by Nurick scores at first follow-up and at 1 year.

Statistical Analysis

For univariate analysis, Student *t*-tests were used for parametric comparisons, and the Mann-Whitney *U*-test or the Fisher exact test was used for nonparametric comparisons, with 1 exception: Nurick scores were compared between presentation and first follow-up and between presentation and 1-year follow-up, using a Wilcoxon matched-pairs signed-rank test. As Nurick scores are an ordinal outcome, stepwise, backward, ordinal multivariable logistic regression was used to identify factors associated with worsened Nurick scores at follow-up.

Nonordinal, stepwise, backward, multivariable logistic regression was used to identify factors independently associated with binary outcomes of interest (death and fracture nonunion). Two nearest-neighbor propensity score matching was used to calculate the average treatment effect (ATE) of surgical stabilization on fracture nonunion and mortality. The STATA psmatch2 algorithm using a logit model was used for full Mahalanobis propensity score matching.[29] Treatment observations were excluded from analysis if their propensity scores were outside the control group's propensity score range, to impose common support.

The following variables were controlled for when assessing the effect of surgery on nonunion: age, fracture type, angulation, displacement ≥3 mm, and comminution.[23] The following variables were controlled for when assessing mortality: age, sex, ISS, presenting Nurick score, CCI, and ICU admission. The following variables were controlled for when assessing predictors of Nurick scores at follow-up: age, sex, presenting Nurick score, surgical stabilization, CCI, type II fracture, fracture angulation, and ISS.

The balance of the propensity score matched model was assessed by calculating Rubin's B and Rubin's R values for the model using the STATA pstest algorithm. Rubin's B ≤ 25 and 0.5 ≤ Rubin's R ≤ 2.0 were used as thresholds to define a balanced model, as is standard.[30,31] Variables used in the propensity score model were compared between treatment and control groups before and after matching. Mean bias and median bias were calculated before and after matching, as well as percent bias and bias reduction. The ATE was calculated for balanced models, for which *P*-values and 95% confidence intervals were calculated by bootstrapping Abadie-Imbens heteroskedasticity-consistent analytical standard errors.[32,33]

RESULTS

Clinical and Demographic Characteristics

Three hundred twenty-five patients with odontoid fracture were identified, of whom 303 had an identifiable traumatic etiology. The average age of the population was 72.7 ± 17.3 years, and 48.8% of patients were male (Table 1). Mean presenting Nurick score was 2.3 ± 1.7, CCI was 4.4 ± 2.5, and ISS was 2.1 ± 4.7. 25.1% had concomitant C1 fractures, and 7.8% had concomitant subaxial cervical spine fractures. 65.4% of patients had type II odontoid fractures, 33.3% had type II fractures, and 2.2% had type I fractures. 21.6% had angulated fractures, and 16.9% had comminuted fractures.

TABLE 1. Clinical and Demographic Data for 303 Patients With Traumatic Odontoid Fractures

Clinical characteristic	Overall	Surgical	Nonoperative	*P* value
Age (mean ± SD)	72.7 ± 17.3	67.4 ± 15.6	74.6 ± 17.5	<.001
Male sex (%)	48.8%	50.0%	48.0%	.786
CCI (med [IQR])	4 [3, 6]	4 [2, 6]	4 [3, 6]	.318
Angulation (%)	23.8%	30.0%	22.2%	.202
Comminution (%)	16.2%	15.7%	16.9%	1.000
Fracture type (%)				
Type I	2.0%	1.4%	2.2%	1.000
Type II	67.7%	72.8%	65.8%	.308
Type III	31.4%	27.1%	32.9%	.462
Nurick (med [IQR])				
Presentation	2 [1, 4]	3 [2, 4]	1 [1, 4]	<.001
First follow-up	1 [0, 4]	2 [0, 4]	1 [0, 4]	.076
1 year	1 [0, 3]	2 [0, 4]	1 [0, 3]	.226
C1 fracture (%)	24.4%	20.0%	25.3%	.425
Subaxial fracture (%)	6.9%	1.4%	8.0%	.053

CCI, Charlson Comorbidity Index; med, median.

Management and Selection for Surgery

Of 296 patients for whom initial management data were available, 64 patients (21.6%) underwent surgical stabilization during their index hospitalization, 14 patients (4.8%) underwent halo vest immobilization, and the remainder were treated with cervical collar only.

On univariate analysis, patients selected for surgery were younger (75 ± 17 vs 67 ± 16, *P* = .0001), had worse Nurick scores at presentation (0.041), and were more likely to have been admitted to the ICU (*P* = .0021). There were no differences between populations with respect to sex, CCI, fracture type, injury severity score, or the presence of fracture angulation, comminution, displacement ≥3 mm, concomitant subaxial cervical spine fractures, or concomitant C1 fractures. On multivariable regression, selection for surgery was positively associated with Nurick score at presentation (odds ratio [OR] = 1.36 [1.13, 1.64], *P* = .001) and negatively associated with age (OR = 0.77 [0.65, 0.91], *P* = .003) (area under the receiver operator curve [AUROC] = 0.71).

Of the 64 patients managed surgically, 27 (42.2%) underwent C1/C2 posterior cervical instrumentation and fusion (Table 2; Figure 1). 15 patients underwent occipito-cervical (OC) fusion, and 4 patients underwent anterior approaches as part of their care: 2 patients underwent odontoid screw placement, and 2 patients underwent multilevel anterior and posterior stabilization and fusion. Median estimated blood loss (EBL) was 200 [100, 300], and median length of surgery was 4.2 hours [3.0, 5.5].

After correcting for multiple comparisons, there were no baseline differences on univariate analysis between patients who underwent OC fusion compared with other surgical interventions. On multivariable analysis, selection for OC fusion was positively associated with concomitant C1 fracture (OR = 6.78 [1.01, 45.59], *P* = .049) and negatively associated with male sex (OR = 0.19 [0.04, 0.90], *P* = .036).

Patients who underwent OC fusion had longer lengths of stay (*P* = .0259), but were not statistically different with respect to length of surgery (*P* = .4833), EBL (*P* = .3396), use of transfusion (*P* = 1.0000), improvement in Nurick score at first follow-up (*P* = .2510) or 1 year (*P* = .3017), or rates of nonunion at 26 weeks (*P* = .5485).

Follow-up Data

Mean follow-up time was 44.7 weeks. Thirty-day mortality data were available for all patients, and the overall 30-day mortality rate was 9.6%. 1-year mortality data were available for 278 patients (91.7%), and the 1-year mortality rate was 13.3%. Data on the presence or absence of nonunion were available for 242 patients (79.9%), and data for nonunion at 26 weeks were available for 196 patients (64.7%). Presenting Nurick scores were available for 295 patients, and Nurick scores were available at first

TABLE 2. Clinical Data for Patients With Odontoid Fracture Managed Surgically

Pathology	
Isolated odontoid Fx (n, %)	50 (78.1%)
Atlas fracture (n, %)	13 (20.3%)
Subaxial fracture (n, %)	1 (1.6%)
Management	
C1/C2 PSF (n, %)	27 (42.2%)
Anterior approach (n, %)	4 (6.3%)
Odontoid screw (n, %)	2 (3.1%)
OC fusion (n, %)	15 (23.4%)
Procedural data	
EBL (mL) (med [95% CI])	200 [100, 300]
Surgery duration (h) (med [95% CI])	4.2 [3.0, 5.5]

EBL, estimated blood loss; med, median; OC, occipito-cervical; PSF, posterior spinal fusion.

follow-up for 246 patients (83.4%) and at 1 year for 77 patients (26.1%).

The Effect of Surgery on Nonunion

On multivariable logistic regression, nonunion at 26 weeks was found to be independently, positively associated with type II fractures (OR = 2.03 [1.07, 3.83], P = .029) and negatively associated with surgical stabilization (OR = 0.46 [0.24, 0.89], P = .020) (AUROC = 0.67) (Table 3). Balanced models could not be obtained for the effect of surgical stabilization on nonunion at 26 weeks.

Nonunion overall was independently, positively associated with type II fractures (OR = 2.61 [1.42, 4.81], P = .002), fracture angulation (OR = 2.38 [1.24, 4.60], P = .009), and age (OR = 1.40 [1.15, 1.70], P = .001) and was negatively associated with surgical stabilization (OR = 0.49 [0.24, 0.97], P = .041) (AUROC = 0.72).

Propensity score analysis showed unbalanced populations before matching (Rubin's B = 70.7, Rubin's R = 1.31) and balanced models after matching (Rubin's B = 21.9, Rubin's R = 0.64) (Table 4). After matching, median bias was 8.8%, representing a 66.5% reduction in median bias, and no covariates were significantly different between populations after matching (**Appendix 1**, http://links.lww.com/NEU/D843). The overall rate of nonunion was 39.7% in the surgical group and 57.3% in the nonoperative group (ATE = −0.153 [−0.279, −0.028], P = .017) (Figure 2).

The Effect of Surgery on Neurological Recovery

On the Wilcoxon matched-pairs signed-rank test, Nurick myelopathy scores were significantly improved at first follow-up for both the surgery (P < .001) and the nonoperative management groups (P < .001) (Figure 3), with strong monotonic correlations for both groups (surgery Spearman R = 0.821, P < .001; nonoperative Spearman rho = 0.907, P < .001). Similarly, Nurick scores had improved significantly at 1 year for both the surgery group (P < .001; Spearman rho = 0.821, P < .001) and the nonoperative management group (P < .001; Spearman rho = 0.832, P < .001).

Excluding patients who died, on ordinal multivariable logistic regression, higher Nurick scores at first follow-up were more likely with higher CCI (OR = 1.15 [1.02, 1.30], P = .018) and presenting Nurick scores (OR = 15.28 [9.78, 23.87], P < .001) and were less likely with surgery (OR = 0.48 [0.25, 0.93], P = .029). Higher Nurick scores at 1 year were more likely with older age (OR = 2.28 [1.42, 3.67], P = .001) and higher presenting Nurick (OR = 9.01 [4.55, 17.83], P < .001) and were less likely with isolated odontoid fracture (OR = 0.20 [0.06, 0.69], P = .011).

The Effect of Surgery on Mortality

Unadjusted, there was no difference in survival between patients who underwent surgery and patients who did not (surgical group hazard ratio [HR] = 0.477 [0.206, 1.102], P = .0832). Adjusting for age, sex, CCI, ISS, Nurick score at presentation, and ICU admission, Cox proportional hazards analysis demonstrated that surgical stabilization conferred a significant mortality benefit (HR = 0.587 [0.426, 0.799], P = .0009), and the model significantly departed significantly from an unadjusted model (log-likelihood ratio P = .0015) (Table 5).

On multivariable regression, factors independently, positively associated with 30-day mortality were Nurick score at presentation (OR = 1.58 [1.18, 2.10], P = .002) and CCI (OR = 1.39 [1.14, 1.69], P = .001), and undergoing surgery was negatively associated (OR = 0.11 [0.01, 0.89], P = .039) (AUROC = 0.82). On propensity score matched analysis, controlling for age, sex, Nurick score at presentation, Charlson Comorbidity Index, ISS, and ICU admission, the mortality rate at 30 days was 1.7% in the surgical group vs 13.8% in the nonoperative group (ATE = −0.101 [−0.172, −0.030], P = .005).

Factors positively associated with mortality at 1 year were Nurick at presentation (OR = 1.73 [1.30, 2.30], P < .001), CCI (OR = 1.51 [1.23, 1.85], P < .001), and odontoid type II fracture morphology (OR = 4.66 [1.41, 15.38], P = .012) (AUROC = 0.88). On propensity score matched analysis, controlling for age, sex, Nurick score at presentation, Charlson Comorbidity Index, ISS, and ICU admission, the mortality rate at 1 year was 7.0% in the surgical group vs 23.7% in the nonoperative group (ATE = −0.099 [−0.181, −0.017], P = .018).

Among all patients who died within 1 year of their index fracture, cause of death data was available for 35 of them, including 4 patients who underwent surgical intervention and 31 patients who underwent conservative care. These causes are summarized in Figure 4, and there was no significant difference in the distribution of causes between groups (analysis of variance P = .780).

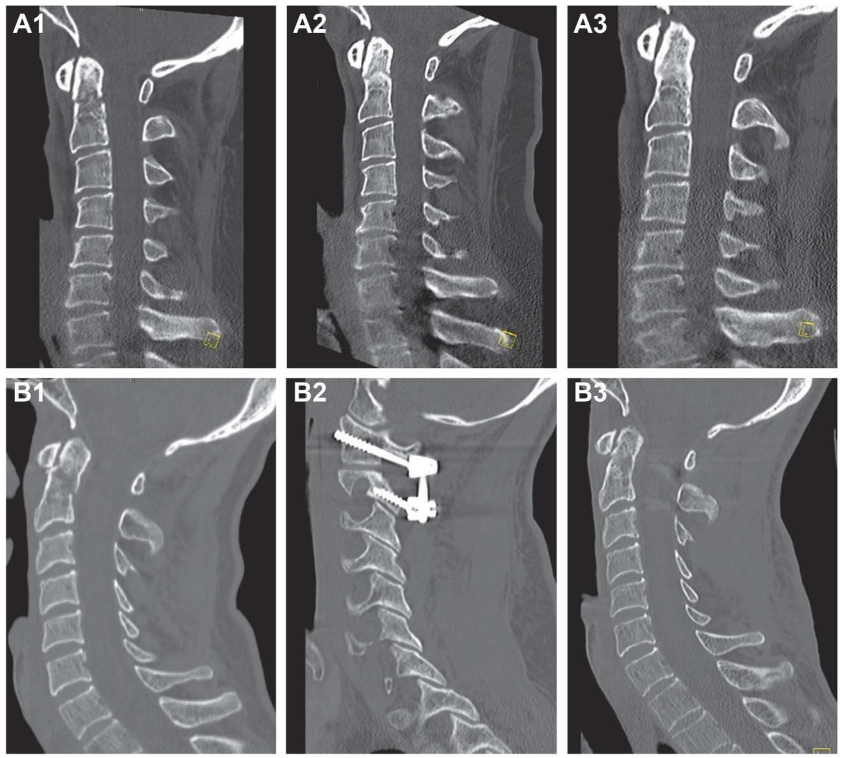

FIGURE 1. *Two illustrative cases. Case A is that of a middle-aged woman injured in a motor vehicle collision, found on trauma workup to have* **A1***, a nondisplaced type II odontoid fracture that was treated with a rigid cervical orthosis and showed progressive healing at* **A2***, 4 months and* **A3***, 7 months after the injury. Case B is that of a middle-aged man injured in a cycling accident who had neck pain with movement and was neurologically intact on examination. CT revealed* **B1***, a mildly displaced and angulated type II odontoid fracture treated with* **B2***, C1-C2 posterior fixation with* **B3***, excellent bony healing on follow-up CT.*

DISCUSSION

Odontoid fractures are the most common traumatic cervical fractures among the older patients, but the high surgical risk associated with the affected population makes surgical decision-making challenging. A growing body of evidence suggests a mortality benefit with surgical stabilization but often does not control for confounding.[10] Here, using propensity score adjustment to control for age, comorbid disease burden, myelopathy, ISS, and selection for ICU admission, we find that surgical stabilization causes a mortality benefit at 30 days and at 1 year. Moreover, we replicate this finding on Cox proportional hazards analysis. Similarly, while controlling for features including age, fracture type, fracture angulation, comminution, and displacement, we find that surgery leads to lower rates of fracture nonunion on propensity score matched analysis. Finally, we demonstrate with ordinal multivariable logistic regression that surgical stabilization leads to decreased odds of worsened myelopathy at follow-up. Our study represents a relatively large institutional series that suggests a benefit from surgical stabilization in this population while controlling for confounding factors more thoroughly than existing literature.

The mortality benefit calculated in the existing literature typically represents an unadjusted mortality rate between 2 potentially different populations, which leaves it liable to confounding. Indeed, the meta-analysis by Pommier et al cited 15 studies in which surgical intervention was associated with a lower mortality risk, but most of the cited studies did not adjust for baseline differences between surgical and nonsurgical patients, despite collecting data that demonstrated that such differences existed.[5,8,10-18] Similarly, in a systemic review from Robinson et al,[34] patients undergoing surgical stabilization had a lower mortality rate, but adjustment for confounding was not performed.

Some investigators have attempted to control for confounding, which we build on by including additional controls in our analysis. Chapman et al[35] found that surgery was associated with a reduced mortality risk when adjusting for age, sex, and CCI. Schoenfeld et al[36] found a mortality benefit when controlling for age alone. However, these series do not adjust for other commonly

TABLE 3. Results of Multivariable Regression Identify Factors Independently Associated With the Outcomes of Interest

Outcome	OR	95% CI	*P* value
Nonunion			
By 26 weeks			
Surgery	0.46	[0.24, 0.89]	.020
Isolated fracture	0.65	[0.34, 1.25]	.193
Angulated fracture	1.63	[0.83, 3.18]	.153
Type II fracture	2.03	[1.07, 3.83]	.029
Overall			
Surgery	0.49	[0.24, 0.97]	.041
Age	1.40	[1.15, 1.70]	.001
Isolated fracture	1.63	[0.87, 3.06]	.126
Angulated fracture	2.38	[1.24, 4.60]	.009
Type II fracture	2.62	[1.42, 4.81]	.002
Comminuted fracture	1.65	[0.78, 3.52]	.192
Myelopathy severity*			
At first follow-up			
CCI	1.15	[1.02, 1.30]	.018
Surgery	0.48	[0.25, 0.93]	.029
Presenting Nurick	15.28	[9.78, 23.87]	<.001
At 1 year			
Age	2.28	[1.42, 3.67]	.001
Presenting Nurick	9.01	[4.55, 17.83]	<.001
Isolated fracture	0.20	[0.06, 0.69]	.011
Angulated fracture	0.28	[0.07, 1.18]	.083
Mortality			
At 30 days			
Surgery	0.11	[0.01, 0.91]	.040
CCI	1.39	[1.14, 1.69]	.001
Presenting Nurick	1.57	[1.17, 2.09]	.002
At 1 year			
Surgery	0.33	[0.10, 1.10]	.072
CCI	1.51	[1.25, 1.82]	<.001
Presenting Nurick	1.68	[1.27, 2.22]	<.001

CCI, Charlson Comorbidity Index; OR, odds ratio.
Myelopathy severity was measured with the Nurick score, which is nonbinary; therefore, ordinal multivariable logistic regression was performed. Other outcomes were binary and used nonordinal multivariable logistic regression.

TABLE 4. Comparisons Between Balancing Statistics Before and After Propensity Score Matching

Outcome	Unmatched	Matched
Nonunion		
By 26 weeks		
Mean bias %	20.6%	18.7%
Median bias %	22.1%	23.5%
Rubin's B	58.2	40.4
Rubin's R	1.31	0.94
Overall		
Mean bias %	24.8%	9.8%
Median bias %	26.3%	8.8%
Rubin's B	70.7	21.9
Rubin's R	1.31	0.64
Mortality		
At 30 days		
Mean bias %	25.5%	6.3%
Median bias %	26.5%	6.3%
Rubin's B	72.5	18.5
Rubin's R	0.69	1.05
At 1 year		
Mean bias %	24.6%	5.4%
Median bias %	23.3%	5.2%
Rubin's B	67.9	20.7
Rubin's R	0.71	0.59

accepted risk factors for negative outcomes: The ISS is a well validated predictor of trauma-related mortality, and spine patients selected for ICU admission are a high-risk population known to have an elevated incidence of adverse events.[19-21] Fagin et al[37] did collect data on ISS but did not adjust or control for this or other confounders with respect to mortality rate. Fehlings et al[38] adjusted for demographic, comorbid disease burden, and ISS but did not examine mortality rate alone, instead assessing a compositive of death, worsened neck disability index, and treatment-related complications using Cox proportional hazards analysis. Here, we build on these prior analyses by performing both Cox proportional hazards analysis and propensity score matched analysis to robustly demonstrate our finding that there is a mortality benefit from surgical stabilization for patients with traumatic odontoid fractures.

The higher rate of bony union we observed with surgical stabilization is consistent with prior analyses and builds on them

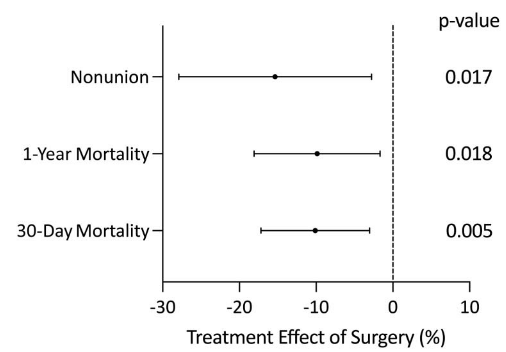

FIGURE 2. *Forest plot depicting the average treatment effect of surgery on nonunion and mortality for patients with traumatic odontoid fractures, calculated using propensity score matching. Bootstrapped P-values and 95% CI were calculated from Abadie-Imbens heteroskedasticity-consistent analytical standard errors.*

TABLE 5. Cox Proportional Hazards Analysis of Mortality After Odontoid Fracture

Variable	HR	95% CI	*P* value
Age	0.995	[0.984, 1.006]	.382
Male sex	1.190	[0.916, 1.546]	.193
CCI	0.972	[0.904, 1.043]	.439
Severe ISS	1.906	[0.768, 4.063]	.124
ICU admission	0.769	[0.586, 1.008]	.057
Surgery	0.587	[0.426, 0.799]	.001
Presenting Nurick	1.078	[0.987, 1.176]	.094

CCI, Charlson Comorbidity Index; HR, hazard ratio; ISS, injury severity score; ICU, intensive care unit.
The model departed significantly from an unadjusted model (log-likelihood ratio *P* = .0015).

by calculating that the treatment effect of surgery is a 15.3% increase in fracture union. Prior meta-analyses have demonstrated decreased rates of nonunion with surgical stabilization, and such a result is therefore expected.[10,34] To the best of our knowledge, however, ours is the first investigation to use propensity score analysis to quantify the treatment effect of surgical stabilization on fracture union while controlling for confounding factors.

Similarly, our finding that surgery was associated with improved myelopathy scores is consistent with existing literature. Vaccaro et al and Smith et al noted worse functional outcomes over time with nonoperative management.[8,9] Our finding that surgery was independently associated with better Nurick scores reinforces these prior analyses.

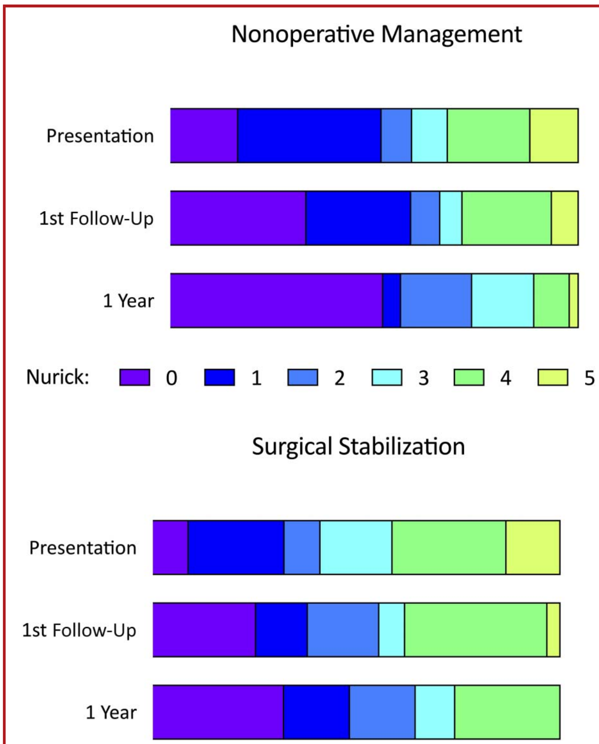

FIGURE 3. *Nurick scores at presentation, first follow-up, and 1 year for patients with traumatic odontoid fractures, stratified by whether the patient was managed with surgical stabilization or nonoperative management.*

Limitations

Our study has limitations. It was conducted retrospectively and therefore has the weaknesses associated with this study design. We

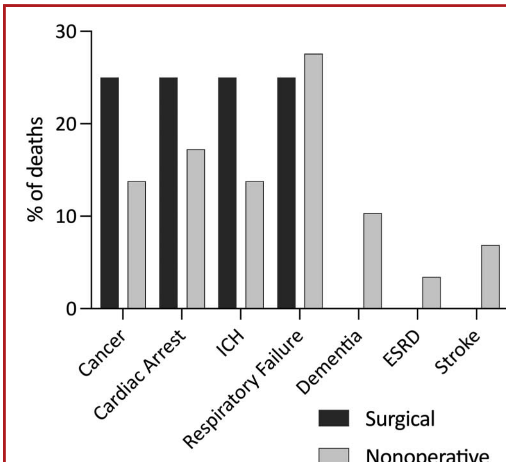

FIGURE 4. *Cause of death at 1 year for patients with traumatic odontoid fractures, stratified by whether the patient was managed with surgical stabilization or nonoperative management. ESRD, end-stage renal disease; ICH, intracranial hemorrhage; PE, pulmonary embolism.*

use propensity score matching, which eliminates patients from analysis who cannot be matched, yielding a curated patient population that may not be generalizable to dissimilar populations. Moreover, while propensity score matched analysis is a powerful tool for controlling for known confounders, it cannot control for unknown confounders, which may continue to bias results. Additionally, there was loss to follow-up in our study, which may have underpowered or biased our analysis with respect to the outcomes assessed. With respect to fracture nonunion, a growing body of evidence suggests that nonunion is not synonymous with instability and that other outcomes should be examined instead.[39] Finally, while we found no difference in cause of death between groups, our sample is likely underpowered to detect a difference if 1 exists. Despite these limitations, to our knowledge, our study is the first to demonstrate a mortality benefit with surgical fixation for patients with odontoid fractures using both Cox proportional hazards analysis and propensity score matched analysis. Moreover, we have done so while controlling more thoroughly for possible confounders than have prior series.

CONCLUSION

Patient age and myelopathy drive selection for surgery. Surgical stabilization was associated with better myelopathy scores at follow-up and caused lower rates of fracture nonunion, 30-day mortality, and 1-year mortality.

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Disclosures

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Appendix 1. Comparison between patients with surgical and nonoperative odontoid fracture before and after propensity score matching. *P*-values assess any differences between the surgical and nonoperative groups and are assessed both before matching and after matching. Percent bias reduction reflects the change in measured bias after matching as compared with before matching.