

C2 Fracture Operative and Non-Operative Management Outcomes in Large Database Review

Christopher Wayne Foote (✉ christopher.foote@uhsinc.com)

South Texas Health System - McAllen <https://orcid.org/0000-0001-5299-0139>

Xuan-Lan Doan

South Texas Health System - McAllen

Cheryl Vanier

Touro University Nevada

Alejandro J Betancourt

South Texas Health System - McAllen

Carlos H Palacio

South Texas Health System - McAllen

Research Article

Keywords: Cervical spine fracture, odontoid fracture, trauma

Posted Date: January 18th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1229294/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Title: C2 Fracture Operative and Non-Operative Management Outcomes in Large Database Review

Authors: Christopher W Foote MD MS^{1 2}, Xuan-Lan Doan MD MS^{1 2}, Cheryl Vanier PhD², Alejandro J Betancourt MD¹, Carlos H Palacio MD FACS¹

Affiliations:

¹South Texas Health System Trauma Department, McAllen Medical Center; ²Valley Health System General Surgery Residency Program, Las Vegas Nevada; ³Touro University Nevada College of Osteopathic Medicine, Touro University Nevada

Keywords: Cervical spine fracture, odontoid fracture, trauma

Corresponding author:

Carlos H. Palacio, MD, FACS

301 West Expressway 83, McAllen, Texas. 78503

Trauma Department

Phone: 956-632-4000

Fax: 956-632-4919

Email: Chplmd@gmail.com

Co-Authors:

Christopher Foote, MD, MS

General Surgery Department

Valley Health Systems, Graduate Medical Education,

Las Vegas, Nevada. United States of America

Xuan-Lan Doan, MD, MS

General Surgery Department

Valley Health Systems, Graduate Medical Education,

Las Vegas, Nevada. United States of America

Cheryl Vanier, Ph.D

Touro University, School of Medicine

Henderson, Nevada. United States of America

Alejandro J Betancourt MD

South Texas Health System Trauma Department, McAllen Medical Center

McAllen, Texas. United States of America

Abstract

Background:

Odontoid fractures are common and projected to increase. Comorbidities compound risk of surgery and balancing the risk of non-operative management is controversial. Stable fractures are managed based on patient comorbidity with suspected clinical prognosis. Type I and III fractures are typically managed safely with cervical orthoses. Management decisions of type II fractures however, come under frequent debate. This paper evaluates overall morbidity and mortality, and outcomes of operative and non-operative management.

Methods:

We performed national database review of C2 fractures from January 2014 to December 2019. Patients were divided into categories based on Glasgow Coma Scale (GCS) and Injury Severity Score (ISS). Outcomes data considered hospital admission, Intensive Care Unit (ICU) admission, hospital length of stay (LOS), ICU LOS, and mortality. Logistic regression was used for mortality, hospital admission, and ICU admission. Odds ratios (OR) and 95% confidence intervals (CI) were calculated from the logistic regression models. The Kruskal-Wallis test was used to compare the hospital and ICU LOS based on surgery overall, and by GCS and ISS.

Results:

42,003 patients were identified, 9,187 had surgery with overall mortality rate of 0.7%. There was a younger operative median age (67) and interquartile range (IQR: 47, 78) than non-operative group (73, IQR: 56, 83). Both had the same median ISS score (10).

Surgery was associated with lower rates of mortality, from 0.1% to 0.9% mortality for non-operative. Mild or moderate GCS mortality improved operative (0.07%) to non-operative (0.23%). Severe GCS patients with surgery had significantly improved mortality rates patients without (0.29% vs 7.69%, respectively). Surgery increased ICU admissions for every ISS category. Severe GCS had higher chances of ICU admission, but no interaction with surgery. Operative patients had longer hospital and ICU stays. For all GCS and ISS categories, hospital and ICU LOS was longer for operative patients.

Conclusions:

This review demonstrates significant improvement in mortality with operative management. Standard non-operative management of type I and III C2 fractures is appropriate. Surgeons should consider operating on type II odontoid fractures unless patient cannot undertake the surgical risks of induction with general anesthesia.

Level of evidence: Level IV

Background:

Odontoid fractures are a common injury among the elderly [1] and with an ever-growing population, the number of injuries will continue. The frequency of injury and location of fracture on the dens of C2 vertebrae led Anderson and D'Alonzo to classify them as type I (fractures through the tip), type II (fractures through the base), and type III (fractures through the body of the C2 vertebral body) [2]. Consensus has established the validity of non-operative management with cervical collars for types I and III odontoid fractures, but the management of type II fractures continues to be a source for continued clinical debate. Odontoid fractures as a result of traumatic mechanism have a bimodal age distribution with peaks in younger adults aged 20-30, and elder adults aged 70-80 [3]. The younger group tend to incur injuries due to high velocity/high energy mechanism, while the elder group is thought to be injured during falls due to aging pathology [3, 4]. It is this aging pathology that causes concern for optimal management as the anatomy of the fracture lends to poor healing due to weaker blood supply and poorer bone quality, as well as high risk for strain from transverse ligament [4, 5].

Due to comorbidities of the elderly and risk of surgery, as well as the risk of further injury in non-operative management, several papers have been published to try to glean evidence toward better decision-making. With the incidence of odontoid fractures reported as 21.4 per 100, 000 inpatient Medicare admissions and estimated costs over \$1.5 billion with the majority being elderly patients older than 65 [4], optimizing outcomes and improving patient care will decrease cost and further morbidity in an already vulnerable population. Unstable cervical fractures with high risk of compromising spinal cord are managed operatively, but fractures with no immediate risk to spinal cord are

managed based on clinical gestalt and balancing patient comorbidity with suspected clinical prognosis. Odontoid fracture mortality has been reported as 10-20% in 30-day, and 20-50% in 1-year post-injury with low hemoglobin, admission from nursing facility, and neurological deficits (demonstrated by decreased GCS) as being predictors of mortality [4].

Non-operative management with cervical orthoses using a halo vest (HV), rigid cervical collar, or semi-rigid cervical collars (common brands: Philadelphia, Aspen, Miami J) are the usual management for stable type I and III odontoid fractures. Operative management is typically used in unstable odontoid and stable type II fractures, based on clinical judgement and weighing patient risk for surgery. The most common odontoid fracture is the type II being 65-74% of all reported odontoid fractures [6]. Management of stable type II odontoid fractures has come under frequent debate due to the unclear guidance or concrete clinical outcomes picture due to several patient factors and limited institutional studies. This paper aims to provide a large multicenter review of the American National Trauma Database system to evaluate overall morbidity and mortality in odontoid fractures, and the outcomes of operative and non-operative management.

Methods:

The National Trauma Database (NTDB) was searched for all C2 fractures from January 2014 to December 2019. Inclusion criteria consisted of International Classification of Diseases (ICD)-9 codes 805.02 or 805.12 and ICD-10 codes beginning with S12.1XX, as well as all ICD-9 and ICD-10 procedure codes included within the standard surgical procedures included in operative repair of C2 fractures. The patients were divided into categories based on Glasgow Coma Scale (GCS) of mild to moderate

(GCS >8) and severe (GCS ≤8). Injury Severity Score (ISS) was also categorized as minor (ISS 1-8), moderate (ISS 9-15), severe (ISS 16-24), and very severe (>24). Outcomes data that were considered included injury leading to hospital admission, injury leading to Intensive Care Unit (ICU) admission, hospital length of stay (LOS), ICU LOS, and mortality of injury. Patients were excluded for subjects who had died on index admission, or who were transferred to another hospital or left against medical advice. The ICU admission model included subjects who had been admitted to the hospital. Surgical intervention was the predictor variable of interest, and sex, age, race, ethnicity, ISS category, and GCS category were all considered as possible covariates or moderators between surgery and the outcome variables. A separate model was fit for each outcome variable. A logistic regression was used for mortality, hospital admission, and ICU admission.

The initial model included surgery, and a second model included surgery and all the possible covariates or moderators. A third model included the terms from the second model and the interactions between surgery and the possible covariates. Based on a log-likelihood test ($\alpha=0.05$), interactions with evidence for statistical significance were followed up using descriptive statistics and estimating confidence intervals for proportions. This approach was taken because, even though the data set was large, the interactions produced some small categories which may have biased the estimates in the logistic regression. Odds ratios (OR) and the associated 95% confidence intervals (CI) were calculated from the first and second logistic regression models. For LOS outcomes, parametric models were a poor fit, so the Kruskal-Wallis test was used to compare the

hospital and ICU LOS for subjects who did and did not have surgery overall and by GCS and ISS. Analyses were done in Rv4.0.5.

Results:

A total of 42,003 subjects were included in the study, and 9,187 had surgery. Mortality rate was 0.7% (295 of 41,519; data for 484 was missing). The surgery group consisted of subjects who were slightly more likely to be male, were less likely to include Pacific Islanders and more likely to include American Indians and Hispanic or Latino, and who had relatively more individuals with severe or very severe ISS or severe GCS (Table 1). In both groups, the age range was 1 to 89, but the surgery group subjects had younger median age (67) and interquartile range (IQR: 47, 78) than for the non-surgery group (median: 73, IQR: 56, 83). Surgically managed and nonoperatively managed patients had the same median ISS score with surgery 10 (IQR: 9, 14) and nonoperative 10 (IQR: 9, 17).

Mortality

Even adjusted for covariates such as injury severity, age, and race, surgery was associated with substantially lower rates of mortality, from 0.1% mortality for subjects who had surgery to 0.9% mortality for subjects who did not have surgery (Table 2). The effect of surgery on mortality was moderated by the GCS (chi-squared=10.7, $p<0.001$). For subjects with mild or moderate GCS, mortality went from 0.07% with surgery to 0.23% with no surgery (Table 3). The effect was larger for subjects with severe GCS, where patients who had surgery had mortality rates that were more than an order of magnitude smaller than for severe GCS patients without surgery (mortality: 0.29% vs 7.69%,

respectively) (Table 3). Mortality rates varied little by sex or race, and the ISS did not have a strong association with mortality. Subjects with a severe GCS had a higher mortality rate than subjects with mild or moderate scores. Mortality rates did not significantly vary by race (chi-squared=6.0, df=5, p=0.311).

Rates of Admission to Hospital or ICU

The rate of admission to the hospital was 97.1%. Surgery increased the admission rate from 96.8% to 98.5% (Table 4), but outcomes varied by ISS (chi-squared=20.7, df=3, p<0.001). For subjects with minor or moderate ISS, surgery slightly increased the chances of hospital admission for those with minor or moderate ISS, whereas surgery did not change the chances of hospitalization for those with severe or very severe ISS (Table 5). The rate of admission to the ICU for those admitted to the hospital was 49.8%, and surgery increased the admission rate to the ICU from 46.0% for those without surgery to 62.8% for those with surgery (Table 6). As with hospital admissions, likelihood of admission varied by ISS (chi-squared=10.4, df=3, p=0.015). Surgery increased ICU admissions for every ISS category (Table 6, 7). Subjects with severe GCS had higher chances of ICU admission, but there was no interaction with surgery (chi-squared=0.9, df=1, p=0.470).

LOS in Hospital and ICU

Overall, subjects who had surgery had longer hospital and ICU stays than subjects who did not have surgery (Table 8, 9). For all GCS and ISS categories, the difference in hospital LOS and ICU between surgery and no surgery groups was larger for categories indicating more severely injured subjects. For example, subjects with mild or moderate

GCS stayed a median of five days without surgery and seven days with surgery. For subjects with severe GCS and no surgery, LOS was a median of six days, whereas it was 17 days with surgery (Table 8).

Discussion:

In the United States NTDB data between January 2014 to December 2019, overall mortality rate in all odontoid fractures was low at 0.7%, with lower mortality in those undergoing operative management in either the mild-moderate and severe GCS groups. Outpatient follow-up and care is not tracked through the NTDB, but longer-term odontoid fracture mortality has been reported as 10-20% in 30-day, and 20-50% in 1-year post-injury with most mortalities related to patient comorbidities and not sequelae from odontoid fracture injuries [4]. Therefore, the immediate mortality of the odontoid fracture is associated with the index admission and management therein. The data demonstrates that mortality is improved with operative management, having a mortality rate of 0.1% compared to non-operative management mortality rate at 0.9%. ISS scores between the two groups were very similar, but GCS was found to be a significant indicator of mortality in this study with OR of 21.9 (14.8, 32.4 95% CI) for severe GCS compared with mild to moderate GCS. Severe GCS in traumatic injuries is likely due to acute brain injury and not a chronic comorbidity of pre-existing conditions for determining pre-operative suitability for which the Charlson Comorbidity Index (CCI) [10] or the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) [11] were designed to aid in clinical decision making. Decisions on whether to operate then become based on weighing the clinical stability of the patient in front of the surgeon and the risk of the non-operative and surgical intervention options.

Non-operative management techniques have been presented as viable options to mitigate patient complications with studies providing evidence of fracture fusion in selected patients. These selected patients are typically of lower severity (lower ISS) and more mild-moderate GCS score. Patients that are deemed too high risk for surgery are also managed non-operatively as the patient comorbidity, frailty, or other perioperative risks lend greater risk to the patient than the injury itself. In these cases, cervical immobilization using one of the methods listed above are utilized. Historically, the halo vest was used for maintaining cervical in-line stabilization for healing but require precise pin placement and have risks of infection, nerve/brain damage, and provide the patient with pain and tissue breakdown beneath the torso, and functional limitation and poor compliance [4, 6-8]. Semi-rigid collars were shown to have fewer complications, with similar or improved fracture union (>70% semi-rigid vs 40% HV) [4, 6, 8, 9]. Differing opinions exist to whether only full osseous fusion or including asymptomatic pseudoarthrosis are considered sufficient in goals of care with these fractures. Measures of quality of life, pain, and neck mobility are taken into consideration for cessation of non-operative management with cervical orthosis, with some still requiring surgery for failure of non-operative management. Stable nonunion or asymptomatic mobile nonunion have been deemed appropriate for clinical outcome in geriatric patients whose operative morbidity and mortality associated with undergoing surgery [4].

Patient comorbidities in odontoid fractures can be misleading as deciding factors for surgery as occult injuries can be missed on radiological studies alone. Stability of injury by measuring anteroposterior displacement >3.5 mm and perceived spinal canal invasion are insufficient for injury severity. Agunbiade, et al. described a patient with complete

cervical cord transection from a ground-level fall in a patient with minimal radiological evidence for spinal cord injury from mildly displaced odontoid fracture [12]. Disruption of the ligamentous tissues and re-alignment in cervical collar during emergency evaluation with routine imaging could miss neurological injury. Suspicion is usually low of severe spinal cord injury as it is typically rare and patients may be intubated, but this must always be considered in seriously sick patients. When taken for MRI, ligamentous injuries may then be found with even minor fractures. Ligamentous injuries may still cause significant comorbidity themselves as sub-failure injury to soft tissues can still cause persistent pain, headaches, dizziness, and chronic spine pain [13].

Cervical ligaments placed under stress during the traumatic injury but not rupturing can still create structural damage causing spinal instability and chronic pain leading to increased future falls or injury. Therefore, even when odontoid fractures are managed non-operatively with fracture union, patients may be left with persistent cervical instability [13]. Lending to cervical instability in these patients is a study by Kepler, et al. that demonstrated 30% of acute traumatic injury with initial findings of type II odontoid fractures had chronic C2 injuries with obvious nonunion from poor primary healing, with 17.5% of these showing new neurologic deficits on secondary injury [14]. These patients in that study were new to the hospital where this study was performed and did not state whether the patient had known of prior diagnosis of odontoid fracture or treatment non-operatively. The number of chronic type II odontoid fracture patients and their likelihood of returning to the emergency department for subsequent injuries found in this single institution may demonstrate an underrepresentation of morbidity for non-operative management causing increased evidence for early operative management.

Operative management techniques for odontoid fractures are divided between anterior and posterior approaches. Anterior cannulated screw fixation (ACSF) is the gold-standard for odontoid fracture surgery and has shown union rates of 88-100% [15, 16]. The operation requires anterior exposure through the prevertebral fascia to place screw through the body of C2 into the dens fragment to pull it towards the fracture line for fusion. This approach provides immediate stabilization, reduced post-operative pain, no bone grafting, and preservation of the atlanto-axial rotational movement [15]. The neck disability index (NDI) measuring the subjective pain and discomfort of the patient was rated as better than posterior instrumentation of C1-2 without fusion (PIWF) but showed decreased union rates (90.9% ACSF vs 96% PIWF; not statistically significant in that study) [15]. Both approaches demonstrate much higher successful union rates compared to non-operative management (90.9-96% vs 40-70%) [4, 6-9, 14, 15]. PIWF involves a second operation to remove the instrumentation, so the patient is put at risk for surgical complications again in order to return some of the axial rotation of the cervical spine, but still not as much as present in ACSF. Another posterior approach is a posterior instrumentation with fusion (PIF) where bone graft is used to fuse the C1-C2 vertebrae to achieve immediate cervical stability but a loss of approximately 50% of axial rotation [4], however it requires only a single operation with 90.5% union rate compared to 96% union rate in PIWF [17]. This approach reduces functionality but saves the patient from additional surgery if patient comorbidity and risk of reoperation is a deciding factor. Another approach is an occipito-cervical fusion (OCF) which is typically used when a posterior decompression is needed. This significantly reduces in cervical mobility, increases risk of dysphagia, has lower fusion rates, and significant post-operative

complications as the procedure requires instrumentation along the occiput through C1 and C2 [18].

Comparing all odontoid fractures in this large national database, low mortality in operative management for all types has shown better outcomes than non-operative management. Given that the standard management of type I and type III odontoid fractures are nonoperative with cervical collars, the operative patients are likely the unstable fractures and type II odontoid fractures. Patients undergoing surgery have demonstrated longer hospital length of stay and increased likelihood of ICU admission. This may represent the time required for post-operative recovery as an operation was associated with longer ICU and hospital LOS for each level of ISS and GCS groups. Longer hospital and ICU LOS in severe GCS compared to mild to moderate GCS, and similarly with more severe ISS scores, likely is associated to other injuries as operative fixation of the fracture immediately stabilizes the odontoid injury. Wagner, et al. reported that non-operative management of type II odontoid fractures led to hazard ratios for mortality at follow-up was 1.35 and an eventual delayed operation of 22% of patients [19].

In the elderly population incurring these injuries, the bone quality and blood supply necessary for non-operative fracture healing was a comorbid risk to optimal healing [19]. Physiology and pre-existing comorbid conditions might be indications toward operative management due to chronic pain and complications leading to eventual and costly continued management. Surgery was not found to have a negative impact on survival with adjusted comorbidities in the AOSpine North America study by Chapman, et al [20]. Mitigating cost and risk associated with prolonged non-operative management in elderly patients 65-84 would be more beneficial to undergo an operation when considering cost

at \$100,000/quality-adjusted life year (QALY) as a surgical benchmark [19]. The longer hospital and ICU LOS associated with surgical healing and management of acute injuries may be marginal financial cost by operating on type II odontoid fractures relative to the opportunity cost of prolonged outpatient clinic hours, subsequent operative time to the surgeon and chronic pain, medication effects, and quality of life lost by patients.

Conclusions:

Odontoid fractures continue to be a common injury and despite multiple publications discussing management, especially with the focus being type II odontoid fractures, there does not appear to be a large enough review to define an optimal decision. Several literature reviews have summarized individual institutional data and described various surgical techniques to manage these fractures with evidence that good long-term clinical outcomes can be achieved from operative management over non-operative management. There have been several surgical approaches described that provide options to the surgeon for handling acceptable post-operative complications while fixing the fracture depending on the frailty or clinical status of the pre-operative patient. The data analyzed in this study of a large national database review demonstrates that statistically significant improvement in mortality can be achieved with operative management in the acute setting with adjusted patient demographics and comorbidities. Injury severity appears to be similar in both operative and non-operative management cohorts to reliably compare the two based on surgical intervention. Overall patient care with acceptance of marginal increase in financial costs due to hospital and ICU stays associated with surgical intervention are preferable to opportunity cost of prolonged management of patients and complications associated with no intervention. Based on

these data, unless the patient cannot undergo the surgical risks of induction with general anesthesia, we recommend be managed operatively with one of the approaches described rather than under non-operative management.

Acknowledgements

Not applicable

Authors' contributions

CF and XD completed data collection. CF and CHP wrote the manuscript. CV performed statistical analysis. AB was senior mentor for this paper. The author(s) read and approved the final manuscript.

Declarations

Ethics approval and consent to participate

National Trauma Database review; not applicable.

Consent for publication

Not applicable

Competing interests

We know of no conflicts of interests associated with the publication and there has been no financial support for this work that could influence its outcome.

Author Details

¹South Texas Health System Trauma Department, McAllen Medical Center, McAllen Texas; ²Valley Health System General Surgery Residency Program, Las Vegas Nevada; ³Touro University Nevada College of Osteopathic Medicine, Touro University Nevada

References:

1. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture-dislocations of the cervical spine. *Injury*. 1992;23(1):38-40. doi: 10.1016/0020-1383(92)90123-a. PMID: 1541497.
2. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Joint Surg Am*. 1974 Dec;56(8):1663-74. PMID: 4434035.
3. 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;2017:8321680. doi: 10.1155/2017/8321680. Epub 2017 Jan 15. PMID: 28182084; PMCID: PMC5274671.
4. Iyer S, Hurlbert RJ, Albert TJ. Management of Odontoid Fractures in the Elderly: A Review of the Literature and an Evidence-Based Treatment Algorithm. *Neurosurgery*. 2018 Apr 1;82(4):419-430. doi: 10.1093/neuros/nyx546. PMID: 29165688.
5. Chapman J, Smith JS, Kopjar B, Vaccaro AR, Arnold P, Shaffrey CI, Fehlings MG. The AOSpine North America Geriatric Odontoid Fracture Mortality Study: a retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients

with long-term follow-up. *Spine (Phila Pa 1976)*. 2013 Jun 1;38(13):1098-104. doi: 10.1097/BRS.0b013e318286f0cf. PMID: 23354104; PMCID: PMC3678887.

6. Gembruch O, Lemonas E, Ahmadipour Y, Sure U, El Hindy N, Müller O. Nonoperative management of C-2 dens fractures: Single center experience and review of the literature. *Clin Neurol Neurosurg*. 2018 Jun;169:166-173. doi: 10.1016/j.clineuro.2018.04.021. Epub 2018 Apr 22. PMID: 29705652.

7. Müller EJ, Schwinnen I, Fischer K, Wick M, Muhr G. Non-rigid immobilisation of odontoid fractures. *Eur Spine J*. 2003 Oct;12(5):522-5. doi: 10.1007/s00586-003-0531-1. Epub 2003 May 14. PMID: 12748895; PMCID: PMC3468001.

8. Girardo M, Rava A, Gargiulo G, Coniglio A, Artiaco S, Massè A, Fusini F. Clinical and radiological union rate evaluation of type 2 odontoid fractures: A comparison between anterior screw fixation and halo vest in elderly patients. *J Craniovertebr Junction Spine*. 2018 Oct-Dec;9(4):254-259. doi: 10.4103/jcvjs.JCVJS_93_18. PMID: 30783350; PMCID: PMC6364356.

9. Aquila F, Tacconi L, Baldo S. Type II Fractures in Older Adults: Can They Be Treated Conservatively?: A Single-Center Experience and Review of the Literature. *World Neurosurg*. 2018 Oct;118:e938-e945. doi: 10.1016/j.wneu.2018.07.105. Epub 2018 Jul 20. PMID: 30036717.

10. Glasheen WP, Cordier T, Gumpina R, Haugh G, Davis J, Renda A. Charlson Comorbidity Index: ICD-9 Update and ICD-10 Translation. *Am Health Drug Benefits*. 2019 Jun-Jul;12(4):188-197. PMID: 31428236; PMCID: PMC6684052.

11. American College of Surgery National Surgical Quality Improvement Program. <https://riskcalculator.facs.org/RiskCalculator/index.jsp>. Last accessed 12/27/2021.
12. Agunbiade S, Belton PJ, Mesfin FB. Spinal Cord Transection in a Type II Odontoid Fracture From a Ground-Level Fall. *Cureus*. 2020 Dec 28;12(12):e12342. doi: 10.7759/cureus.12342. PMID: 33520537; PMCID: PMC7837629.
13. Trajkovski A, Hribernik M, Kunc R, Kranjec M, Krašna S. Analysis of the mechanical response of damaged human cervical spine ligaments. *Clin Biomech (Bristol, Avon)*. 2020 May;75:105012. doi: 10.1016/j.clinbiomech.2020.105012. Epub 2020 Apr 19. PMID: 32371284.
14. Kepler CK, Vaccaro AR, Dibra F, Anderson DG, Rihn JA, Hilibrand AS, Harrop JS, Albert TJ, Radcliff KE. Neurologic injury because of trauma after type II odontoid nonunion. *Spine J*. 2014 Jun 1;14(6):903-8. doi: 10.1016/j.spinee.2013.07.443. Epub 2013 Sep 27. PMID: 24080191.
15. Yuan S, Wei B, Tian Y, Yan J, Xu W, Wang L, Liu X. The comparison of clinical outcome of fresh type II odontoid fracture treatment between anterior cannulated screws fixation and posterior instrumentation of C1-2 without fusion: a retrospective cohort study. *J Orthop Surg Res*. 2018 Jan 8;13(1):3. doi: 10.1186/s13018-017-0702-0. PMID: 29310670; PMCID: PMC5759802.
16. Yuan S, Wei B, Tian Y, Yan J, Xu W, Wang L, Liu X. Posterior temporary C1-2 fixation for 3-part fractures of the axis (odontoid dens and Hangman fractures). *Medicine (Baltimore)*. 2018 Nov;97(48):e12957. doi: 10.1097/MD.0000000000012957. PMID: 30508884; PMCID: PMC6283111.

17. Guo Q, Deng Y, Wang J, Wang L, Lu X, Guo X, Ni B. Comparison of Clinical Outcomes of Posterior C1-C2 Temporary Fixation Without Fusion and C1-C2 Fusion for Fresh Odontoid Fractures. *Neurosurgery*. 2016 Jan;78(1):77-83. doi: 10.1227/NEU.0000000000001006. PMID: 26348006.
18. Bhimani AD, Chiu RG, Esfahani DR, Patel AS, Denyer S, Hobbs JG, Mehta AI. C1-C2 Fusion Versus Occipito-Cervical Fusion for High Cervical Fractures: A Multi-Institutional Database Analysis and Review of the Literature. *World Neurosurg*. 2018 Nov;119:e459-e466. doi: 10.1016/j.wneu.2018.07.182. Epub 2018 Jul 30. PMID: 30071333.
19. Wagner SC, Schroeder GD, Kepler CK, Schupper AJ, Kandziora F, Vialle EN, Oner C, Fehlings MG, Vaccaro AR. Controversies in the Management of Geriatric Odontoid Fractures. *J Orthop Trauma*. 2017 Sep;31 Suppl 4:S44-S48. doi: 10.1097/BOT.0000000000000948. PMID: 28816875.

Table 1. Description of population based on surgical status. The number of subjects (n), then number who had surgery (Surgery), the percent who had surgery (% surgery), and p-values from chi-squared tests comparing groups for different rates of surgical intervention are provided.

	n	Surgery	% surgery	p-values
Sex				<0.001
Female	21214	4199	20%	
Male	20789	4988	24%	
Race				<0.001
American Indian	179	55	31%	
Asian	514	120	23%	
Black	2731	759	28%	
Pacific Islander	53	7	13%	
Other	1723	441	26%	
White	35833	7575	21%	
ISS				0.009
Not Hispanic or Latino	36128	7768	22%	
Hispanic or Latino	2110	505	24%	
GCS				0.070
Mild to Moderate (>8; 96% were 15)	30547	2689	9%	
Severe (≤8; 78% were 3)	3380	691	20%	
ISS				<0.001
Minor	6306	1385	22%	
Moderate	24687	5041	20%	
Severe	6897	1695	25%	
Very Severe	3629	913	25%	

Table 2. Differences in mortality based on surgical intervention, sex, age, injury severity score (ISS), Glasgow Coma Scale (GCS), and race. The odds ratio (OR) and 95% confidence interval (CI), the p-value based on logistic regression, and the number of subjects with a characteristic who died and lived, as well the percent mortality for the group, are reported. For age, median and inter-quartile range are reported for each group.

		OR (95% CI)	p-value	Died	Lived	% mortality
Surgery (Unadjusted)		0.12 (0.07,0.23)	<0.001			
Surgery (Adjusted)	No Surgery			286	32199	0.9%
	With Surgery	0.1 (0.04,0.22)	<0.001	9	9025	0.1%
Sex	Female			127	20856	0.6%
	Male	1.01 (0.76,1.34)	0.970	168	20364	0.8%
Age (years)		1.01 (1,1.02)	0.011	62 (41,80)	72 (54,82)	
ISS	Minor			26	6280	0.4%
	Moderate	0.49 (0.28,0.87)	0.015	60	24627	0.2%
	Severe	0.78 (0.43,1.44)	0.434	56	6841	0.8%
	Very Severe	1.54 (0.86,2.78)	0.148	153	3476	4.2%
GCS	Severe	21.9 (14.8,32.4)	<0.001	206	3129	6.2%
	Mild or moderate			68	35147	0.2%
Race	White			225	35273	0.6%
	American Indian	4 (1.4,11.7)	0.012	4	172	2.3%
	Asian	1.2 (0.4,3.4)	0.702	4	489	0.8%
	Black	1.1 (0.7,1.7)	0.681	28	2663	1.0%
	Pacific Islander	3.4 (0.4,29.2)	0.268	1	46	2.1%
	Other	0.9 (0.5,1.7)	0.736	13	1613	0.8%

Table 3. Mortality with and without surgery by GCS category. The number of subjects who died and lived and mortality with 95% confidence interval are reported for each combination of surgery and GCS.

GCS	Surgery	Died	Lived	Mortality	95% CI
GCS Mild or Moderate	No Surgery	63	27521	0.23%	(0.18,0.29)
	Surgery	5	7626	0.07%	(0.02,0.16)
GCS Severe	No Surgery	204	2448	7.69%	(6.72,8.79)
	Surgery	2	681	0.29%	(0.05,1.17)

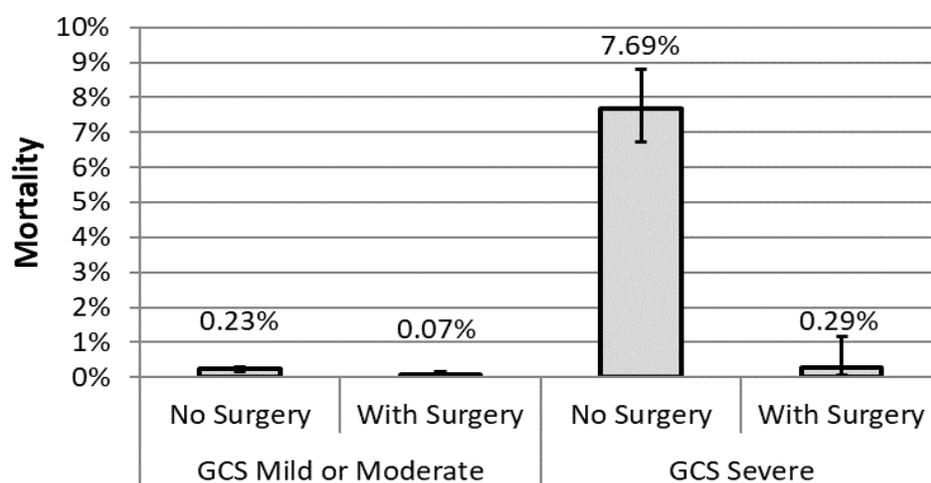


Table 4. Differences in hospitalization rate based on surgical intervention, sex, age, injury severity score (ISS), Glasgow Coma Scale (GCS), and race. The odds ratio (OR) and 95% confidence interval (CI), the p-value based on logistic regression, and the number of subjects with a characteristic who were and were not admitted, as well the admission rate for the group, are reported. For age, median and inter-quartile range are reported for each group.

		OR (95% CI)	p-value	Admitted	Not admitted	% Admitted
Surgery (Unadjusted)		2.16 (1.79,2.59)	<0.001			
Surgery (Adjusted)	No Surgery			28447	953	96.8%
	With Surgery	2.46 (2,3.03)	<0.001	8370	130	98.5%
Sex	Female			18661	523	97.3%
	Male	0.92 (0.8,1.06)	0.257	18152	560	97.0%
Age (years)		1.01 (1.10,1.01)	<0.001	72 (54,82)	69 (49,80)	
ISS	Minor			5349	292	94.8%
	Moderate	1.6 (1.37,1.88)	<0.001	21810	703	96.9%
	Severe	5.26 (3.91,7.08)	<0.001	6402	64	99.0%
	Very Severe	5.37 (3.44,8.4)	<0.001	3256	24	99.3%
GCS	Mild or moderate			31424	988	97.0%
	Severe	2.5 (1.6,3.9)	<0.001	2948	23	99.2%
Race	White			31470	908	97.2%
	American Indian	1.4 (0.4,4.3)	0.597	153	3	98.1%
	Asian	1 (0.6,1.9)	0.955	449	12	97.4%
	Black	0.7 (0.6,0.9)	0.004	2373	104	95.8%
	Pacific Islander	1.2 (0.2,9.2)	0.832	42	1	97.7%
	Other	1.1 (0.8, 1.6)	0.499	1477	35	97.7%

Table 5. Effect of GCS on hospital admission with and without surgery. The number of subjects who were and were not admitted and the admission rate, with 95% confidence interval, are reported for each combination of surgery and GCS.

ISS	Surgery	Admitted	Not admitted	Hospital admission	95% CI
Minor	No Surgery	4105	252	94.22%	(93.47,94.88)
	Surgery	1244	40	96.88%	(95.74,97.74)
Moderate	No Surgery	17165	639	96.41%	(96.12,96.68)
	Surgery	4645	64	98.64%	(98.25,98.94)
Severe	No Surgery	4790	47	99.03%	(98.69,99.28)
	Surgery	1612	17	98.96%	(98.29,99.37)
Very Severe	No Surgery	2387	15	99.38%	(98.94,99.64)
	Surgery	869	9	98.97%	(97.98,99.50)

Table 6. Differences in ICU admission rate based on surgical intervention, sex, age, injury severity score (ISS), Glasgow Coma Scale (GCS), and race. The odds ratio (OR) and 95% confidence interval (CI), the p-value based on logistic regression, and the number of subjects with a characteristic who were and were not admitted, as well the admission rate for the group, are reported. For age, median and inter-quartile range are reported for each group.

		OR (95% CI)	p-value	Admitted	Not admitted	% Admitted
Surgery (Unadjusted)		1.98 (1.88,2.08)	<0.001			
Surgery (Adjusted)	No Surgery			13129	15394	46.0%
	With Surgery	2.02 (1.9,2.14)	<0.001	5267	3123	62.8%
Sex	Female			8446	10268	45.1%
	Male	1.21 (1.15,1.27)	<0.001	9946	8249	54.7%
Age (years)		1 (1,1)	0.666	69 (50,81)	75 (59,83)	
ISS	Minor			1800	3569	33.5%
	Moderate	1.47 (1.36,1.58)	<0.001	9023	12850	41.3%
	Severe	4.43 (4.05,4.84)	<0.001	4543	1866	70.9%
	Very Severe	14.325 (12.17,16.91)	<0.001	3030	232	92.9%
GCS	Mild or Moderate	15.6 (12.5,19.5)	<0.001	14566	16946	46.2%
	Severe	1 (1,1)	<0.001	2846	105	96.4%
Race	White			15264	16286	48.4%
	American.Indian	1.1 (0.7,1.6)	0.654	92	62	59.7%
	Asian	1.1 (0.9,1.4)	0.498	239	212	53.0%
	Black	1.1 (1,1.2)	0.136	1348	1032	56.6%
	Pacific.Islander	1.5 (0.7,3.3)	0.285	26	16	61.9%
	Other	1.3 (1.2,1.5)	<0.001	921	558	62.3%

Table 7. ICU admission rates with and without surgery by ISS category. The number of subjects who died and lived and mortality with 95% confidence interval are reported for each combination of surgery and ISS.

ISS	Surgery	Admitted	Not admitted	ICU admission	95% CI
Minor	No Surgery	1274	2847	30.91%	(29.51,32.36)
	Surgery	526	722	42.15%	(39.39,44.95)
Moderate	No Surgery	6429	10787	37.34%	(36.62,38.07)
	Surgery	2594	2063	55.70%	(54.25,57.13)
Severe	No Surgery	3228	1567	67.32%	(65.96,68.64)
	Surgery	1315	299	81.47%	(79.47,83.32)
Very Severe	No Surgery	2198	193	91.93%	(90.74,92.97)
	Surgery	832	39	95.52%	(93.87,96.76)

Table 8. Hospital length of stay (LOS) with and without surgery by GCS and ISS categories. The number of subjects (n), median and interquartile range for LOS, and test statistic and p-values from a Kruskal-Wallis test (W) are reported.

		Surgery	n	LOS	W	P
All Subjects		No Surgery	28104	5 (3,8)	2386	<0.001
		Surgery	8349	7 (5,8)		
GCS	Mild or Moderate	No Surgery	24060	5 (3,7)	1995	<0.001
		Surgery	7092	7 (5,12)		
	Severe	No Surgery	2222	6 (2,17)	268	<0.001
		Surgery	655	17 (9,28)		
ISS	Minor	No Surgery	4044	3 (2,5)	243	<0.001
		Surgery	1242	5 (3,8)		
	Moderate	No Surgery	17001	4 (3,7)	1545	<0.001
		Surgery	4633	7 (4,10)		
	Severe	No Surgery	4728	7 (4,11)	340	<0.001
		Surgery	1609	10 (6,17)		
	Very Severe	No Surgery	2331	8 (3,18)	313	<0.001
		Surgery	865	17 (10,28)		

Table 9. ICU length of stay (LOS) with and without surgery by GCS and ISS categories. The number of subjects (n), median and interquartile range for LOS, and test statistic and p-values from a Kruskal-Wallis test (W) are reported.

		Surgery	n	ICU LOS	W	P
All Subjects		No Surgery	11763	3 (2,6)	404	<0.001
		Surgery	3449	5 (3,11)		
GCS	Mild or Moderate	No Surgery	9708	3 (2,5)	312	<0.001
		Surgery	2846	5 (3,9)		
	Severe	No Surgery	1349	5 (2,12)	158	<0.001
		Surgery	372	13 (7,21)		
ISS	Minor	No Surgery	1230	2 (2,3)	26	<0.001
		Surgery	340	3 (2,4)		
	Moderate	No Surgery	6293	3 (2,4)	178	<0.001
		Surgery	1625	4 (2,7)		
	Severe	No Surgery	2630	4 (2,7)	100	<0.001
		Surgery	902	6 (3,12)		
	Very Severe	No Surgery	1610	5 (2,13)	160	<0.001
		Surgery	582	12 (6,20)		