Original Article

The demographic, clinical, and management differences between traumatic dens fracture patients with and without simultaneous atlas fractures

ABSTRACT

Introduction: Atlas fractures often accompany traumatic dens fractures, but existing literature on the management of simultaneous atlantoaxial fractures is limited.

Methods: We examined all patients with traumatic dens fractures at our institution between 2008 and 2018. We used multivariable logistic regression and ordinal logistic regression to identify factors independently associated with presentation with a simultaneous atlas fracture, as well myelopathy severity, fracture nonunion, and selection for surgery.

Results: Two hundred and eighty-two patients with traumatic dens fractures without subaxial fractures were identified, including 65 (22.8%) with simultaneous atlas fractures. The distribution of injury mechanisms differed between groups (χ^2 $P = 0.0360$). On multivariable logistic regression, dens nonunion was positively associated with type II fractures (odds ratio [OR] = 2.00, $P = 0.038$) and negatively associated with having surgery (OR = 0.52, $P = 0.049$), but not with having a C1 fracture ($P = 0.3673$). Worse myelopathy severity on presentation was associated with having a severe injury severity score (OR = 102.3, $P < 0.001$) and older age (OR = 1.28, $P = 0.002$), but not with having an atlas fracture ($P = 0.2446$). Having a simultaneous atlas fracture was associated with older age (OR = 1.29, $P = 0.024$) and dens fracture angulation (OR = 2.62, $P = 0.004$). Among patients who underwent surgery, C1/C2 posterior fusion was the most common procedure, and having a simultaneous atlas fracture was associated with selection for occipitocervical fusion (OCF) (OR = 14.35, $P = 0.010$).

Conclusions: Among patients with traumatic dens, patients who have simultaneous atlas fractures are a distinct subpopulation with respect to age, mechanism of injury, fracture morphology, and management. Traumatic dens fractures with simultaneous atlas fractures are independently associated with selection for OCF rather than posterior cervical fusion alone.

Keywords: Atlantoaxial, atlas, C1, C2, dens, fracture, odontoid

INTRODUCTION

Traumatic dens fractures are often accompanied by fractures of the atlas, highlighting the need for evidence-based management strategies for simultaneous injuries.[1-3] Historic series on simultaneous atlantoaxial fractures have based management on the morphology of the dens fracture.[4-8] However, these series often lack comparison groups to assess the validity of the management strategies that were reported.[4-6,9] Indeed, recent guidelines on atlantoaxial fracture management noted that only 7 out of 47 series identified from the literature (14.9%) included more than 10 patients.[10] Moreover, the existing literature on the

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management of simultaneous atlantoaxial fractures often does not control for confounders that are relevant to clinical outcomes, which precludes drawing evidence-based conclusions about the most effective treatment options for atlantoaxial fractures. As such, while it is standard practice to manage simultaneous dens-atlas fractures according to the dens fracture's morphology, there are little data on the effect of atlas fractures on dens fracture outcomes.[5,9]

Here, we examined patients with dens fractures and identified risk factors for simultaneous fractures of the atlas, as well as the impact of these fractures on clinical outcomes. Specifically, we analyzed the need for surgical intervention, the severity of myelopathy, and the occurrence of fracture nonunion at follow-up with and without simultaneous atlas fractures.

METHODS

Data sources

We examined all patients with traumatic dens fractures at our institution between January 2008 and December 2018 and identified any other simultaneous cervical spine fractures. Patients were identified using an institutional data repository that allows patient records to be searched using structured query language, using both the International Classification of Diseases codes and natural language. Patients who presented to our institution during the study period with a new diagnosis of a dens fracture were retrospectively reviewed. Patients without identifiable traumatic events leading up to presentation were excluded from the analysis. Patients with subaxial fractures were excluded from the analysis. Dens fracture patients with and without simultaneous atlas fractures were compared. The study was approved by our Institutional Review Board. Given the retrospective study design, patient consent was waived.

Clinical and demographic variables

Data on age and sex were collected on all patients. Comorbid disease was quantified using the Charlson Comorbidity Index (CCI).[11] Data on the following clinical variables were collected: mechanism of injury, whether the patient had any simultaneous atlas or subaxial fracture, severity of myelopathy, and overall traumatic injury severity. Myelopathy severity was quantified using the Nurick score.[12] Traumatic injury severity was quantified using the Injury Severity Score (ISS) and was calculated for each patient's injuries other than their index dens fracture.[13,14] As patients selected for intensive care unit (ICU) admission are known to represent a high-risk patient subgroup, selection for ICU admission was included as a binary variable.[15,16]

Prior series have established links between fracture nonunion and age,[17-19] and surgical fixation,[20] as well as dens fracture morphological characteristics including fracture type,[21,22] angulation,[22,23] displacement,[24,25] and comminution.[8,26] As such, data were collected on Anderson and D'Alonzo fracture type,[21] fracture angulation $>10°$, fracture displacement ≥ 3 mm, and fracture comminution.

Data management and statistical analysis

Data were managed with Microsoft Excel version 16.61 (Microsoft, Redmond, WA, USA). Data visualization was performed with Prism 9.0b (GraphPad Software, Inc., La Jolla, CA, USA). Data analysis was performed using Stata 12.0 (StataCorp, College Station, TX, USA) and Prism 9.0b.

For regression analysis, CCI and Nurick score were treated as ordinal variables. Age was treated as a continuous variable but scaled by a factor of 10, such that associated odds ratios (ORs) reflect a change in odds due to a 10-year change in patient age. Fracture type was treated as a binary variable (type II fracture versus nontype II fracture). ISS was treated as a binary variable, severe versus not severe, as is conventionally defined by ISS ≥ 15.[13,14] Fracture angulation $>10°$, comminution, and displacement ≥ 3 mm were all treated as binary variables by their presence or absence. As mechanisms of injury may affect clinical presentation, mechanisms of injury were recorded and classified as fall, motor vehicle collision (MVC), or other.[18,27,28]

For univariate analysis, means and standard deviations were presented. Binary variables were compared with Fisher's exact test, and OR and their 95% confidence intervals were calculated. Multiway contingency comparisons were performed with the Chi-square test. Normality was not assumed; therefore, continuous and ordinal variables were compared with the Mann–Whitney *U*-test.

Data on selection for surgery and fracture nonunion at follow-up were treated as binary outcomes and analyzed using stepwise, backward multivariable logistic regression. Myelopathy severity at follow-up was treated as an ordinal outcome and analyzed with ordinal multivariable logistic regression. $P < 0.20$ was used as a threshold for retention in the multivariable model, and $P < 0.050$ was considered statistically significant.

RESULTS

Demographics and clinical characteristics

Three hundred and twenty-five odontoid fracture patients were identified, of whom 22 were excluded for having a nontraumatic etiology [Figure 1]. Sixty-five patients had simultaneous dens-atlas fractures (21.5%), more than all

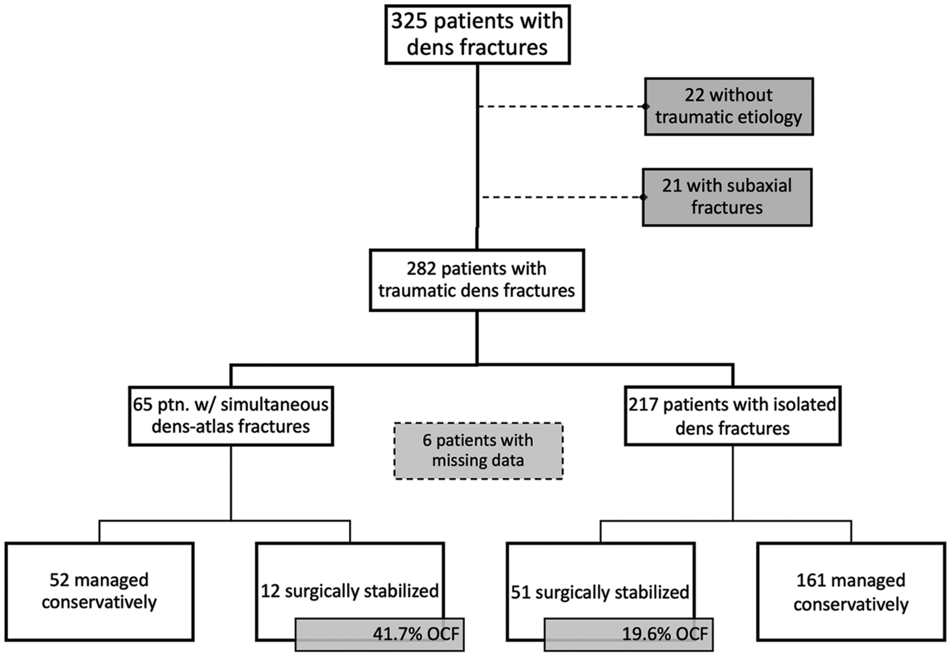

Figure 1: Patient population flowchart demonstrating the patients included and excluded from this series

Table 1: Baseline Clinical and Demographic Characteristics

	All Patients	Dens-Atlas Fractures	Isolated Dens Fracture	*P*
Demographics				
Age (mean±SD)	73±17	77±14	71±18	0.0829
Male sex (*n*, %)	135 (47.9%)	28 (44.6%)	106 (48.8%)	0.5739
Injury mechanism				0.0360
Fall (*n*, %)	201 (71.3%)	54 (83.1%)	147 (67.7%)	0.0187
Motor vehical collision (*n*, %)	48 (17.0%)	8 (12.3%)	40 (18.4%)	0.3464
Other (*n*, %)	34 (12.1%)	3 (4.6%)	31 (14.3%)	0.0483
Clinical baseline				
Nurick Score (mean±SD)	2.3±1.7	2.7±1.8	2.2±1.7	0.0509
CCI (mean±SD)	4.4±2.5	4.8±2.1	4.3±2.6	0.3035
Severe ISS (*n*, %) (*n*=274)	9 (3.3%)	3 (4.9%)	6 (2.8%)	0.4216
ICU admission (*n*, %) (*n*=272)	127 (46.7%)	31 (50.0%)	96 (45.7%)	0.5656
Dens Fracture Characteristics				
Angulation (*n*, %)	65 (23.0%)	23 (35.4%)	42 (19.4%)	0.0112
Comminution (*n*, %)	46 (16.3%)	13 (20.0%)	33 (15.2%)	0.3458
Displacement ≥3 mm (*n*, %)	48 (17.0%)	13 (20.0%)	35 (16.1%)	0.4569
Anderson-D'Alonzo Type				0.1773
Type I (*n*, %)	6 (2.1%)	0 (0.0%)	6 (2.8%)	0.3419
Type II (*n*, %)	191 (67.7%)	48 (77.4%)	143 (65.0%)	0.0672
Type III (*n*, %)	88 (31.2%)	17 (26.2%)	71 (32.7%)	0.3617
Initial Management (*n*=276)				0.4634
Collar (*n*, %)	196 (71.0%)	46 (75.4%)	150 (69.8%)	0.4280
Halo (*n*, %)	12 (4.3%)	4 (6.6%)	8 (3.7%)	0.3074
Surgery (*n*, %)	63 (22.8%)	12 (18.75%)	51 (24.1%)	0.3754

subaxial fractures ($n = 21$) combined (21.5% vs. 6.9%, $P < 0.0001$). Patients with subaxial fractures were excluded, leaving 282 patients. Their average age was 72.7 ± 17.3 years, and 47.9% of patients were male [Table 1]. Regarding the mechanism of injury, 201 patients had falls (71.8%), 48 had MVCs (17.1%), and 33 patients (11.7%) had other injury mechanisms.

For all patients, the mean presenting Nurick score was 2.3 ± 1.7 and CCI was 4.4 ± 2.5. ISS was available on

274 patients (97.2%), and 3.3% a severe ISS. ICU admission data were available on 272 patients, of whom 46.7% were admitted to the ICU on presentation. 2.2% of patients had type I fractures, 65.4% had type II odontoid fractures, and 33.3% had type III fractures. 21.6% had angulated fractures, and 16.9% had comminuted fractures. Sixty-three patients (22.8%) underwent surgical stabilization during their index hospitalization, 12 patients (4.4%) underwent halo vest immobilization, and the remainder were treated with rigid cervical collar only.

Demographic and clinical comparisons

The distribution of injury mechanisms differed between groups (χ^2 $P = 0.0360$) [Figure 2]. Patients with simultaneous dens-atlas fractures were more likely to have falls as their mechanism of injury (83.1% vs. 67.7%, OR = 2.34 [1.16–4.69], $P = 0.0187$) and were more likely to have angulated fractures (35.3% vs. 19.4%, OR = 2.28 [1.25–4.18], $P = 0.0112$) [Table 1].

Patients with atlas fractures were no different with respect to age (0.0829), sex ($P = 0.5739$), myelopathy severity at presentation ($P = 0.0509$), CCI ($P = 0.3035$), severe ISS ($P = 0.4216$), or ICU admission ($P = 0.5656$). There was no overall difference in the distribution of fracture types between patients with and without simultaneous atlas fractures (χ^2 $P = 0.1773$), comminution ($P = 0.3458$), or displacement ≥3 mm ($P = 0.4569$). Among patients with simultaneous atlas fractures, there was no association between atlas fracture type and dens fracture type (0.4820) [Table 2].

On multivariable logistic regression, simultaneous atlas fractures were independently associated with older age (OR = 1.29 [1.03–1.61], $P = 0.024$) and dens fracture angulation (OR = 2.62 [1.35–5.07], $P = 0.004$) [Table 3 and Figure 3].

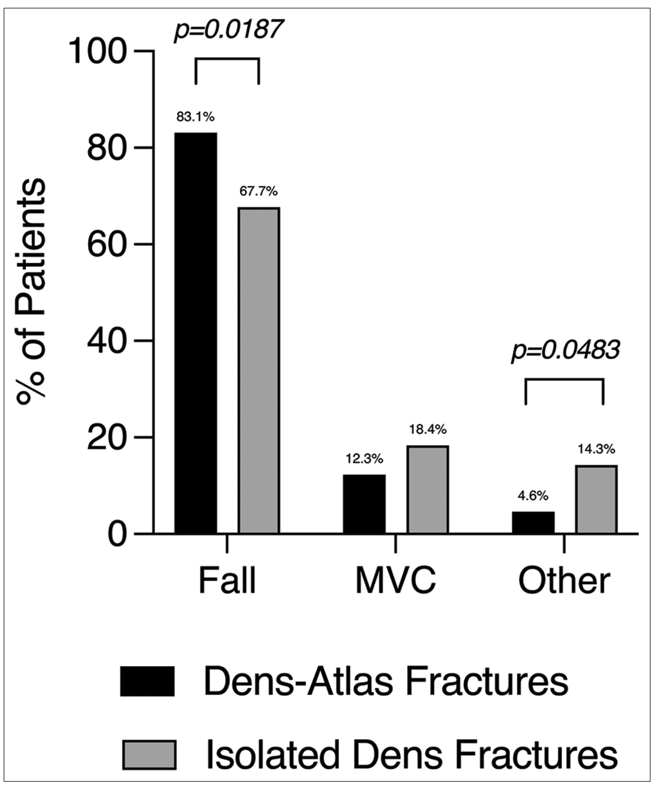

Figure 2: The percent of patients with each category of injury mechanism, stratified by whether they had a simultaneous dens-atlas fracture or isolated dens fracture. The overall distribution varied significantly between groups (χ^2 $P = 0.0360$). MVC - Motor vehicle collision

Management decisions

Data on the choice of management were available for 276 patients (97.9%). There was no overall difference in the distribution of management choices between groups (χ^2 $P = 0.4634$). Patients with simultaneous fractures were

Table 2: Fracture types for patients with simultaneous dens-atlas fractures

	Dens Fracture Type		
	Type I	Type II	Type III
Atlas Fracture Type			
Type 1	0	13	5
Type 2	0	11	2
Type 3	0	18	5
Type 4	0	4	4
Type 5	0	2	1

Table 3: Factors associated with simultaneous dens-atlas fractures

	OR	95% CI	*P*
Age	1.29	[1.03, 1.61]	0.024
Fracture Angulation	2.62	[1.35, 5.07]	0.004
OC Fusion*	14.35	[1.87, 110.42]	0.010

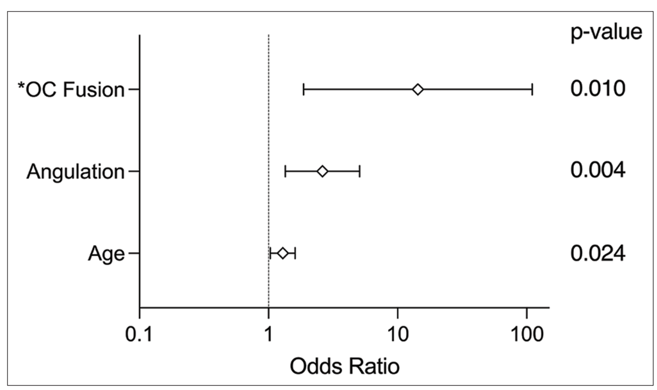

Figure 3: Forest plot depicting the odds ratios and confidence intervals of factors associated with having a simultaneous dens-atlas fracture. Note that myelopathy severity was assessed with ordinal logistic regression, while the other outcomes were assessed with logistic regression. *Note that simultaneous dens-atlas fracture predicted occipitocervical fusion, whereas age and fracture angulation predicted simultaneous dens-atlas fractures. OC - occipitocervical

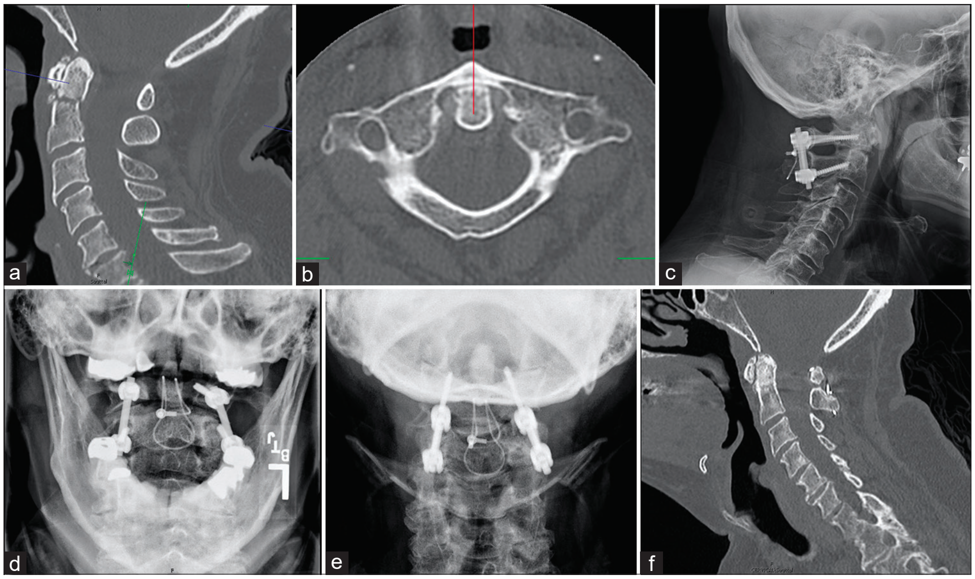

Figure 4: A 76-year-old man presented after a fall from standing with a computed tomography (CT) demonstrating an acute, nondisplaced type II dens fracture (a) with an intact atlas (b). The patient underwent C1/C2 posterior spinal fusion, with good alignment on postoperative lateral (c), open-mouth (d), and anterior-posterior vies (e). A follow-up CT showed interval bony healing of the dens fracture (f)

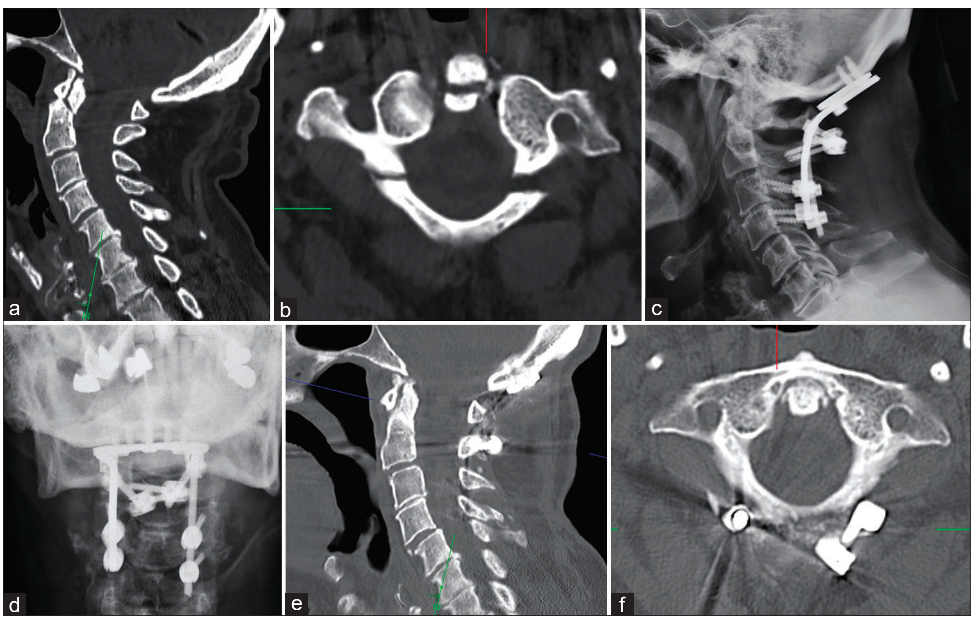

Figure 5: An 83-year-old man who presented after a fall with a computed tomography (CT) demonstrating a type II dens fracture (a) and type 2 atlas fracture (b). The patient underwent posterior fusion from occiput to C4 with C2 translaminar screws, with ostoperative plain films showed good alignment in the lateral (c) and anterior-posterior (d) views. Follow-up CT demonstrated bony healing of both the dens (e) C1 ring (5f)

equally likely to be selected for surgery ($P = 0.5059$), halo ($P = 0.4997$), or c-collar ($P = 0.6456$). On multivariable regression, selection for surgery was positively associated with worse myelopathy (OR = 1.33 [1.11–1.60], $P = 0.002$) and negatively associated with age (OR = 0.77 [0.65–0.91], $P = 0.003$), but not associated with the presence of a simultaneous atlas fracture ($P = 0.2146$) [Table 4].

Among patients selected for surgery, C1/C2 posterior arthrodesis (C1/2 posterior spinal fusion [PSF]) was the most common procedure for both groups [Figure 4]. There was no difference between groups in the number of levels fused ($P = 0.5431$), estimated blood loss (200 cc [75–500] vs. 150 cc [100–400], $P = 0.5696$), the proportion treated with C1/2 PSF (41.7% vs. 44.0%, $P = 1.0000$), or the proportion treated with an occipitocervical fusion (OCF) (41.7% vs. 19.6%, $P = 0.1366$).

On multivariable analysis, selection for a C1/2 PSF was positively associated with older age (OR = 1.74 [1.08–2.78],

Table 4: Multivariable analysis results

Outcome, predictors	OR	95% CI	P
Simultaneous Dens-Atlas Fracture			
Age	1.29	[1.03, 1.61]	0.024
Dens fracture angulation	2.62	[1.35, 5.07]	0.004
Myelopathy severity at presentation			
Severe ISS	102.31	[11.71, 893.70]	<0.001
Age	1.28	[1.10, 1.49]	0.002
Selection for surgery			
Age	0.77	[0.65, 0.91]	0.003
Myelopathy severity at presentation	1.33	[1.11, 1.60]	0.002
Selection for C1/C2 PSF			
Age	1.74	[1.08, 2.78]	0.022
Dens fracture angulation	0.22	[0.06, 0.81]	0.023
Selection for OC Fusion			
Dens fracture angulation	4.74	[1.16, 19.37]	0.030
Simultaneous Dens-Atlas Fracture	14.35	[1.87, 110.42]	0.010
Myelopathy severity at follow-up			
Age	1.25	[1.04, 1.50]	0.015
Myelopathy severity at presentation	15.75	[9.95, 24.95]	<0.001
Dens fracture nonunion at 26 weeks			
Type II fracture	2.00	[1.04, 3.84]	0.038
Surgery	0.52	[0.27, 0.99]	0.049

$P = 0.022$) and was negatively associated with dens fracture angulation (OR = 0.22 [0.06–0.81], $P = 0.023$). Selection for OCF was positively associated with dens fracture angulation (OR = 4.74 [1.16–19.37], $P = 0.030$) and having a simultaneous atlas fracture (OR = 14.35 [1.87–110.42], $P = 0.010$) [Figure 5].

Follow-up data

Among 282 patients, the mean follow-up time was 44.7 weeks. Twenty-five patients (8.9%) passed away within 30 days of their initial trauma. Of the surviving 257 patients, 42 patients were lost to follow-up (16.3%). Of the remaining 215 patients, Nurick scores at the first follow-up were available on 198 patients (77.0% of the initial 257 patients). Of the 215 patients with follow-up, 181 patients (84.2%) either had follow-up imaging with confirmed fracture healing or 26 weeks of follow-up with imaging showing ongoing fracture nonunion.

There was no difference between patients who were lost to follow-up and those who were not with respect to age ($P = 0.0724$), CCI ($P = 0.0800$), Nurick score ($P = 0.7777$), or the proportion with a severe ISS ($P = 0.6189$), fracture angulation ($P = 0.2455$), comminution ($P = 0.2604$), displacement ≥3 mm ($P = 1.0000$), or type II morphology ($P = 0.8598$).

Myelopathy severity

On ordinal multivariable logistic regression, worse myelopathy severity on presentation was independently associated with having a severe ISS (OR = 102.31 [11.71–893.70], $P < 0.001$) and older age (OR = 1.28 [1.10–1.49], $P = 0.002$), but not with having an atlas fracture ($P = 0.2446$). Myelopathy severity at the first follow-up was independently associated with myelopathy severity at presentation (OR = 15.75 [9.95–24.95], $P < 0.001$) and older age (OR = 1.25 [1.04–1.50], $P = 0.015$), but not with having an atlas fracture ($P = 0.7003$).

Nonunion

The rate of dens fracture nonunion was no different between patients with isolated dens fractures (40.0%) and patients with simultaneous dens-atlas fractures (48.8%) (OR = 1.43 [0.71–2.86], $P = 0.3695$). On multivariable regression, dens fracture nonunion was positively associated with type II fractures (OR = 2.00 [1.04–3.84], $P = 0.038$) and negatively associated with having surgery (OR = 0.52 [0.27–0.99], $P = 0.049$), but not with having an atlas fracture ($P = 0.3673$).

DISCUSSION

Traumatic dens fractures are often accompanied by atlas fractures and are typically managed according to the dens fracture's morphology despite limited evidence examining this strategy.[4-6,9] Here, we found that traumatic simultaneous dens-atlas fractures are independently associated with older age, dens fracture angulation, and OCF among patients who were selected for surgery. Moreover, these populations differed with respect to the mechanism of injury. However, having a simultaneous atlas fracture was not independently associated with myelopathy severity or dens fracture nonunion. To our knowledge, our series is the largest on simultaneous dens-atlas fractures to date, the first to control for confounding factors when examining the outcomes of interest, and the first to identify demographic, clinical, and management differences between these subpopulations.

Literature on the management of simultaneous atlas-dens fractures is scarce. Ryken *et al*. recently published guidelines on atlantoaxial fracture management, in which only 7 out of 47 series they identified (14.9%) included more than 10 patients.[10] That being the case, the existing treatment paradigm comes from a small number of series: Greene *et al*. reported a series of 340 patients with axis fractures of varying morphology, of whom 48 had associated atlas fractures, though the effect of the atlas fractures on overall management and outcomes was not examined.[7] Similarly, Hadley *et al*. reported that simultaneous atlantoaxial fractures should be managed according to the morphology of the axis fracture from their series of 25 such patients, of which only 15 had dens fractures specifically.[5] While these are landmark studies on atlantoaxial pathology, they lack statistical comparisons between groups to validate the reported management strategy and do not control for confounding factors.[4-6] As such, the data supporting current practices for atlantoaxial fractures remain limited.

Notably, we found that atlas fractures do not increase the risk of dens fracture nonunion or myelopathy on multivariable analysis. Similarly, Sonntag *et al*. saw no neurologic deficits in their series of 32 patients with isolated atlas fractures but noted deficits in 3 of 25 patients with simultaneous atlantoaxial injuries.[29] This backs the existing consensus that management should be driven by the dens fracture's morphology.[5,9] Indeed, Sonntag *et al*. note that their management was determined by the C2 fracture type,[29] and recent guidelines from the Congress of Neurological Surgeons recommend that C2 fracture morphology should drive management, based on the limited available evidence.[10] As the presence of an atlas fracture did not affect nonunion or myelopathy in our series, our findings support the existing consensus that management be driven by the dens fracture's morphology.[5,9]

However, we also observed that among patients who were selected for surgery, having a simultaneous atlas fracture was associated with selection for OCF. To our knowledge, this finding is novel. Multiple posterior atlantoaxial fixation constructs have been described, such as those by Goel and Laheri,[30] Harms and Melcher,[31] and Resnick and Benzel.[32] However, simultaneous dens-atlas fractures may be less amenable to treatment with such constructs, due to concurrent atlanto-occipital instability or inadequate fixation into a fractured C1 vertebra. Indeed, Ylönen *et al*. recently reported a series of 47 surgically treated unstable atlas fractures, 75.4% of which had concurrent C2 fractures, and most of which were treated with OCF.[3] On the other hand, Lleu *et al*. recommend C1/C2 PSF based on their multicenter series of 63 operative unstable isolated atlas fractures.[33] Our analysis is not sufficient to examine whether OCF is superior to C1/2 PSF alone for simultaneous dens-atlas fractures but shows a bias toward OCF at our center for operative simultaneous dens-atlas fractures. To the extent that OCF is more appropriate for combination dens-atlas fractures than posterior cervical fusion alone, atlas fracture morphology does in fact inform the management of dens fractures.

Moreover, management differences between patients with and without simultaneous dens-atlas fractures may reflect a difference in the risks associated with each subgroup's injuries. Indeed, we found that having a simultaneous dens-atlas fracture was associated with dens fracture angulation, which increases the risk of fracture nonunion.[23] Furthermore, fracture nonunion can lead to delayed sequelae: Vaccaro *et al*. have shown that patients with conservatively managed odontoid fractures had high rates of nonunion and significantly worsened Neck Disability Index scores at follow-up.[34] In addition, Kepler *et al*. reported rates of secondary neurologic injury as high as 17.5% among patients with odontoid fracture nonunion.[35] While we did not find a significant difference in myelopathy severity between groups ($P = 0.0506$), Fujimura *et al*. suggested a higher rate of neurologic injury with combined atlantoaxial fractures than with isolated fractures.[36] As patients with simultaneous dens-atlas fractures were more likely to have angulated fractures and to be treated with OCF, they may represent a subpopulation whose risks are distinct from those of patients with isolated dens fractures.

Our study has its limitations. It was conducted retrospectively. Loss to follow-up also occurred, which could have biased our results, particularly with respect to nonunion and severity of myelopathy at follow-up. Moreover, we examined patients with dens fractures, which account for roughly 60% of C2 fractures, but did not examine other C2 fracture types.[37] While we have here examined the effect of atlas fractures on outcomes among patients with dens fractures, our methodology does not allow for the examination of the inverse relationship – comparing patients with isolated atlas fractures to atlas fracture outcomes with simultaneous dens fractures. In addition, our data were collected from an urban, academic tertiary referral center whose patients may not be representative of atlantoaxial fracture patients in other clinical contexts. Furthermore, our analysis characterizes the management of our providers during the study period, but we cannot determine whether the chosen management was optimal.

Despite its limitations, our study better characterizes the presentation and clinical outcomes of simultaneous dens and atlas fractures, which are injuries that frequently coincide. Moreover, to our knowledge, ours is the first analysis to do so while rigorously controlling for confounding factors. On multivariable analysis, we identified significant differences between patients with and without simultaneous atlas fractures with respect to age, dens fracture angulation, and surgical treatment, representing demographic, clinical, and management differences between groups. Nevertheless, we confirmed that the presence of an atlas fracture is not the driver of myelopathy or fracture nonunion when controlling for confounders, which supports the existing consensus that management should be driven by the dens fracture's morphology in such cases.

CONCLUSIONS

Among patients with traumatic dens fractures, patients who have simultaneous atlas fractures are a distinct subpopulation with respect to age, mechanism of injury, fracture morphology, and management. Among patients with traumatic dens fractures, having a simultaneous atlas fracture is independently associated with selection for occipitocervical fusion rather than posterior cervical fusion alone.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture-dislocations of the cervical spine. Injury 1992;23:38-40.
2. Gleizes V, Jacquot FP, Signoret F, Feron JM. Combined injuries in the upper cervical spine: Clinical and epidemiological data over a 14-year period. Eur Spine J 2000;9:386-92.
3. Ylönen H, Danner N, Jyrkkänen HK, Kämäräinen OP, Leinonen V, Huttunen J. Surgically treated C1 fractures: A population-based study. World Neurosurg 2021;154:e333-42.
4. Dickman CA, Hadley MN, Browner C, Sonntag VK. Neurosurgical management of acute atlas-axis combination fractures. A review of 25 cases. J Neurosurg 1989;70:45-9.
5. Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute traumatic atlas fractures: Management and long term outcome. Neurosurgery 1988;23:31-5.
6. Levine AM, Edwards CC. Fractures of the atlas. J Bone Joint Surg Am 1991;73:680-91.
7. Greene KA, Dickman CA, Marciano FF, Drabier JB, Hadley MN, Sonntag VK. Acute axis fractures. Analysis of management and outcome in 340 consecutive cases. Spine (Phila Pa 1976) 1997;22:1843-52.
8. Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute axis fractures: A review of 229 cases. J Neurosurg 1989;71:642-7.
9. Kakarla UK, Chang SW, Theodore N, Sonntag VK. Atlas fractures. Neurosurgery 2010;66:60-7.
10. Ryken TC, Hadley MN, Aarabi B, Dhall SS, Gelb DE, Hurlbert RJ, *et al.* Management of acute combination fractures of the atlas and axis in adults. Neurosurgery 2013;72 Suppl 2:151-8.
11. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. J Chronic Dis 1987;40:373-83.
12. Nurick S. The natural history and the results of surgical treatment of the spinal cord disorder associated with cervical spondylosis. Brain 1972;95:101-8.
13. Palmer C. Major trauma and the injury severity score – Where should we set the bar? Annu Proc Assoc Adv Automot Med 2007;51:13-29.
14. Baker SP, O'Neill B, Haddon W Jr., Long WB. The injury severity score: A method for describing patients with multiple injuries and evaluating emergency care. J Trauma 1974;14:187-96.
15. Cloney MB, Goergen J, Hopkins BS, Dhillon ES, Dahdaleh NS. Factors associated with venous thromboembolic events following ICU admission in patients undergoing spinal surgery: An analysis of 1269 consecutive patients. J Neurosurg Spine 2018;30:99-105.
16. Cloney MB, Hopkins B, Shlobin NA, Kelsten M, Goergen J, Driscoll C, *et al.* Surgical site infection in the intensive care setting after posterior spinal fusion: A case series highlighting the microbial profile, risk factors, and the importance of comorbid disease burden. Oper Neurosurg (Hagerstown) 2022;23:312-7.
17. Lennarson PJ, Mostafavi H, Traynelis VC, Walters BC. Management of type II dens fractures: A case-control study. Spine (Phila Pa 1976) 2000;25:1234-7.
18. Kim HS, Cloney MB, Koski TR, Smith ZA, Dahdaleh NS. Management of isolated atlas fractures: A retrospective study of 65 patients. World Neurosurg 2018;111:e316-22.
19. Cloney MB, Kim HS, Dahdaleh NS. Risk factors for fracture nonunion and transverse atlantal ligament injury after isolated atlas fractures: A case series of 97 patients. Neurosurgery 2022;91:900-5.
20. Cloney M, Thirunavu V, Roumeliotis A, Azad H, Shlobin NA, Swong K, *et al.* Surgery decreases nonunion, myelopathy, and mortality for patients with traumatic odontoid fractures: A propensity score matched analysis. Neurosurgery 2023;93:546-54.
21. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. J Bone Joint Surg Am 1974;56:1663-74.
22. Cloney M, Thirunavu V, Roumeliotis A, Azad H, Shlobin N, Swong K, *et al.* Odontoid fracture type and angulation affect nonunion risk, but comminution and displacement do not: A propensity score matched analysis of fracture morphology. Clin Neurol Neurosurg 2023;231:107855.
23. Stoney J, O'Brien J, Wilde P. Treatment of type-two odontoid fractures in halothoracic vests. J Bone Joint Surg Br 1998;80:452-5.
24. Koivikko MP, Kiuru MJ, Koskinen SK, Myllynen P, Santavirta S, Kivisaari L. Factors associated with nonunion in conservatively-treated type-II fractures of the odontoid process. J Bone Joint Surg Br 2004;86:1146-51.
25. Osman A, Alageli NA, Short DJ, Masri WS. Conservative management of odontoid peg fractures, long term follow up. J Clin Orthop Trauma 2017;8:103-6.
26. Lewis E, Liew S, Dowrick A. Risk factors for non-union in the non-operative management of type II dens fractures. ANZ J Surg 2011;81:604-7.
27. Cloney M, Kim H, Riestenberg R, Dahdaleh NS. Risk factors for transverse ligament disruption and vertebral artery injury following an atlas fracture. World Neurosurg 2021;146:e1345-50.
28. Cloney MB, El-Tecle N, Dahdaleh NS. Traumatic atlas fracture patients comprise two subpopulations with distinct demographics and mechanisms of injury. Clin Neurol Neurosurg 2022;221:107414.
29. Sonntag VK, Hadley MN, Dickman CA, Browner CM. Atlas fractures: Treatment and long-term results. Acta Neurochir Suppl (Wien) 1988;43:63-8.
30. Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. Acta Neurochir (Wien) 1994;129:47-53.
31. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. Spine (Phila Pa 1976) 2001;26:2467-71.
32. Resnick DK, Benzel EC. C1-C2 pedicle screw fixation with rigid cantilever beam construct: Case report and technical note. Neurosurgery 2002;50:426-8.

33. Lleu M, Charles YP, Blondel B, Barresi L, Nicot B, Challier V, *et al.* C1 fracture: Analysis of consolidation and complications rates in a prospective multicenter series. Orthop Traumatol Surg Res 2018;104:1049-54.
34. Vaccaro AR, Kepler CK, Kopjar B, Chapman J, Shaffrey C, Arnold P, *et al.* Functional and quality-of-life outcomes in geriatric patients with type-II dens fracture. J Bone Joint Surg Am 2013;95:729-35.
35. Kepler CK, Vaccaro AR, Dibra F, Anderson DG, Rihn JA, Hilibrand AS, *et al.* Neurologic injury because of trauma after type II odontoid nonunion. Spine J 2014;14:903-8.
36. Fujimura Y, Nishi Y, Chiba K, Kobayashi K. Prognosis of neurological deficits associated with upper cervical spine injuries. Paraplegia 1995;33:195-202.
37. Robinson AL, Möller A, Robinson Y, Olerud C. C2 fracture subtypes, incidence, and treatment allocation change with age: A retrospective cohort study of 233 consecutive cases. Biomed Res Int 2017;2017. [DOI: 10.1155/2017/8321680].