

Predictors of surgical management and its impact on outcomes for combined C1–C2 fractures: National registry study

Kristin Salottolo¹, W. Tyler Crawley², Kaysie Banton², David Acuna³, Carlos H. Palacio⁴, Darryl Auston⁵, Peter Syre⁶, and David Bar-Or^{1,*} 

¹ Swedish Medical Center, Trauma Research Department, 601 E Hampden Avenue, Suite 100, Englewood, CO, 80113, USA

² Trauma Services Department, Swedish Medical Center, 501 E. Hampden Ave, Englewood CO, 80113, USA

³ Trauma Services Department, Wesley Medical Center, 550 N Hillside Street, Wichita KS, 67214, USA

⁴ Trauma Services Department, South Texas Health System McAllen, 301 W Expy 83, McAllen TX, 78503, USA

⁵ Trauma Services Department, Lutheran Hospital, 12911 W. 40th Ave, Wheat Ridge CO, 80401, USA

⁶ Neurosurgery Department, Swedish Medical Center, 500 E. Hampden Ave, Suite 200, Englewood CO, 80113, USA

Received 11 September 2025, Accepted 19 October 2025, Published online 6 January 2026

Abstract – Introduction: Combined C1–C2 fractures are common upper cervical injuries with high morbidity and mortality. Controversy exists regarding which patients benefit from surgery because this is an understudied population with only class III evidence available. We examined surgical intervention and its impact on outcomes in patients with C1–C2 fractures. **Methods:** This retrospective cohort study of the National Trauma Data Bank included patients admitted between 1/2017 and 1/2023 for combined C1–C2 fractures (ICD-10 diagnosis codes S12.0 and S12.1). Exclusions were admission to a level III–V or non-trauma center, not admitted (died or discharged from the ED), and non-index/readmission. The first aim was to identify predictors of surgical intervention (vertebral fusion or internal fixation); multivariate backward regression included the following covariates: Patient demographics, injury severity, concomitant injuries, and specific C1 and C2 fractures. The second aim was to compare hospital outcomes between operative and nonoperative groups utilizing a propensity-matched (1:1) analysis: Mortality, ICU admission, complications, and hospital and ICU LOS. **Results:** There were 19,264 patients, and 3,759 (19.5%) were surgically managed. The adjusted odds of surgical intervention were greater with unstable injuries (displaced C1 fracture, displaced C2 fracture, spinal cord injury, vertebral ligament dislocation), specific C1 and C2 fractures (odontoid fracture, Jefferson burst fracture, posterior arch fracture), whereas surgical intervention odds decreased for frailty ($mFI \geq 2$), ED hemodynamic instability, ED Glasgow coma score ≤ 8 , and increasing age quintile. Propensity matching resulted in 6,710 well-matched patients. After matching, surgical intervention was associated with lower mortality (4.8% vs. 11.3%, $p < 0.001$) but higher ICU rates, longer LOS, and greater complication rates compared to the nonoperative group. **Conclusion:** This study of nearly 20,000 patients with combined C1–C2 fractures provides class II evidence for surgical intervention, highlighting the balance between injury characteristics and patient resilience. Surgical intervention was associated with a significant survival benefit, emphasizing its role in select patients.

Key words: Cervical spine fracture, Trauma, Mortality, Spine surgery.

Introduction

The unique anatomy and biomechanical relationship between the first and second cervical vertebrae (C1 and C2), also known as the atlas and axis, result in a wide array of injury patterns [1]. Combined atlas and axis fractures are common [2]. Approximately 40% of atlas fractures have a concomitant axis fracture [3]; this rate increases to 57% in geriatric patients [4]. Combined fractures have higher morbidity and greater biomechanical instability than isolated fractures [5].

Although combined C1–C2 injuries are not infrequent, there are few published studies in this population; the largest cohort was 107 patients [4] and the largest systematic review included 230 patients [6]. Expert-based consensus recommendations for surgical management of combined C1–C2 fractures by the AANS/CNS were based on class III evidence only [7]. Thus, the optimal management of upper cervical fractures is controversial, as they can be managed operatively or nonoperatively with no clear criteria for surgical intervention.

Several authors have proposed surgical management of combined fractures based on the C2 fracture type and location, [7–10] as well as the presence of ligamentous injuries [6, 9].

*Corresponding author: davidbme49@gmail.com

The frequency of upper cervical injuries among the elderly is a major consideration for management due to patient comorbidity and frailty, and the aging pathology resulting in weaker blood supply and bone quality [11, 12]. These factors may lend greater risk to the patient than the fracture pattern or its subsequent management [13–15].

Because this is an understudied population, we sought to use a large national registry to examine patients with combined C1–C2 fractures. The primary aim was to identify covariates that increased the likelihood of surgical intervention. The secondary aim was to determine the effect of surgical management on in-hospital outcomes.

Materials and methods

This study utilized the National Trauma Databank (NTDB), which is the largest aggregation of admissions due to traumatic injury in the United States. A trauma patient is defined as sustaining a traumatic injury with International Classification of Diseases (ICD)-10 injury codes S00–S99, T07, or T14. Study specific inclusion criteria were index admission from January 1, 2017 to January 1, 2023 and diagnoses of both C1 and C2 fractures using ICD-10 codes beginning with S12.0 and S12.1. Exclusions were as follows: Admission to a lower level ($\geq$ III) or non-trauma center, readmissions, and patients not admitted (ED discharge home, jail, against medical advice, morgue, and transfer to another facility).

The NTDB uses a standardized data dictionary and quality checks [16]. Covariates included [17] injury characteristics (cause of injury, injury severity score (ISS; <25 vs. ≥ 25 indicating polytrauma), ED Glasgow Coma Scale (GCS) of severe (3–8) vs. mild/moderate (9–15), ED hemodynamic instability (systolic blood pressure <90 mmHg or pulse >120 beats/minute); frailty (5-item modified frailty index (mFI-5), <2 vs. ≥ 2), [17]; concomitant injuries using ICD-10 diagnosis codes (spinal cord injury, traumatic brain injury, cervical ligamentous sprain, vertebral ligament dislocation); specific C1 fracture patterns (Posterior arch, Jefferson burst fracture, lateral mass fracture, other C1 fractures); and specific C2 fractures patterns (odontoid type II, odontoid type I/III, non-odontoid fractures of Hangman's and base fractures); fracture displacement; and demographics (age quintile, sex, race). Exact ages of individuals older than 89 are considered protected health information (PHI) and were recorded as 90 or above. Patients >89 years were denoted as having an age of 90 to define age quartiles.

Statistical analysis

Analyses were performed with SAS version 9.4 (SAS Institute, Cary, NC). Frequencies and descriptive statistics were used to characterize the study population using Pearson chi-square tests. An alpha <0.05 was used for statistical significance.

Surgical intervention was defined by ICD-10 procedure codes for vertebral fusion or internal fixation. A multivariate logistic regression analysis was used to examine covariates associated with surgical intervention. There were no formal hypotheses tested; following iterative backwards selection of

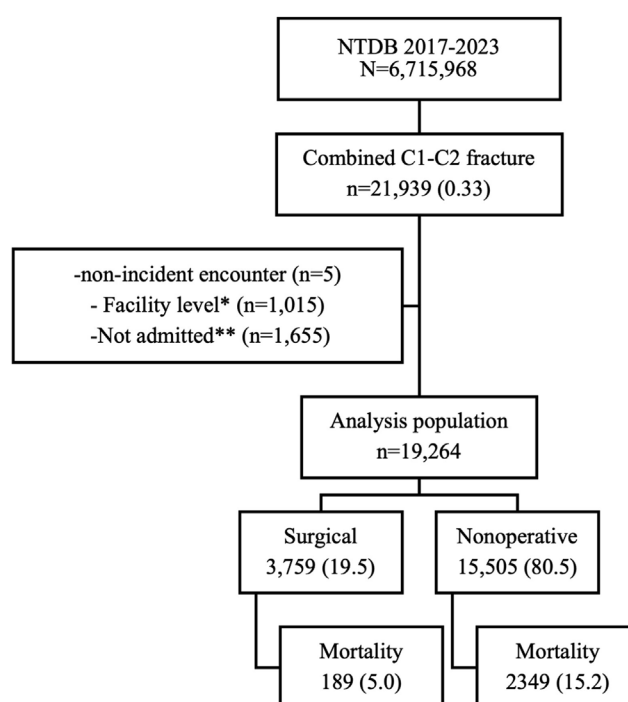


Figure 1. Study population. *Lower level (III–V) or non-trauma center designation/accreditation status. **ED discharge disposition to home, jail, transfer, against medical advice or morgue.

covariates from the model based on $p > 0.05$, all remaining covariates independently associated with surgery were reported. The model was evaluated for collinearity using a correlation coefficient >0.50 and the Akaike information criterion. Age and cause of injury were highly collinear. Additionally, there was collinearity with odontoid type II fractures and non-odontoid fractures. Cause of injury and non-odontoid fracture were not included as covariates in the regression model.

The secondary aim examined the following in-hospital outcomes: Mortality, ICU admission, development of a complication, nonsurvival (discharge destination to hospice or morgue), and hospital and ICU LOS. Evaluation of our secondary aim was performed using a propensity-matched analysis with a 1:1 ratio and caliper distance of 0.005. After matching, McNemars tests analyzed the difference in categorical outcomes (in-hospital mortality, ICU admission, complication, nonsurvival) and Wilcoxon signed-rank tests analyzed differences in median hospital and ICU LOS.

Results

Population

The records of 19,247 patients with combined C1–C2 fractures were identified for analysis (Figure 1). The median age was 76 years (interquartile range: 62–86), and 38% of patients were considered frail based on a modified frailty index ≥ 2 . There were similar proportions of men and women (51:49). The majority (69%) were injured in a fall, with 22% injured in a motor vehicle crash (MVC), 5% injured in an

Table 1. Univariate associations with surgical intervention.

Characteristic, <i>n</i> (%)	Nonsurgical (<i>n</i> = 15,505)	Surgical (<i>n</i> = 3,759)	<i>p</i> -Value
Age quintile			<0.001
<55	2506 (16.2)	817 (21.7)	
55–69	2705 (17.5)	1009 (26.8)	
70–79	3165 (20.4)	1019 (24.4)	
80–86	3138 (20.2)	610 (16.2)	
≥87	3991 (25.7)	304 (8.1)	
Frail (mFI-5 ≥2)	6069 (39.1)	1202 (32.0)	<0.001
Male sex	7597 (49.1)	2241 (59.9)	<0.001
White race	13410 (86.5)	3189 (84.8)	0.009
Cause of injury			<0.001
Fall	10929 (70.5)	2387 (63.5)	
Vehicle occupant	3293 (21.2)	1009 (26.8)	
Bicycle or pedestrian	675 (4.4)	227 (6.0)	
All other causes	608 (3.9)	136 (3.6)	
ED hemodynamic instability	1325 (8.6)	223 (5.9)	<0.001
ED GCS 3–8 (severe)	1894 (12.8)	285 (7.9)	<0.001
ISS ≥25 (polytrauma)	1720 (11.1)	430 (11.5)	0.54
Concomitant injuries			
Cervical ligament sprain	1078 (7.0)	683 (18.2)	<0.001
Vertebral dislocation	687 (4.4)	463 (12.3)	<0.001
Traumatic brain injury (TBI)	2918 (18.8)	623 (16.6)	0.001
Spinal cord injury (SCI)	1281 (8.3)	739 (19.7)	<0.001
Fracture patterns			
Odontoid type II	7220 (46.6)	2031 (54.0)	<0.001
Odontoid type I/III	2358 (15.2)	663 (17.6)	<0.001
Non-odontoid C2 fracture	4445 (28.7)	957 (25.5)	<0.001
Jefferson burst	1080 (7.0)	397 (10.6)	<0.001
Posterior arch	4537 (29.3)	1114 (29.6)	0.65
Lateral mass	1978 (12.8)	429 (11.4)	0.03
Other C1 fracture	5027 (32.4)	1180 (31.4)	0.23
Displaced C2 fracture	11701 (75.5)	3329 (88.6)	<0.001
Displaced C1 fracture	10382 (67.0)	2754 (73.3)	<0.001

Bolding denotes statistical significance.

auto-pedestrian or auto-bike crash, and 4% by another cause. Most patients had displaced upper cervical fractures (C1, 68%; C2, 78%). The most common C2 fracture was an odontoid type II fracture (48%), and the most common C1 fracture was a posterior arch fracture (29%). Most patients did not have severe injuries, based on ISS ≥25 (11%), ED GCS 3–8 (12%), and ED hemodynamic instability (8%). Concomitant injuries were also infrequent: 18% had TBI, 10% had SCI (78% were partial cord injuries), 9% had cervical ligament sprain, and 6% had vertebral ligament dislocation.

Surgical management

Nearly twenty percent (*n* = 3,758) of patients were surgically managed. As shown in Table 1, there were significant differences between surgical and nonsurgical groups for almost every covariate. Surgically managed patients were less likely to be frail and to have severe injuries (ISS ≥25, GCS ≤8, hemodynamic instability) and were more likely to be younger, male, have concomitant injuries, odontoid fractures, and displaced C1/C2 fractures.

After adjustment, covariates that remained significantly associated with greater odds of surgical intervention were as

follows: Displaced C1 fracture, displaced C2 fracture, spinal cord injury, vertebral ligament dislocation, and specific fracture patterns of odontoid type II, odontoid type I/III, Jefferson burst fracture, and posterior arch fracture (Table 2). At the same time, odds of surgical intervention decreased for ED GCS ≤8, hemodynamic instability in the ED, mFI ≥2, and increasing age quintile (Table 2).

Outcomes

In-hospital mortality was 13.2%; further, one in six (16.6%) patients either died in hospital or were discharged to hospice care (nonsurvival). There was substantial morbidity in this population: 55.8% were admitted to the ICU, 16.1% developed a complication, and the median (IQR) hospital LOS and ICU LOS were 6 (4–10) days and 4 (2–7) days, respectively.

Before matching, operative intervention was associated with a significant survival benefit, both in-hospital and when discharge to hospice was considered (Table 3). However, patients who were operatively managed had significantly worse morbidity, including higher ICU admission, longer ICU LOS and hospital LOS, and a greater likelihood of developing a complication (Table 3).

Table 2. Stepwise multivariate regression modelling surgical intervention.

Covariate	OR (95% CI)	p-Value
Spinal cord injury	2.39 (2.13–2.69)	<0.001
Vertebral ligament dislocation	2.16 (1.86–2.51)	<0.001
Displaced C2 fracture	2.15 (1.90–2.43)	<0.001
Cervical ligament sprain	2.03 (1.81–2.28)	<0.001
Odontoid type II fracture	1.90 (1.74–2.08)	<0.001
Jefferson burst fracture	1.71 (1.46–1.99)	<0.001
Male (vs. female)	1.24 (1.14–1.34)	<0.001
Odontoid I/III fracture	1.22 (1.08–1.38)	0.001
Displaced C1 fracture	1.22 (1.09–1.35)	<0.001
Posterior arch fracture	1.12 (1.02–1.22)	0.01
Frailty ≥ 2 (MFI-5)	0.91 (0.83–0.99)	0.04
ED hemodynamic instability	0.72 (0.61–0.85)	<0.001
ED GCS ≤ 8	0.31 (0.27–0.37)	<0.001
Age (ref: Age <55)	55–69: 0.96 (0.85–1.09)	0.54
	70–79: 0.75 (0.66–0.85)	<0.001
	80–86: 0.44 (0.38–0.50)	<0.001
	≥ 87 : 0.17 (0.14–0.20)	<0.001

Bolding denotes statistical significance. Model c-statistic: 0.75. Variables removed from the model with backward elimination: Race ($p = 0.89$), lateral mass fracture ($p = 0.28$), TBI ($p = 0.24$), Other C1 fracture ($p = 0.11$), and ISS ≥ 25 ($p = 0.09$).

Table 3. Outcomes of combined C1–C2 fractures, prior to and after propensity matching.

Outcome, <i>n</i> (%) or median (IQR)	All patients			Propensity matched		
	Nonoperative (15,505)	Operative (3,759)	<i>p</i> -value	Nonoperative (3,355)	Operative (3,355)	<i>p</i> -value
Mortality	2349 (15.2)	189 (5.0)	<0.001	380 (11.3)	161 (4.8)	<0.001
Morgue/hospice	2950 (19.0)	246 (6.5)	<0.001	481 (14.3)	214 (6.4)	<0.001
ICU admission	8058 (52.0)	2683 (71.4)	<0.001	1803 (53.7)	2389 (71.2)	<0.001
Complication	2164 (14.0)	939 (25.0)	<0.001	504 (15.0)	810 (24.1)	<0.001
ICU LOS	3 (2–6)	6 (3–11)	<0.001	3 (2–6)	5 (3–10)	<0.001
Hospital LOS	5 (3–9)	10 (7–16)	<0.001	5 (3–9)	10 (7–16)	<0.001

Bolding denotes statistical significance.

The propensity analysis resulted in 6,710 patients: 3,355 nonoperative and 3,355 operative (representing 89% of surgically managed patients). Patients were well matched on all study covariates (Supplementary Table 1). In the matched population, mortality was significantly lower for operatively managed patients compared to the nonoperative subset (4.8% vs. 11.3%, $p < 0.001$, Figure 2). The matched patients who were operatively managed continued to have significantly worse morbidity than the matched patients who were not operated, including higher ICU admission, longer ICU LOS and hospital LOS, and a greater likelihood of developing a complication (Table 3).

When comparing outcomes in the operative group who were matched ($n = 3,355$) and unmatched ($n = 404$), there were no differences in mortality, both in-hospital and when discharge to hospice was considered, and no differences in ICU admission rates and hospital LOS (Supplementary Table 2). The matched operative subset was less likely to have a complication (24% vs. 32%) and a shorter ICU LOS (5 vs. 6 days) than the unmatched operative subset. When comparing outcomes in nonoperatively managed patients, those in the matched analysis had

significantly lower mortality and worse secondary outcomes than unmatched patients (Supplementary Table 2).

Discussion

Expert-based consensus recommendations for surgical management of combined C1–C2 fractures by the AANS/CNS are based on class III evidence only [7]. This large, population-based analysis is the first study to provide class II evidence of surgical management for patients with combined C1–C2 fractures. This study offers valuable insights into the factors influencing surgical management and their association with outcomes. We identified patient-specific and injury-specific predictors for operative intervention and used a well-matched cohort to provide evidence that surgical intervention was associated with a significant survival benefit.

This study has several limitations. First, database studies are unable to establish causality, and there is a potential bias caused by unmeasured confounders not collected in the database. Second, participation in the NTDB is voluntary and thus does

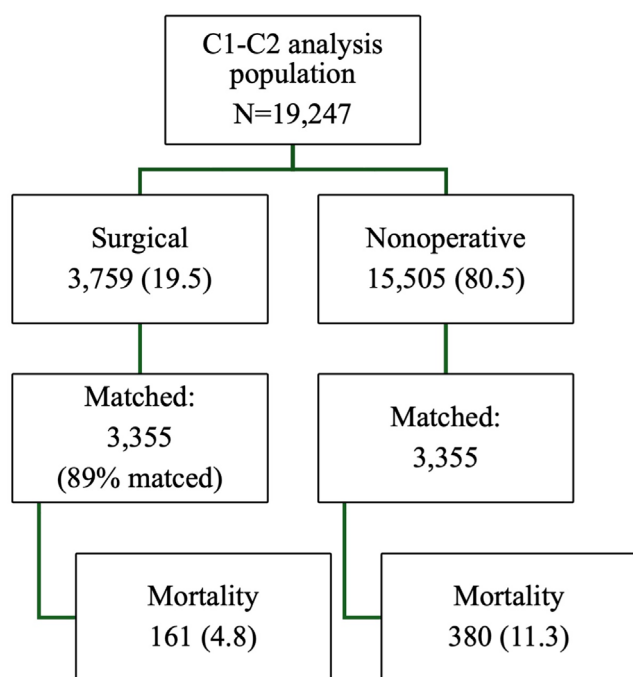


Figure 2. Propensity-matched analysis population.

not represent a true representative sample of all U.S. level I and II trauma centers. Third, the database lacks post-discharge follow-up, precluding assessment of intermediate and long-term survival and functional outcomes beyond discharge disposition. Fourth, ICD-10 codes do not capture important radiographic details such as the degree of fracture displacement, atlanto-dental interval, and union/nonunion status, which may influence surgical decision-making and prognosis. Finally, the low surgical management rate among patients ≥ 87 years old (7.1%) highlights potential selection bias, whereby only the healthiest patients were selected for surgery. Propensity score matching was employed to mitigate this bias, although residual confounding remains possible. Even in the matched cohort, the rate of surgical intervention in the oldest age quintile was only 8.1%, underscoring the cautious approach to operative care in this demographic.

Injury characteristics suggestive of mechanical instability – such as displaced C1 and C2 fractures, spinal cord injury, and vertebral ligament dislocation – were the strongest predictors for surgical intervention. Two large systematic reviews on the management of combined C1–C2 fractures recommended treatment based on specific characteristics of the axis fracture, namely unstable C1-type II odontoid fractures and unstable C1–Hangman fractures, or axis fracture with a disrupted transverse ligament [6, 7]. Odontoid type II fractures were the most prevalent fracture pattern in our cohort (48%), followed by posterior arch fractures (29%). Our rate of odontoid type II fractures is lower than previously reported but the rate of posterior arch fractures is consistent with prior reports. Mohile et al. noted odontoid type II fractures in 66% and posterior arch fractures in 32% of patients in their systematic review [6]. Similarly, Di Domenico et al. reported 73% of patients with odontoid type II fractures and a 30% incidence of posterior arch

fractures [18]. Such differences may reflect variations in study population, institutional practices, surgeon preferences, and patient selection criteria.

Conversely, increasing age, higher frailty scores, hemodynamic instability, and GCS ≤ 8 were associated with a lower likelihood of surgery. The C1–C2 injury pattern predominantly affects older adults injured from falls; in our study, the median age was 76 years, and 69% were injured from falls. These findings align with Di Domenico et al., who reported a mean age of 76 years and falls as the predominant mechanism of injury (85%) [18]. Age was an independent predictor of surgical management, where increasing age quintile was associated with decreased likelihood of surgical intervention. Likewise, frailty was also independently associated with decreased odds of surgery. In a previous investigation, Salottolo et al. found that age was the primary determinant for surgery in odontoid type II fractures, supporting the present analysis [19]. Age and frailty likely play critical roles in determining candidacy for surgery in this vulnerable population [13]. These patient- and injury-specific characteristics were not previously identified as factors for surgical management in prior large systematic reviews [6, 7].

Importantly, surgical intervention was associated with significantly lower mortality. This survival benefit persisted after generating a representative, propensity-matched cohort, further supporting the benefit of surgical management in appropriately selected patients. Our results are consistent with a study by Foote et al. that demonstrated a survival benefit associated with surgical management in patients with odontoid type II fractures using a propensity-matched NTDB cohort [20]. Despite the observed survival benefit, surgical intervention was associated with worse secondary outcomes, including higher rates of ICU admission, increased complications, and longer hospital length of stay.

Conclusions

Fracture characteristics suggestive of mechanical instability were associated with surgical management, whereas age ≥ 70 years, frailty, hemodynamic instability, and GCS ≤ 8 were associated with a lower likelihood of surgery, highlighting the balance between fracture patterns and patient resilience. Surgical intervention for combined C1–C2 fractures was associated with significantly improved survival compared to nonoperative management, even after propensity score matching. This survival advantage must be weighed against the increased risk of complications, greater ICU utilization, and longer hospital stay. Future prospective studies should clarify the relative benefits of specific operative techniques (e.g., occipitocervical fusion, posterior fusion, anterior fixation) and nonoperative approaches (e.g., cervical collar versus halo immobilization) to optimize outcomes in this high-risk population.

Funding

There was no outside financial support to produce this article.

Conflicts of interest

The authors declare that they have no relevant financial or non-financial interests to report.

Data availability statement

The datasets used and/or analyzed during the current study are publicly available. The NTDB remains the full and exclusive copyrighted property of the American College of Surgeons. The American College of Surgeons is not responsible for any claims arising from works based on the original Data, Text, Tables, or Figures.

Author contribution statement

The authors read and approved the final manuscript.

Author 1: Literature review, methodology, data acquisition, data analysis, drafting the manuscript

Author 2: conception, data interpretation, critical revisions

Author 3: Data interpretation, critical revisions

Author 4: Data interpretation, critical revisions

Author 5: Data interpretation, critical revisions, supervision

Author 6: Data interpretation, critical revisions

Author 7: Data acquisition, data interpretation, drafting the manuscript, supervision

Ethics approval

This study did not require IRB approval because the analysis of secondary, de-identified, publicly available data does not constitute research involving human subjects under the federal Common Rule, 45 CFR Part 46.

Informed consent

This article does not contain any studies involving human subjects.

Supplementary material

Supplementary Table 1: Differences in characteristics in the propensity matched population.

Supplementary Table 2: Outcomes of matched compared to unmatched patients.

The supplementary material of this article is available at <https://sicotj.edpsciences.org/10.1051/sicotj/2025058/olm>.

References

- Rahman S, Das JM (2025) Anatomy, head and neck: Cervical spine. Treasure Island FL, StatPearls Publishing.
- Gleizes V, Jacquot FP, Signoret F, Feron JM (2000) Combined injuries in the upper cervical spine: Clinical and epidemiological data over a 14-year period. *Eur Spine J* 9, 386–392.
- Kakarla UK, Chang SW, Theodore N, Sonntag VKH (2010) Atlas fractures. *Neurosurgery* 66, 60–67.
- Fiedler N, Spiegl UJA, Jarvers JS, Josten C, Heyde CE, Osterhoff G (2020) Epidemiology and management of atlas fractures. *Eur Spine J* 29, 2477–2483.
- Riddoch FI, Leerssen A, Abu-Rajab R, Leung A (2022) Mortality from combined fractures of the atlas (C1) and axis (C2) in adults. *Cureus* 14, 1–8.
- Mohile NV, Kuczmarski AS, Minaie A, Syros A, Geller JS, Maaieh MA (2023) Management of combined atlas and axis fractures: A systematic review. *North Am Spine Soc J* 14, 1–11.
- Ryken TC, Hadley MN, Aarabi B, Dhall SS, Gelb DE, Hurlbert RJ Management of acute combination fractures of the atlas and axis in adults. *Neurosurgery* 72, 151–158.
- Lin B, Wu J, Chen ZD, Zeng W, Liu Q, Dai LL (2016) Management of combined atlas-axis fractures: A review of forty one cases. *Int Orthop* 40, 1179–1186.
- Zhao ZS, Wu GW, Lin J, Zhang YS, Huang YF, Chen ZD (2019) Management of combined atlas fracture with type II odontoid fracture: A review of 21 cases. *Indian J Orthop* 53, 518–524.
- Spiegl UJA, Keil H, Krause J, Osterhoff G, Scheyerer MJ, Schnake KJ (2023) Combined odontoid (C2) and atlas (C1) fractures in geriatric patients: A systematic review and treatment recommendation. *Global Spine J* 13, 22S–28S.
- Smit AE, Meijer OC, Winter EM (2024) The multi-faceted nature of age-associated osteoporosis. *Bone Rep* 20, 1–16.
- Migliorini F, Giorgino R, Hildebrand F, Spiezia F, Peretti GM, Alessandri-Bonetti M, Eschweiler J, Maffulli N (2021) Fragility fractures: Risk factors and management in the elderly. *Med (Kaunas)* 57, 1–9.
- von der Höh NH, Keuchel J, Pieroh P, Spiegl UJA, Osterhoff G, Heyde CE (2025) Inpatient outcomes of upper cervical fractures in the elderly: A retrospective analysis of 268 cases. *BMC Geriatr* 25, 1–11.
- Fehlings MG, Arun R, Vaccaro AR, Arnold PM, Chapman JR, Kopjar B (2013) Predictors of treatment outcomes in geriatric patients with odontoid fractures: AOSpine North America multi-centre prospective GOF study. *Spine (Phila Pa 1976)* 38, 881–886.
- Vaccaro AR, Kepler CK, Kopjar B, Chapman J, Shaffrey C, Arnold P (2013) Functional and quality-of-life outcomes in geriatric patients with type-II dens fracture. *J Bone Joint Surg* 95, 729–735.
- American College of Surgeons Committee on Trauma (2021) National Trauma Data Standard Data Dictionary, 2021 Admissions. Chicago, American College of Surgeons.
- Kweh BTS, Lee HQ, Tan T, Liew S, Hunn M, Wee Tee J (2024) Posterior instrumented spinal surgery outcomes in the elderly: A comparison of the 5-item and 11-item modified frailty indices. *Global Spine J* 14, 593–602.
- Di Domenico J, Abode-Iyamah K, Khanna R, Roberts H, Hitchon PA, Smith ZA (2017) Management of acute combined fractures of the atlas and axis: A retrospective study of two trauma centers. *J Craniovertebr Junction Spine* 8, 311–315.
- Salottolo K, Betancourt A, Banton KL, Acuna D, Panchal R, Bar-Or D, Palacio CH (2023) Epidemiology of C2 fractures and determinants of surgical management: Analysis of a national registry. *Trauma Surg Acute Care Open* 8, 1–9.
- Foot CW, Salottolo K, Doan XL, Vanier C, Betancourt AJ, Bar-Or D, Palacio CH (2024) Operative management improves near-term survival of patients with odontoid type II fractures a propensity-matched national registry analysis. *Clin Spine Surg* 37, 15–22.

Cite this article as: Salottolo K, Crawley WT, Banton K, Acuna D, Palacio CH, Auston D, Syre P & Bar-Or D. (2025) Predictors of surgical management and its impact on outcomes for combined C1–C2 fractures: National registry study. *SICOT-J* 11, 59. <https://doi.org/10.1051/sicotj/2025058>.