Original Article

Atlas fractures with and without simultaneous dens fractures differ with respect to clinical, demographic, and management characteristics

ABSTRACT

Background: Patients with simultaneous fractures of the atlas and dens have traditionally been managed according to the dens fracture's morphology, but data supporting this practice are limited.

Methods: We retrospectively examined all patients with traumatic atlas fractures at our institution between 2008 and 2016. We used multivariable regression and propensity score matching to compare the presentation, management, and outcomes of patients with isolated atlas fractures to patients with simultaneous atlas-dens fractures.

Results: Ninety-nine patients were identified. Patients with isolated atlas fractures were younger (61 ± 22 vs. 77 ± 14, $P = 0.0003$), had lower median Charlson Comorbidity Index (3 vs. 5, $P = 0.0005$), had better presenting Nurick myelopathy scores (0 vs. 3, $P < 0.0001$), and had different mechanisms of injury ($P = 0.0011$). Multivariable regression showed that having a simultaneous atlas-dens fracture was independently associated with older age (odds ratio [OR] =1.59 [1.22, 2.07], $P = 0.001$), worse presenting myelopathy (OR = 3.10 [2.04, 4.16], $P < 0.001$), and selection for surgery (OR = 4.91 [1.10, 21.97], $P = 0.037$). Propensity score matching yielded balanced populations (Rubin's $B = 23.3$, Rubin's $R = 1.96$) and showed that the risk of atlas fracture nonunion was no different among isolated atlas fractures compared to simultaneous atlas-dens fractures ($P = 0.304$). Age was the only variable independently associated with atlas fracture nonunion (OR = 2.39 [1.15, 5.00], $P = 0.020$), having a simultaneous atlas-dens fracture was not significant ($P = 0.2829$).

Conclusions: Among patients with atlas fractures, simultaneous fractures of the dens occur in older patients and confer an increased risk of myelopathy and requiring surgical stabilization. Controlling for confounders, the risk of atlas fracture nonunion is equivalent for isolated atlas fractures versus simultaneous atlas-dens fractures.

Keywords: Atlas, C1, C2, dens, fracture, odontoid, spine fracture

INTRODUCTION

Traumatic atlas fractures often coincide with dens fractures, and while management has traditionally been driven by the dens fracture's morphology, data supporting this practice are limited.[1-8] Existing series have lacked comparison groups to assess the validity of this reported management strategy.[2,6,8-12] Moreover, recent guidelines on the management of combined atlantoaxial fractures noted that 40 out of 47 relevant articles (85.1%) featured only 10 or fewer patients.[5] In addition, existing studies on simultaneous atlas-dens fractures topic often have not

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controlled for confounding factors that affect outcomes in this population. As such, data supporting treatment according to the dens fracture's morphology are severely limited. Here, we compared all patients with traumatic atlas fractures who presented to our institution with and without simultaneous dens fractures with respect to their demographics, clinical characteristics, fracture morphology, presenting neurology, management of choice, and fracture healing.

METHODS

Data source

We used an institutional data repository to retrospectively identify all patients who presented to our institution with traumatic fractures of the atlas between January 1, 2008, and December 31, 2016. Patients with simultaneous subaxial cervical spine fractures, or fractures of the axis other than the dens, were excluded from analysis. Patients with isolated atlas fractures were compared to patients with simultaneous fractures of the dens. The study was approved by our institutional review board, and patient consent was waived due to the retrospective study design.

Baseline clinical and demographic data

We collected data on all atlas fractures patients for the following characteristics at presentation: age, sex, mechanism of injury, comorbid disease burden, myelopathy severity, and the presence of any associated dens fracture. Comorbid disease burden was quantified using the Charlson Comorbidity Index (CCI).[13] Myelopathy severity was quantified using the Nurick score.[14] Injury mechanisms were classified as fall, motor vehicle collision (MVC), or other.

Fracture morphologic characteristics

Atlas fractures were classified into 5 types according to the Gehweiler classification system.[15] A given fracture could simultaneously meet criteria for more than one fracture type, and in such cases, it would be classified as both types. For all patients for whom magnetic resonance imaging (MRI) was obtained within 72 h of presentation at the discretion of the treating provider, ligamentous injury to the transverse atlantal ligament (TAL) was evaluated. For patients with dens fractures, dens fractures were classified using the Anderson-D'Alonso fracture type.[16]

Outcomes

We assessed predictors of myelopathy severity at presentation, the presence of TAL injury, selection for surgical stabilization, having a simultaneous atlas-dens fracture, and fracture nonunion at 12 weeks. Nonunion was defined as an absence of bony bridging on follow-up imaging. Only patients with imaging that confirmed fracture healing before 12 weeks, or who had at least 12 weeks of follow-up with imaging demonstrating no fracture healing, were included for analysis. Twelve weeks was chosen because of existing recommendations on the duration of immobilization for atlas fracture treatment.[1,17] Radiographic outcomes were screened from attending neuroradiology reports and confirmed by the study authors.

The distribution of fracture types was determined for all patients' atlas fractures, as well as the distribution of dens fracture types for the subset of patients with atlas-dens fractures. Any morphologic association between atlas fractures and simultaneous dens fractures was assessed. Length of stay was compared for patients with and without simultaneous dens fractures.

Data management

Data were managed with Microsoft Excel version 16.61 (Microsoft, Redmond, WA, USA). Figures were generated with Prism 10.0 (GraphPad Software, Inc., La Jolla, CA, USA). Statistical analysis was performed using Stata 12.0 (StataCorp, College Station, TX, USA).

For analysis, CCI and Nurick score were treated as ordinal variables. Age was treated as a continuous variable scaled by a factor of 10, such that calculated odds ratios (ORs) reflect a change in the outcome of interest associated with a 10-year difference in patient age. Atlas fracture type was treated as a binary variable (type 3 or 4 vs. other types), as Gehweiler type 3 and type 4 fracture morphologies have been demonstrated to be associated with instability necessitating more aggressive intervention.[17,18] Mechanism of injury (fall vs. not) and the presence or absence of a simultaneous atlas-dens fracture were also treated as binary variables.

For univariate analysis, continuous or ordinal variables were compared with Mann–Whitney *U*-tests, as normality was not assumed. Binary variables were compared with Fisher's exact test when two groups were compared and a χ^2 test when more than two groups were compared. Bonferroni corrections for multiple univariate comparisons were used.

Stepwise, backward multivariable logistic regression was used to identify factors independently associated with binary outcomes of interest (selection for surgery, TAL injury, and fracture nonunion). Ordinal logistic regression was used to identify factors independently associated with worsening myelopathy as measured by the Nurick score. An initial P value threshold ≤ 0.20 was used to select candidate variables for retention in these models, and $P < 0.05$ was considered statistically significant. Length of stay was compared using logrank statistics, and a corresponding Kaplan–Meier curve was generated.

The following candidate variables were included to model selection for surgery: age, sex, CCI, myelopathy severity, TAL injury, atlas fracture type, and the presence of a simultaneous atlas-dens fracture. The the aforementioned variables were also used to model myelopathy severity at presentation, except for myelopathy severity itself was excluded, and mechanism of injury was included. Nonunion was modeled with age, sex, CCI, atlas fracture type, whether the patient underwent surgery, and the presence of a simultaneous atlas-dens fracture. Having a simultaneous atlas-dens fracture was modeled with age, sex, CCI, mechanism of injury, and atlas fracture type.

In addition, we used two-nearest neighbor propensity score matching to quantify the effect, if any, of having a simultaneous dens fracture on atlas fracture nonunion. Matching was performed with the psmatch2 algorithm in Stata, across the following variables: age, sex, CCI, fracture type, and whether the patient underwent surgery. The propensity score matching was assessed using Stat's Pstest algorithm, and models were considered balanced if Rubin's $B \leq 25.0$ and $0.5 \leq$ Rubin's $R \leq 2.0$. The mean bias was calculated before and after matching, and any differences in covariates were assessed before and after matching.

RESULTS

Clinical and demographic characteristics

Ninety-nine patients with traumatic atlas fractures were identified, of whom 43 (43.4%) had simultaneous dens fractures. The mean age of the population was 68 ± 21 years old, 51.7% were men, and their median CCI was 4, and Nurick was 0. 68.7% of patients had fall as their mechanism of injury, 13.1% had MVC, and the remainder had a variety of other traumatic etiologies. 24.7% of patients had MRI-confirmed injury to the TAL. 12.1% of patients were treated with surgical stabilization, 7.1% with halo vest immobilization, and the remainder (80.8%) were treated with rigid cervical collar (c-collar) only. The median length of stay was 3 days among patients with isolated atlas fractures, compared to 6 days among patients with simultaneous atlas-dens fractures [hazard ratios = 0.5000 (0.3295, 0.7586), $P = 0.0072$, Figure 1].

Compared to patients with atlas-dens fractures, patients with isolated atlas fractures were younger (61 ± 22 vs. 77 ± 14, $P = 0.0003$), had lower median CCI (3 vs. 5, $P = 0.0005$), and had a different distribution of injury mechanisms (χ^2 $P = 0.0011$), where $P < 0.0024$ (0.05/21) was the threshold for significance after correcting for multiple univariate comparisons [Table 1]. On multivariable regression, older age independently predicted having a simultaneous atlas-dens fractures (OR = 1.59 [1.20, 2.09], $P = 0.001$) (area under the receiver operator characteristic curve [AUROC] =0.76) [Table 2 and Figure 2].

Fracture type

Type 4 fractures were the most common type among patients with isolated atlas fractures ($n = 25$, 44.6%), and type 1 and type 3 fractures were the equally most common among patients with atlas-dens fractures ($n = 13$, 34.2% each) [Table 3 and Figure 3]. There was no overall difference in the distribution of fracture types between patients with and without simultaneous dens fractures (χ^2 $P = 0.1480$) or in the proportion of patients in each group with type 3 or type 4 fractures (50.0% vs. 71.4%, $P = 0.0501$).

Myelopathy

Patients with simultaneous atlas-dens fractures had worse myelopathy at presentation (median Nurick score 3 vs. 0, $P < 0.0001$). On ordinal multivariable logistic regression, having a simultaneous atlas-dens fracture was independently associated with worse myelopathy at presentation (OR = 3.10 [2.04, 4.16], $P < 0.001$) [Table 2].

Management

Regardless of the presence of a dens fracture, equal proportions of patients in each group were selected for surgery (7.1% vs. 18.6%, $P = 0.1178$), halo (5.4% vs. 9.5%, $P = 0.4575$), and c-collar alone (87.5% vs. 71.4%, $P = 0.0696$) on univariate analysis, and

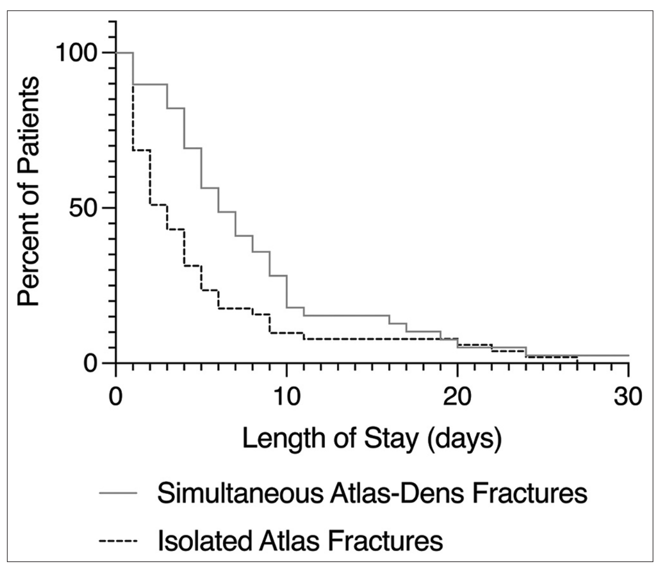

Figure 1: Kaplan–Meier curve comparing the length of stay for patients with isolated atlas fractures and patients with simultaneous atlas-dens fractures. The median length of stay was 3 days among patients with isolated atlas fractures, compared to 6 days among patients with simultaneous atlas-dens fractures (hazard ratios = 0.5000 [0.3295, 0.7586], *P* = 0.0072)

Table 1: Demographic and clinical characteristics

	All patients	Atlas-dens fracture	Isolated atlas fracture	*P*
Demographics				
Age	68±21	77±14	61±22	0.0003
Male sex (%)	49.5	46.5	51.8	0.6029
CCI	3.9±2.6	5.0±2.2	3.1±2.6	0.0005
Nurick score	1.5±1.9	2.7±1.9	0.6±1.4	<0.0001
Injury mechanism (%)				0.0011
Fall	67.7	83.7	55.4	0.0044
MVC	10.1	11.6	8.9	0.7428
Other	22.2	4.7	35.7	0.0002
Fracture morphology				
C1 fracture type (%)				0.1480
1	24.5	34.2	17.9	0.0889
2	18.1	21.1	16.1	0.5914
3	35.1	34.2	35.7	1.0000
4	35.1	21.1	44.6	0.0272
5	7.4	5.3	8.9	0.6973
Type 3 or 4	59.6	50.0	71.4	0.0501
TAL injury	24.7	15.0	32.1	0.0884
Management (%)				0.1268
Cervical collar	80.6	71.4	87.5	0.0696
Halo	7.1	9.5	5.4	0.4575
Surgery	12.2	19.0	7.1	0.1178

CCI - Charlson Comorbidity Index; MVC - Motor vehicle collision; TAL - Transverse atlantal ligament

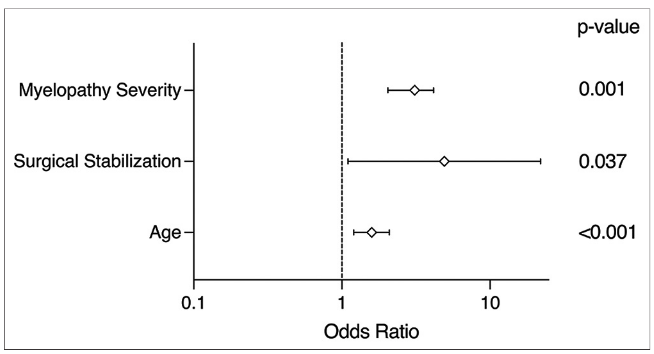

Figure 2: Forest plot depicting the calculated odds ratio and 95% confidence intervals for factors found to be independently associated with having a simultaneous atlas-dens fracture, among all patients with atlas fractures

there was no overall difference in the proportion of patients selected for each management strategy (χ^2 $P = 0.1268$). On multivariable regression, selection for surgery was independently associated with transverse atlantal ligament injury (OR = 6.81 [1.55, 29.80], $P = 0.011$) and having a simultaneous atlas-dens fracture (OR = 4.91 [1.10, 21.97], $P = 0.037$) (AUROC = 0.77).

Twelve patients were selected for surgery, including 4 with isolated atlas fractures and 8 with simultaneous atlas-dens fractures. 58.3% were men, and their mean age was 70 ± 15 years, CCI was 4.1 ± 1.9, and Nurick score was 2.6 ± 2.0 [Table 4 and Figure 4]. Six patients underwent occipitocervical fusion, including three patients with isolated atlas fractures and two patients with atlas-dens fractures ($P = 0.2222$). The remainder underwent posterior spinal fusion.

Follow-up data

Of the 99 patients included in the study, six patients died within 30 days of their index trauma, including 2 (3.6%) patients with isolated atlas fractures and 4 (9.3%) patients with atlas-dens fractures ($P = 0.3987$). Of the remaining 93 patients, 74 (79.6%) had sufficient 12-week follow-up with imaging, including 28 (71.8%) of the patients with simultaneous atlas-dens fractures, and 46 (85.2%) patients of the patients with isolated atlas fractures.

Nonunion

Overall, 9 of 74 patients with sufficient follow-up had fracture nonunion (12.1%), including 6 (21.4%) patients with combined atlas-dens fractures [Figure 5], and 3 (6.5%) patients with isolated atlas fractures. The difference was not significant (OR = 3.91 [0.96, 15.66], $P = 0.0742$) on univariate analysis. On multivariable regression, age was the only variable that independently predicted atlas fracture nonunion (OR = 2.39 [1.15, 5.00], $P = 0.020$) and having a simultaneous dens fracture was not significant ($P = 0.2829$) (AUROC = 0.80).

Propensity score analysis matched 25 patients with simultaneous atlas-dens fractures to 44 patients with isolated

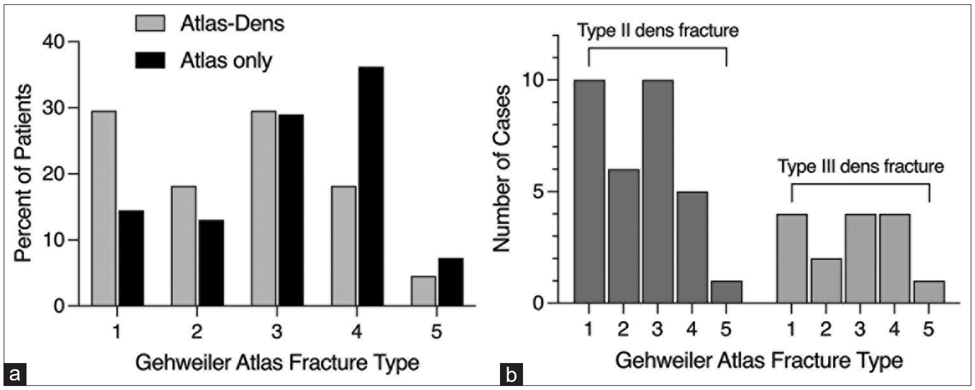

Figure 3: The distribution of atlas fracture type, stratified by (a) whether a simultaneous dens fracture is present and (b) by what kind of dens fracture is present, among the subset of patients with simultaneous fractures

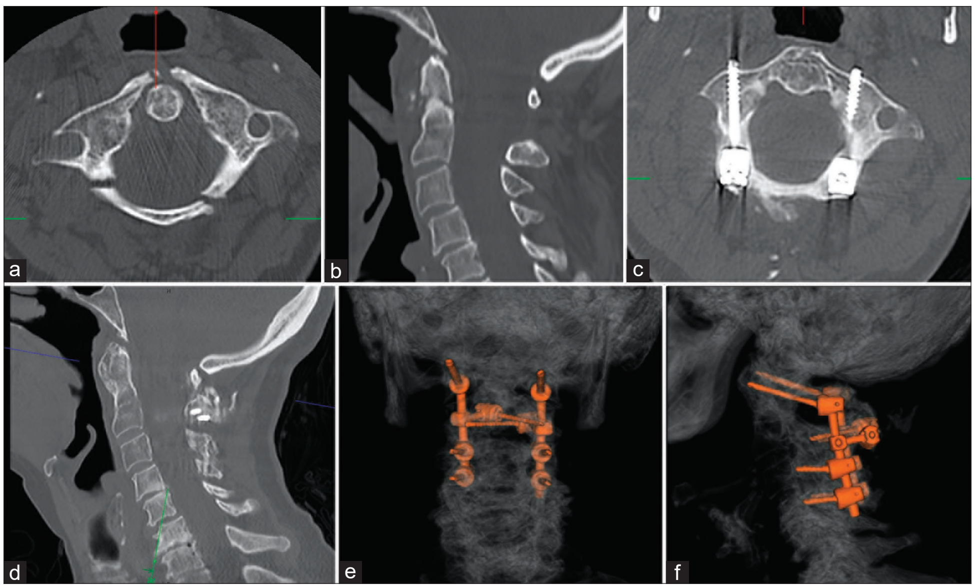

Figure 4: The patient is a 67-year-old woman who presented after a head trauma. Computed tomography demonstrated a type 3 atlas fracture (a) and a type II dens fracture (b). She underwent surgical fixation with C1 lateral mass screws (c), C2 translaminar screws (e, f), and C3 and C4 lateral mass screws (e, f). Follow-up imaging showed bony bridging of the C1 anterior and posterior arches (c), as well as reconstitution of the odontoid peg (d)

atlas fractures. The match successfully yielded a balanced model (Rubin's $B = 23.3$, Rubin's $R = 1.96$). The mean bias after matching was 4.7%, representing a 90.8% reduction in overall bias, and no covariates remained significantly different between groups after matching [Table 5]. The presence of a simultaneous atlas-dens fracture did not change atlas fracture nonunion risk (average treatment effect = 16.0% [−14.5%, 46.5%], $P = 0.304$).

DISCUSSION

Traumatic atlas fractures frequently coincide with dens fractures, as was seen in 43.4% of atlas fracture cases in our series. Existing series have reported management strategies driven by the dens fracture's morphology, but have not measured the effect of such strategies on atlas fracture outcomes.[8-12,19] Here, on multivariable regression, we found that patients with simultaneous atlas-dens fractures were older, had worse myelopathy on presentation, and were more likely to be selected for surgery than patients with isolated atlas fractures. Moreover, these populations differed with respect to mechanism of injury and comorbid disease burden. While controlling for these factors, there was no difference between patients with isolated atlas fractures and simultaneous atlas-dens fractures with respect to fracture nonunion. To our knowledge, our series is among the largest to date on traumatic atlas or atlantoaxial fractures and is the first to examine the effect of associated dens fractures on atlas fracture outcomes while controlling for confounders.

Existing data guiding the management of simultaneous atlantoaxial fractures are severely limited. Recent guidelines on the management of atlantoaxial fractures examined the literature over a 45-year period and noted that 40 out of

47 relevant original articles (85.1%) featured 10 or fewer patients.[5] Only two original series included 30 patients or more: a landmark 1997 study from Greene *et al*. that included 48 patients,[11] as well as another from Gleizes *et al*. that included 31 patients.[20] However, neither series compared the subpopulation of patients with atlantoaxial fractures to patients with fractures of the atlas or axis alone. More recent series have similarly lacked such comparisons: Zhao *et al*. recently reported a series of 23 atlas fractures with concurrent type II odontoid fractures,[2] and Lin *et al*. reported on 41 simultaneous atlantoaxial fractures,[6] but neither compared their management strategies with a control group.

Notably, the populations affected by isolated atlas fractures and simultaneous atlas-dens fractures differed across clinically relevant parameters. Traumatic atlas fracture patients are known to comprise distinct subpopulations that are demographically and clinically distinct, and we here noted differences in age and comorbid disease burden.[21] Indeed, we found a marked age difference of 16 years between these populations, and older age is associated with atlas fracture nonunion.[18,22,23] Moreover, age affects management, as halo use for atlas fractures in patients age ≥50 is associated with complications.[21] Horn *et al*. noted a halo complication rate as high as 52.3% among elderly patients, and Majercik *et al*. reported 46.6% rate of pneumonia among elderly patients treated with halo.[24,25] The difference in CCI we observed is similarly relevant, as comorbid disease burden is associated with complications among patients with spine fractures.[26] As such, the differences we identified between patients with isolated atlas fractures and patients with simultaneous atlas-dens fractures are clinically significant.

Table 2: Factors associated with simultaneous atlas-dens fractures on multivariable regression

	OR	95% CI	*P*
Age	1.59	1.20–2.09	0.001
Surgical stabilization	4.91	1.10–21.97	0.037
Myelopathy severity	3.10	2.04–4.16	<0.001

CI - Confidence interval; OR - Odds radio

Table 3: Cross-section of atlas and dens fracture types

Atlas fractures	Dens fractures		
	Type I	Type II	Type III
Type I	0	10	4
Type II	0	6	2
Type III	0	10	4
Type IV	0	5	4
Type V	0	1	1

In point of fact, having a simultaneous dens fracture may be a marker for a more severe injury than having an atlas fracture alone.[5] This is consistent with our finding that simultaneous atlas-dens fractures were associated with worse myelopathy and selection for surgery. 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.[27] Atlas fractures are not typically associated with neurologic deficits due to the resultant expansion of the spinal canal,[28] but fractures of the axis do carry a higher risk of neurologic compromise.[5,27] Moreover, isolated atlas fractures have low nonunion rates and rarely require surgery.[1,21,28] By contrast, dens fractures have high rates of nonunion for which surgical intervention may be required.[29-34] As such, having an associated dens fracture likely implies a more severe injury with an associated increased burden of care.[5] Indeed, we observed that length of hospitalization was twice as long for patients with simultaneous atlas-dens fractures than with isolated atlas fractures alone. We find, therefore, that patients with isolated atlas fractures and atlas-dens fractures differ with respect to both baseline clinical characteristics and the severity of their pathology.

After controlling for the above differences in demographic and clinical characteristics, rates of nonunion after 12 weeks were

Table 4: Clinical characteristics of patients selected for surgery

Age	Sex	Deficits	Mechanism	Dens fracture	TAL injury	Surgery	Nonunion
83	Male	Yes	Fall	Yes	No	O-C4 PSF	No
76	Female	Yes	MVC	Yes	No	O-C5 PSF	No
86	Male	Yes	Fall	Yes	Yes	C1-2 PSF	No
61	Female	Yes	Fall	Yes	No	C1-C2 PSF	No
67	Female	Yes	Head trauma	Yes	Yes	C1-C4 PSF	No
77	Male	Yes	Fall	Yes	No	C1-C2 PSF	Yes
74	Female	Yes	Fall	Yes	No	O-C3°CF	No
94	Female	Yes	Fall	Yes	No	C1-C2 PSF	No
62	Male	Yes	Fall	No	Yes	O-T4 PSF	No
52	Male	No	Surfing	No	Yes	O-C4°CF	No
65	Male	No	MVC	No	Yes	O-T3 PSF	No
36	Female	No	Diving	No	Yes	C1-2 PSF	No

MVC - Motor vehicle collision; TAL - Transverse atlantal ligament; PSF - Posterior spinal fusion

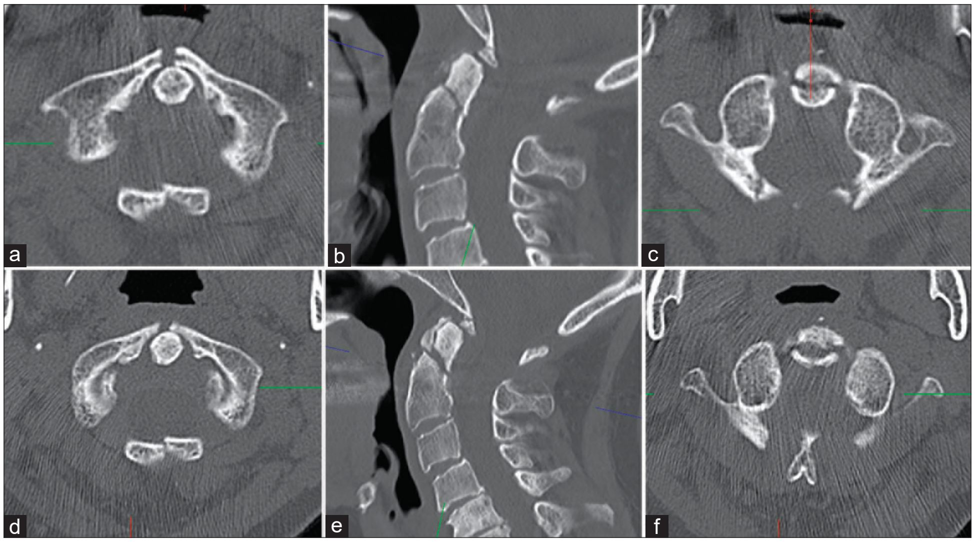

Figure 5: The patient is a 75-year-old woman who presented with neck pain after a ground-level fall. Computed tomography demonstrated (a) a type 3 atlas fracture and (b) type II dens fracture. She was managed conservatively with a rigid cervical orthosis (c). On follow-up CT 12 weeks following her initial injury (d, e, f), no bony bridging was noted of her atlas fracture or dens fracture, and the angulation of her dens fracture had progressed (e)

Table 5: Comparison between groups before and after propensity score matching

	Unmatched			Matched		
	Atlas-dens fracture	Isolated atlas fracture	*P*	Atlas-dens fracture	Isolated atlas fracture	*P*
Age	77	62	0.002	77	75	0.673
Male sex (%)	40.7	50.0	0.451	40.0	40.0	1.000
CCI	5.0	3.2	0.004	4.9	5.1	0.783
Surgery (%)	22.2	8.7	0.108	16.0	18.0	0.854
Type 3 or 4 (%)	48.1	71.7	0.045	52.0	52.0	1.000

CCI - Charlson Comorbidity Index

no different for atlas fracture patients with and without dens fractures. To our knowledge, no prior series has compared rates of fracture healing between patients with isolated atlas fractures and patients with simultaneous atlantoaxial fractures, though these pathologies often coincide.[1] Among patients with sufficient follow-up, we observed a 12.2% rate of fracture nonunion, which is comparable to existing literature: Lleu *et al*., in their prospective series of 63 patients, noted a 9.5% rate of nonunion after conservative management, leading to subsequent surgical fixation.[35] Segal *et al*. reported a nonunion rate of 18% after nonoperative management in their series.[36] This provides an evidential basis for the common practice of treating simultaneous atlas-dens fractures according to the den's fractures morphology.[1,5]

Our study has limitations

Our series is taken from an urban, tertiary care, level 1 trauma center whose patient population may not reflect traumatic atlas fracture patient populations in other settings. Our study was conducted retrospectively and therefore is liable to information bias and other weaknesses that accompany a retrospective design. For example, there was 21.4% loss to follow-up in our series, which may bias our results. In addition, we used propensity score matching to control for confounders when assessing fracture nonunion, but propensity score-matched populations exclude patients who cannot be matched, leading to a curated patient subset that may not reflect the broader population from which those patients are drawn. Despite these limitations, to our knowledge, our series is among the largest on combined atlantoaxial fractures to date, the first to compare isolated atlas fractures to simultaneous atlas-dens fractures to determine whether a clinical effect was noted, and the first to do so when controlling for multiple clinical confounders.

CONCLUSIONS

Among patients with atlas fractures, simultaneous fractures of the dens occur in older patients and confer an increased risk of myelopathy and requiring surgical stabilization. Controlling for confounders, the risk of atlas fracture nonunion is equivalent for isolated atlas fractures versus simultaneous atlas-dens fractures.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Kakarla UK, Chang SW, Theodore N, Sonntag VK. Atlas fractures. Neurosurgery 2010;66:60-7.
2. Zhao ZS, Wu GW, Lin J, Zhang YS, Huang YF, Chen ZD, *et al.* Management of combined atlas fracture with type II odontoid fracture: A review of 21 cases. Indian J Orthop 2019;53:518-24.
3. Walters BC, Hadley MN, Hurlbert RJ, Aarabi B, Dhall SS, Gelb DE, *et al.* Guidelines for the management of acute cervical spine and spinal cord injuries: 2013 update. Neurosurgery 2013;60:82-91.
4. Stillerman CB, Wilson JA. Atlanto-axial stabilization with posterior transarticular screw fixation: Technical description and report of 22 cases. Neurosurgery 1993;32:948-54.
5. 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.
6. Lin B, Wu J, Chen ZD, Zeng W, Liu Q, Dai L. Management of combined atlas-axis fractures: A review of forty one cases. Int Orthop 2016;40:1179-86.
7. Guiot B, Fessler RG. Complex atlantoaxial fractures. J Neurosurg 1999;91:139-43.
8. 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.
9. Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute traumatic atlas fractures: Management and long term outcome. Neurosurgery 1988;23:31-5.
10. Levine AM, Edwards CC. Fractures of the atlas. J Bone Joint Surg Am 1991;73:680-91.
11. 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.
12. Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute axis fractures: A review of 229 cases. J Neurosurg 1989;71:642-7.
13. 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.
14. 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.
15. Gehweiler JA, Duff DE, Martinez S, Miller MD, Clark WM. Fractures of the atlas vertebra. Skeletal Radiol 1976;1:97-102.
16. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. J Bone Joint Surg Am 1974;56:1663-74.
17. Kandziora F, Scholz M, Pingel A, Schleicher P, Yildiz U, Kluger P, *et al.* Treatment of atlas fractures: Recommendations of the spine section of the German society for orthopaedics and trauma (DGOU). Global Spine J 2018;8:5S-11S.
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. Goel A, Jain S, Shah A, Patil A, Vutha R, Ranjan S, *et al*. Atlantoaxial Fixation for Odontoid Fracture: Analysis of 124 Surgically Treated Cases. World Neurosurg 2018;110:558-67.
20. 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.
21. 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.
22. 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.
23. Delcourt T, Bégué T, Saintyves G, Mebtouche N, Cottin P. Management of upper cervical spine fractures in elderly patients: Current trends and outcomes. Injury 2015;46 Suppl 1:S24-7.
24. Horn EM, Theodore N, Feiz-Erfan I, Lekovic GP, Dickman CA, Sonntag VK. Complications of halo fixation in the elderly. J Neurosurg Spine 2006;5:46-9.
25. Majercik S, Tashjian RZ, Biffl WL, Harrington DT, Cioffi WG. Halo vest immobilization in the elderly: A death sentence? J Trauma 2005;59:350-6.
26. Cloney MB, Yamaguchi JT, Dhillon ES, Hopkins B, Smith ZA, Koski TR, *et al.* Venous thromboembolism events following spinal fractures: A single center experience. Clin Neurol Neurosurg 2018;174:7-12.
27. Sonntag VK, Hadley MN, Dickman CA, Browner CM. Atlas fractures: Treatment and long-term results. Acta Neurochir Suppl (Wien) 1988;43:63-8.
28. Chan KS, Shlobin NA, Dahdaleh NS. Diagnosis and management of isolated C1 fractures: A systematic review. J Craniovertebr Junction Spine 2022;13:233-44.
29. Pommier B, Ollier E, Pelletier JB, Castel X, Vassal F, Tetard MC. Conservative versus surgical treatment for odontoid fracture: Is the surgical treatment harmful? Systematic review and meta-analysis. World Neurosurg 2020;141:490-9.e2.
30. Deng H, Yue JK, Upadhyayula PS, Burke JF, Suen CG, Chan AK, *et al.* Odontoid fractures in the octogenarian: A systematic review and meta-analysis. J Neurosurg Sci 2016;60:543-55.
31. Di Paolo A, Piccirilli M, Pescatori L, Santoro A, D'Elia A. Single institute experience on 108 consecutive cases of type II odontoid fractures: Surgery versus conservative treatment. Turk Neurosurg 2014;24:891-6.
32. Hanigan WC, Powell FC, Elwood PW, Henderson JP. Odontoid fractures in elderly patients. J Neurosurg 1993;78:32-5.
33. Müller EJ, Wick M, Russe O, Muhr G. Management of odontoid fractures in the elderly. Eur Spine J 1999;8:360-5.
34. Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. Clin Orthop Relat Res 1985;193:178-83.
35. 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.
36. Segal LS, Grimm JO, Stauffer ES. Non-union of fractures of the atlas. J Bone Joint Surg Am 1987;69:1423-34.