Original Article

Epidemiology of C2 fractures in the United States: A National Electronic Injury Surveillance System database study

ABSTRACT

Introduction: C2 fractures are one of the most common traumatic injuries of the cervical spine, with high rates of morbidity and mortality. Current literature on the incidence of C2 fractures is limited to populations outside of the United States (US), prior to 2014, or specific age cohorts. The purpose of this study is to report the incidence rate (IR) of C2 fractures and associated patient demographics in the US between 2002 and 2021 using the National Electronic Injury Surveillance System (NEISS) database.

Methods: This study analyzed the NEISS database to identify cases of C2 fractures presenting to US Emergency Departments (EDs) from 2002 to 2021. Annual and overall numbers of fractures, IR, and patient demographics were analyzed. IR is expressed as the number of fractures per 100,000 person-years at risk (PYR). Patients were split into three different age groups for comparison (children and young adults, 0–64 years; older adults, 65–79 years; elderly individuals, 80 + years).

Results: A national estimate of $n = 72,764$ patients (95% confidence interval [CI] = 54,371–91,156) presented to US EDs with a C2 fracture (IR was 1.17/PYR; 95% CI = 0.87–1.46), and elderly individuals had the highest IR overall (IR = 15.9; $P < 0.05$). The IR of C2 fractures between 2002 and 2021, reported as average annual percent change (AAPC), increased significantly, regardless of age or sex (AAPC = 10.9; 95% CI = 6.3–15.6; $P < 0.0001$).

Conclusion: C2 fractures occur at higher rates than previous years, with especially high IR in elderly individuals. Emphasis of public health efforts toward osteoporosis and coordination difficulties in elderly individuals would likely significantly reduce the overall IR of these injuries.

Keywords: Axis, C2, epidemiology, national electronic injury surveillance system

INTRODUCTION

Traumatic cervical spine fractures are found in approximately 3% of all trauma patients.[1-3] The dynamic nature of cervical spine anatomy as a person ages results in variability of the motion segment levels susceptible to injury.[4,5] Younger patients often sustain injuries to the lower cervical vertebra secondary to motor vehicle collisions (MVCs), while elderly patients commonly suffer injuries of the upper cervical vertebrae due to falls.[2,4-8] Overall, upper cervical fractures comprise approximately 25%–40% of all cervical trauma across all age groups.[4] Specifically, fractures of the axis (C2 vertebra) are the most common cervical spine fracture, especially in the elderly.[1-7,9,10]

When present, fractures of the C2 vertebra result in high morbidity and mortality.[4,6,8,11,12] Concomitant injuries often include contiguous and noncontiguous cervical

Fehmi Berkay[1], Arjun Minhas[1], Joseph G. Lyons[1], Elizabeth Fonte[1], Norah Foster[1,2]

[1]Department of Orthopaedic Surgery, Wright State University Boonshoft School of Medicine, [2]Department of Orthopaedic Surgery, Miami Valley Hospital, Dayton, OH, USA

Address for correspondence: Dr. Fehmi Berkay, No. 30 East Apple Street, Suite 2200, Dayton 45409, OH, USA.
E-mail: fehmiberkay93@gmail.com

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spine fractures, spinal cord injuries, head-and-neck injuries, and pelvic fractures with variable rates of association.[8,10,13,14] Furthermore, patients may suffer complications such as respiratory infection, pressure ulcers, and venous thromboembolism regardless of operative versus nonoperative management.[10,13,14] As a result, there is a significant financial burden due to increased length of stay, direct costs, and lost productivity.[10,12,13]

There has been increased focus on disease and injury prevention, with attention directed toward public health and preventative medicine.[10] This obviates the need for accurate epidemiological data to ensure that common injuries receive appropriate recognition. Previous literature reporting on the incidence of C2 fractures has observed an increased rate over time.[10,11] However, the current epidemiological data available are limited to populations outside of the United States (US), based on regional data, or focused on a specific age cohort or fracture type, limiting generalizability to our population.[7,9,11,12,15] The purpose of this study is to report the updated incidence rate (IR) of C2 fractures and associated patient demographics in the US between 2002 and 2021 using the National Electronic Injury Surveillance System (NEISS) database. We hypothesize that due to the increasing age of the US population, with associated difficulties in coordination leading to increased fall risk and inherent reduction in bone quality, there will be a trend of increasing incidence of C2 fractures in the US.

METHODS

The NEISS database is a public health research database that collects data on consumer product-related injuries in the US. This database is a nationally representative probability sample of Emergency Departments (EDs) in the US collected by the Consumer Product Safety Commission (CPSC). Product-related injury data are gathered from approximately 100 EDs in the US. NEISS hospitals are a composite of small, medium, large, and very large hospitals across the US which are representative of the 5000 + EDs in the US. Trained coders at each participating facility collect data variables including demographic information, injury diagnoses, and a brief narrative description of each injury incident. Each NEISS database record carries a weighting factor for the conversion of cases (unweighted records, *n*) to national injury estimates (weighted estimates, *n*) by accounting for the NEISS stratified probability sampling design. This allows the total number of ED visits nationwide (related to a certain product/activity) to be estimated from the sample of cases which are reported in the NEISS dataset. The NEISS database has been widely used to analyze various injuries and is an established model for epidemiological surveillance of musculoskeletal injuries.[16-21] The description of the design of this database is available on the CPSC webpage.[22,23]

No Institutional Review Board review was required as this is a de-identified database. The NEISS database was used to search for patients with C2 fractures in the US from the years 2002–2021. Search terms to identify C2 fractures included "C2, hangman, odontoid, axis, and dens." The following descriptive terms were excluded as C2 fractures during analysis due to their ambiguity with respect to the presence of a fracture: pseudosubluxation, subluxation, neck strain, C2 tenderness, C2 sprain, old C2 fracture, rule-out C2 fracture, and possible C2 fracture.

Statistical analysis was performed using the survey data commands (svyset) in STATA/IC, version 17.0 (StataCorp, College Station, TX, USA), accounting for sample weights and the complex survey design. Results are reported as numbers of unweighted cases (*n*) and/or as weighted national estimates (*N*) with corresponding 95% confidence intervals (CIs). Each unweighted case (*n*) in the NEISS database represents a single patient ED encounter and has a sample weight which represents the inverse of the probability of selection of the case. Sample weights are summed to provide national estimates (*N*). The US Census Bureau population estimates for the years 2002 through 2021 were used to calculate at-risk person-years during the study period.[24] Thus, the population at risk was defined as the entire US population in order to derive national incidence estimates. IRs are expressed as the number of injuries per 100,000 person-years at risk (PYR) and are calculated as the number of estimated injuries (*N*) divided by PYR. IR ratios (IRRs) are reported and represent unitless expressions of risk used for the comparison of IRs between two distinct subgroups, with the IR of an identified referent subgroup serving as the denominator. IRRs among sex and age groups are reported. Patients were split into three different age groups for comparisons (children and young adults, 0–64 years; older adults, 65–79 years; elderly individuals, 80 + years). Chi-square tests were used to compare estimated IRs between groups. Student's *t*-test/analysis of variance and design-adjusted Rao–Scott Chi-square analysis was used for direct comparisons of means for continuous variables and proportions for categorical variables, respectively.[25,26] Temporal trends in annual IRs over the course of the study period were assessed with regression analyses (Joinpoint Regression Program, version 4.9.1.0 – April 2022; Statistical Methodology and Applications Branch, Surveillance Research Program, National Cancer Institute).[27] Annual percent change (APC) estimates are presented to indicate the magnitude and direction of trends in injury rates for each time period as determined by

Joinpoint regressions. Average APC (AAPC) estimates indicate the average magnitude/direction of trends over the entire study period (2002–2021). $P < 0.05$ was the threshold for statistical significance.

RESULTS

A total of $n = 2069$ unweighted cases were identified over the course of the 20-year study period from 2002 to 2021, corresponding to a national estimate of $N = 72,764$ patients (95% CI = 54,371–91,156) presenting to US EDs with a C2 fracture. Overall IR was 1.17 PYR (95% CI = 0.87–1.46; total population at risk = 6,230,824,200 person-years). The mean age of patients with C2 fractures was 74.8 years (95% CI = 73.2–76.4). Overall, a large majority (81.7%) of patients required hospital admission.

Accounting for population growth yielded a significantly increasing incidence over the study period from 0.36 PYR in 2002–2.2 PYR in 2021 (AAPC = 10.9, 95% CI = 6.3–15.6; $P < 0.0001$). Injury rates increased sharply during the period from 2002 to 2006 (APC = 26.3, $P = 0.03$), and increased steadily thereafter, although at a slower rate, for the duration of the observation period from 2006 to 2021 (APC = 7.1, $P < 0.0001$) [Figure 1].

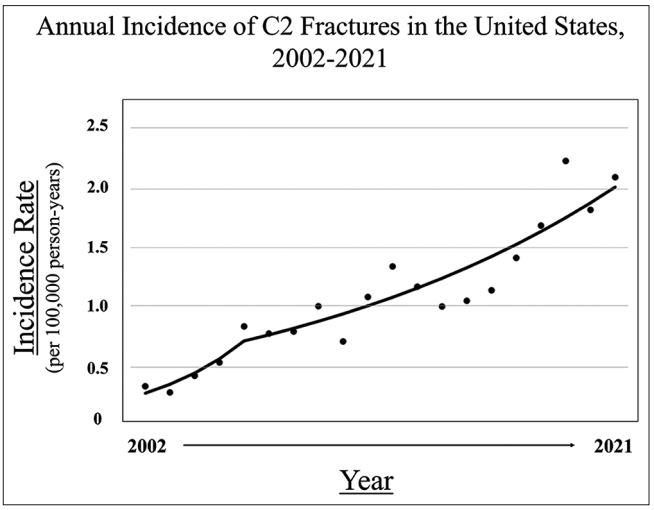

Figure 1: Annual incidence of C2 fractures in the US, 2002–2021

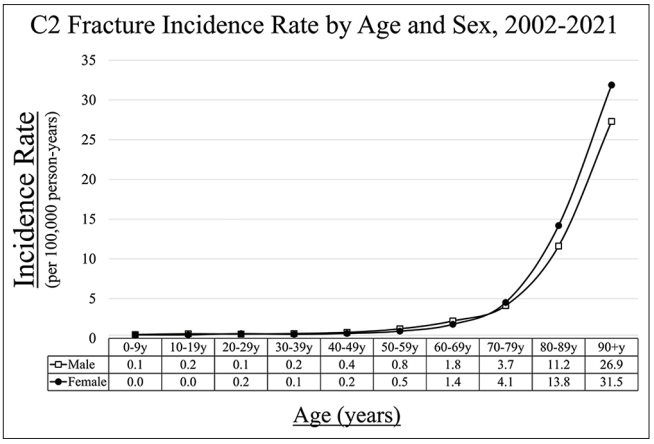

Figure 2: C2 fracture incidence rate by age and sex, 2002–2021

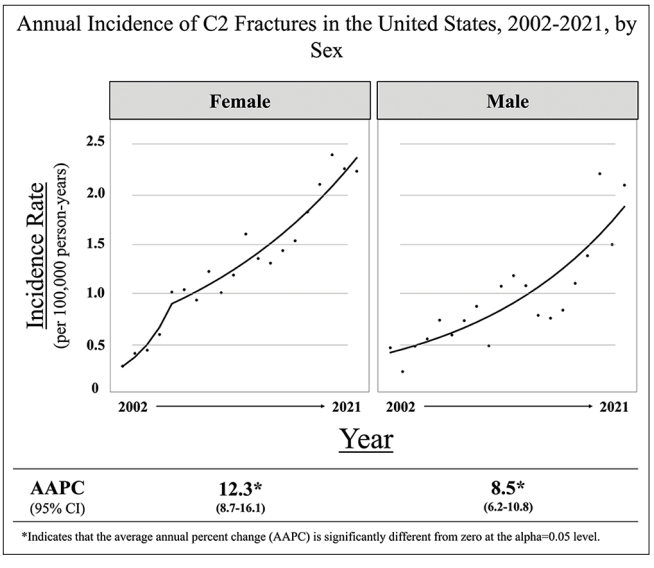

Figure 3: Annual incidence of C2 fractures in the US, 2002–2021, by sex

Sex

Females accounted for 58.6% of all cases. Overall, an estimated $n = 42,671$ cases (95% CI = 31,137–54,205) occurred in female patients for an overall IR of 1.35 PYR (95% CI = 0.98–1.71; total female population at risk = 3,164,991,156 person-years). Males accounted for 41.4% of all cases. Overall, an estimated $n = 30,093$ cases (95% CI = 22,468–37,717) occurred in male patients for an overall IR of 0.98 PYR (95% CI = 0.73–1.23; total male population at risk = 3,065,833,044 person-years). Overall injury rates did not differ significantly between female and male patients (female: male IRR = 1.4, 95% CI = 0.9–2.0; $P > 0.05$). Similar fracture distributions were also observed, primarily affecting older patients and with a progressive increase in incidence with age seen among both males and females [Figure 2]. However, the mean age of females was significantly higher than that of males (78.1 vs. 70.0 years, respectively; $P < 0.001$). Annual injury rates increased significantly among both female (AAPC = 12.3, 95% CI = 8.7–16.1; $P < 0.0001$) and male (AAPC = 8.5, 95% CI = 6.2–10.8; $P < 0.0001$) patients [Figure 3], and there was no statistically significant difference in the rate of annual increase between the sexes ($P = 0.08$).

Age

Children and adolescents (<18 years of age) accounted for just 1.8% of all cases, while adults (aged 18–64 years) accounted for 19.4% of cases. Together, the children/younger adults' age group (including all individuals <65 years of

age) accounted for slightly less than one-fourth (21.2%) of all cases of C2 fractures (overall IR = 0.29 PYR). Older adults (aged 65–79 years) accounted for slightly more than one-fourth (28.6%) of cases (overall IR = 3.21 PYR), and elderly individuals (80 + years of age) accounted for half (50.2%) of all cases (overall IR = 15.9 PYR). When compared with children/younger adults, overall C2 fracture injury rates were 11.1 times higher in older adults and 55.4 times higher in elderly individuals [Table 1]. Injury rates among elderly individuals were also significantly higher than that of older adults (IRR = 5.0, 95% CI = 2.9–8.6; $P < 0.05$).

Stratified by sex, male and female IRs were similar for all age groups except children/younger adults, with a significantly lower IR observed among females when compared with males of this age group [Table 2]. Annual C2 fracture IRs increased significantly among children/young adults (AAPC = 6.2, 95% CI = 4.0–8.4; $P < 0.0001$), older adults (AAPC = 7.6, 95% CI = 4.8–10.4; $P < 0.0001$), and elderly individuals (AAPC = 11.9, 95% CI = 6.9–17.3; $P < 0.0001$) [Figure 4]. The annual incidence of C2 fractures among elderly individuals increased at a significantly higher rate than that among children/younger adults ($P = 0.04$). Similar trends were observed when each age group was stratified by sex. Among children/young adults, annual injury rates increased significantly and at similar rates in males (AAPC = 5.8, 95% CI = 2.8–8.9; $P = 0.007$) and females (AAPC = 5.7, 95% CI = 1.5–10.0; $P = 0.01$). Similarly, among older adults, annual incidence increased significantly and at similar rates in both males (AAPC = 8.2, 95% CI = 4.1–12.4; $P = 0.0004$) and females (AAPC = 7.4, 95% CI = 3.9–11.0; $P = 0.0003$). Finally, among elderly individuals, annual injury rates also increased significantly and at similar rates in both males (AAPC = 7.5, 95% CI = 4.4–10.8; $P = 0.0001$) and females (AAPC = 12.0, 95% CI = 5.9–18.5; $P = 0.0001$).

DISCUSSION

Fractures of the axis are one of the most common cervical vertebral injuries and a significant cause of yearly morbidity, mortality, and associated economic burden.[10,11,12,14] To our knowledge, there is no recent literature on the epidemiology

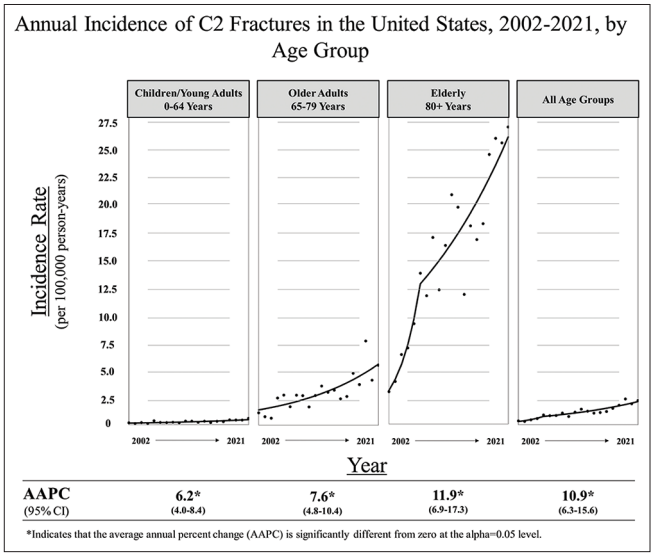

Figure 4: Annual incidence of C2 fractures in the US, 2002–2021, by age

Table 1: Estimates, incidence rates, and incidence rate ratios of all C2 fractures, 2002–2021, by age group

	n	*N*	Person-years at risk	IR (95% CI)	IRR[a] (95% CI)
Elderly	986	36,529	229,046,794	15.9 (11.7–20.3)	55.4* (18.7–164.0)
Older adults	606	20,835	650,035,400	3.21 (23.1–41.0)	11.1* (5.4–23.1)
Children/younger adults	477	15,400	5,351,742,006	0.29 (0.20–0.37)	Reference

*A statistically significant difference in IR when compared with children/younger adults; [a]Ratio of children/younger adults, older adults, and elderly populations with "children/younger adults" as the referent. *n* - Unweighted cases; *N* - Weighted national estimate; IRR - Incidence rate ratio; CI - Confidence interval; IR - Incidence rate (expressed per million person-years at risk)

Table 2: Estimates, incidence rates, and incidence rate ratios of all C2 fractures, 2002–2021, by sex and age group

	n	*N*	Person-years at risk	IR (95% CI)	IRR[a] (95% CI)
Female					
All	1202	42,671	3,164,991,156	1.35 (0.98–1.71)	1.4 (0.9–2.0)
Children/younger	192	5947	2,668,607,948	0.22 (0.15–0.30)	0.6* (0.4–0.98)
Older adults	333	11,613	352,171,696	3.30 (2.30–4.29)	1.1 (0.7–1.6)
Elderly	677	25,111	144,211,512	17.4 (12.4–22.4)	1.3 (0.9–1.9)
Male					
All	867	30,093	3,065,833,044	0.98 (0.73–1.23)	Reference
Children/younger	285	9453	2,683,134,058	0.35 (0.25–0.45)	Reference
Older adults	273	9222	297,863,704	3.10 (2.17–4.03)	Reference
Elderly	309	11,418	84,835,282	13.5 (9.76–17.2)	Reference

*A statistically significant difference in IR when compared with male sex; [a]Ratio of total, children/younger adults, older adults, and elderly populations by sex with male sex as the referent. *n* - Unweighted cases; *N* - Weighted national estimate; IRR - Incidence rate ratio; CI - Confidence interval; IR - Incidence rate (expressed per million person-years at risk)

of C2 fractures from 2014 to present, that is generalizable to the US population.[5,6,9,10,12-14] The purpose of this study was to report the incidence rate of C2 fractures presenting to emergency departments in the United States from 2002 to 2021. Secondarily, this study aimed to analyze the associated demographics and changes in the incidence rate of C2 fractures over time.

Cumulative incidence

In this study, the overall IR of C2 fractures in the US from 2002 to 2021 was 1.17 PYR. Comparable to our study, Robinson *et al*. report an overall incidence of 3–6 between 1997 and 2014 using the Swedish National Patient Registry.[9] Daniels *et al*. reported a C2 fracture incidence of 4.7 PYR between 2000 and 2010, using the Nationwide Inpatient Sample.[13] Otherwise, previous literature largely focuses on Medicare beneficiaries that are 65 years and older.[5,12] Age-stratified estimates of older individuals are higher than the overall IR estimates, and heterogeneity between studies with respect to specific age groups reported makes it difficult to compare overall incidences between studies.

Temporal trends

There was a statistically significant increase in the incidence of C2 fractures in the US between 2002 and 2021 (0.36 PYR in 2002–2.20 PYR in 2021; AAPC = 10.9) and the largest increase in incidence was seen between 2002 and 2006 (APC = 26.3), even after accounting for total population growth. The incidence of C2 fractures was significantly higher over time, across all age groups and regardless of sex. However, patients aged 80 and older demonstrated the highest APC of all groups [Figure 4]. Robinson *et al*. reported an increase in overall incidence of 3–6 PYR between 1997 and 2014, using the Swedish National Patient Registry.[9] Pearson *et al*. reported an increase in incidence of C2 fractures in Medicare beneficiaries from 9 to 21.4 PYR between 2000 and 2011.[12] Lomoschitz *et al*. report an increasing incidence similar to our study and further validate the sharp rate of increase between 2002 and 2008, especially in older individuals.[5] Confirming our hypothesis, the incidence of C2 fractures in the US continues to increase, although at a slower rate than in the 2000s. This is likely of multifactorial etiology, related to the increasing relative proportion of the elderly within the population that are inherently at an increased risk of vertebral fractures due to higher rates of osteoporosis.[28-30]

Age

Age, by its association with declining health and osteoporosis, is a known risk factor for all fragility fractures.[29,30] In this study, the mean age of patients with C2 fractures was 74.8 years, similar to prior database studies.[9,13] In contrast, Passias *et al*. reported a mean age of 59 years in 2013, likely due to inclusion of all cervical fractures and motor vehicle accidents.[10] As stated previously, it is difficult to make exact comparisons of incidence between our study and previous literature due to heterogeneity between referenced age groups. Pearson *et al*. reported that the mean annual rate of admission for C2 fractures in patients older than 85 years of age (41.9 PYR) was eight times greater than those who were 65–69 years old (4.8 PYR).[12] In our study, patients 80 years of age and older were found to have a C2 fracture incidence of 15.9 PYR between 2002 and 2021, while patients 65–79 had an IR of 3.21 PYR. As mentioned prior, the IR of C2 fractures has increased at a slower rate since 2008 (APC 7.1%), possibly explaining the lower overall IR compared to the study by Pearson *et al*. which is limited to 2011. Robinson *et al*. demonstrated a significantly higher incidence of C2 fractures (10.2–23.7 PYR between 1997 and 2014) in geriatric patients (70 years and older) compared to nongeriatric patients (<70). Lomoschitz *et al*. also show an increased incidence of fractures in patients that are 85 years and older.[5,9] Age is known to lead to osteoporosis and difficulties with gait and coordination, which contribute to increased predisposition to fractures of the axis with low energy falls.[29,30]

Sex

Declining levels of estrogen in postmenopausal women have been shown to lead to changes in the activity of osteoclasts and osteoblasts that lead to bone resorption and subsequent osteoporosis.[31] Consequently, postmenopausal patients with osteoporosis have higher rates of morbidity and mortality secondary to fragility fractures.[30-32] In our study, females accounted for 58.6% of all cases; IRR of all females compared to males was 1.4 (0.9–2.0). Females below the age of 65 had a significantly lower IRR compared to similar-aged males. However, there were no statistically significant differences in the incidence of C2 fractures between males and females in individuals older than 64 and both groups demonstrated an increased incidence with increasing age. Robinson *et al*. reported no differences in the incidence of C2 fractures between males and females in individuals older than 80 years. Regardless of sex, management of osteoporosis-related C2 fractures should include endocrine work-up. Similar to our study, males below the age of 80 had a significantly higher incidence of C2 fractures compared to females younger than 80 years old.[9] C2 fractures in younger patients are more likely to occur from an MVC rather than low-energy falls.[6] Younger men are disproportionately affected by MVC-related injuries compared to younger females, which could explain the differences seen in such a broad age cohort in the study by Robinson *et al*.[33] As the NEISS database does not reliably capture all MVCs, this explanation does not fully extend to our study. Although the aging population and rising rates of

osteoporosis likely play a role, it is important to emphasize that the trends seen in our study are likely multifactorial and beyond the scope of this epidemiological study.

The strength of our study is that it is based on the NEISS database, which is a nationwide sample of consumer product-related injuries generalizable to the US population. To our knowledge, it is also the only study that provides a large-scale epidemiological analysis of C2 fractures after 2014. It is imperative to reassess epidemiological data as population-level health is constantly changing. In contrast to much of previous literature, our study is also not limited to the elderly Medicare population.

This study also possesses several limitations primarily centered around the use of the NEISS database. First, the NEISS data only account for ED visits. While it would be unusual for a patient with a C2 fracture to present to an outpatient setting for primary evaluation, the potential for selection bias cannot be ignored. Additionally, the descriptive narratives in the database lack standardization, which does not permit the detailed characterization of C2 fracture morphology. Furthermore, MVCs are not consistently included in the NEISS database, reducing the perceived IR of fractures in the younger population. Finally, this study provides only an epidemiological update of C2 fractures in the US and does not intend to describe management, morbidity, or mortality.

CONCLUSION

C2 fractures are associated with high morbidity and mortality, especially in elderly populations. This study showed that the incidence of C2 fractures has increased from 0.36 PYR in 2002 to 2.2 PYR in 2021 (cumulative incidence of 1.17 PYR), with the highest rate of increase between 2002 and 2006. Older adults (65–79) and elderly individuals (80+) have a significantly higher incidence of C2 fractures, while no major differences are seen when comparing males and females.

Author contribution

Author A was involved in study design, data collection, manuscript preparation, editing, and formatting. Author B was involved in study design, data collection, manuscript preparation, and editing. Author C was involved in data collection and analysis, manuscript preparation, and formatting. Author D was involved in data collection, manuscript preparation, and review. Author E was involved in study design, data analysis, and manuscript preparation and review.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Tang A, Pawar J, Bridge C, King R, Kakarmath S, Harris M, *et al.* Traumatic cervical spine fracture patterns on CT: A retrospective analysis at a level 1 trauma center. Emerg Radiol 2021;28:965-76.
2. Fredø HL, Rizvi SA, Lied B, Rønning P, Helseth E. The epidemiology of traumatic cervical spine fractures: A prospective population study from Norway. Scand J Trauma Resusc Emerg Med 2012;20:85.
3. Khanpara S, Ruiz-Pardo D, Spence SC, West OC, Riascos R. Incidence of cervical spine fractures on CT: A study in a large level I trauma center. Emerg Radiol 2020;27:1-8.
4. Barrey CY, di Bartolomeo A, Barresi L, Bronsard N, Allia J, Blondel B, *et al.* C1-C2 Injury: Factors influencing mortality, outcome, and fracture healing. Eur Spine J 2021;30:1574-84.
5. Lomoschitz FM, Blackmore CC, Mirza SK, Mann FA. Cervical spine injuries in patients 65 years old and older: Epidemiologic analysis regarding the effects of age and injury mechanism on distribution, type, and stability of injuries. AJR Am J Roentgenol 2002;178:573-7.
6. Bakhsh A, Alzahrani A, Aljuzair AH, Ahmed U, Eldawoody H. Fractures of C2 (Axis) vertebra: Clinical presentation and management. Int J Spine Surg 2020;14:908-15.
7. Zusman NL, Ching AC, Hart RA, Yoo JU. Incidence of second cervical vertebral fractures far surpassed the rate predicted by the changing age distribution and growth among elderly persons in the United States (2005-2008). Spine (Phila Pa 1976) 2013;38:752-6.
8. Tadros A, Sharon M, Craig K, Krantz W. Characteristics and management of emergency department patients presenting with C2 cervical spine fractures. Biomed Res Int 2019;2019:4301051.
9. 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.
10. Passias PG, Poorman GW, Segreto FA, Jalai CM, Horn SR, Bortz CA, *et al.* Traumatic fractures of the cervical spine: Analysis of changes in incidence, cause, concurrent injuries, and complications among 488,262 patients from 2005 to 2013. World Neurosurg 2018;110:e427-37.
11. Pearson AM, Martin BI, Lindsey M, Mirza SK. C2 vertebral fractures in the medicare population: Incidence, outcomes, and costs. J Bone Joint Surg Am 2016;98:449-56.
12. Daniels AH, Arthur M, Esmende SM, Vigneswaran H, Palumbo MA. Incidence and cost of treating axis fractures in the United States from 2000 to 2010. Spine (Phila Pa 1976) 2014;39:1498-505.
13. Dhall SS, Yue JK, Winkler EA, Mummaneni PV, Manley GT, Tarapore PE. Morbidity and mortality associated with surgery of traumatic C2 fractures in octogenarians. Neurosurgery 2017;80:854-62.
14. Wang H, Xiang Q, Li C, Zhou Y. Epidemiology of traumatic cervical spinal fractures and risk factors for traumatic cervical spinal cord injury in China. J Spinal Disord Tech 2013;26:E306-13.
15. Wang H, Liu X, Zhao Y, Ou L, Zhou Y, Li C, *et al.* Incidence and pattern of traumatic spinal fractures and associated spinal cord injury resulting from motor vehicle collisions in China over 11 years: An observational study. Medicine (Baltimore) 2016;95:e5220.
16. Lyons JG, Mian HM, Via GG, Brueggeman DA, Krishnamurthy AB. Trends and epidemiology of knee extensor mechanism injuries presenting to United States emergency departments from 2001 to 2020. Phys Sportsmed 2023;51:183-92.
17. Cheng R, Kahan JB, Li D, Schneble CA, Gardner EC. Sex- and sports-specific epidemiology of traumatic lumbar spine injuries sustained during sporting activities: Male snowboarders and female horseback riders at greatest risk. Arthrosc Sports Med Rehabil 2021;3:e515-20.

18. Lyons JG, Mian HM. Epidemiology of atlas fractures in the United States: A 20-year analysis. J Craniovertebr Junction Spine 2022;13:85-93.
19. Wakim J, Rajan T, Beschloss A, Albayar A, Ozturk A, Saifi C. Etiologies, incidence, and demographics of lumbar vertebral fractures in U.S. Emergency departments. J Spine Surg 2022;8:21-8.
20. Lyons JG. Epidemiology of ballistic fractures in the United States: A 20-year analysis of the Firearm Injury Surveillance Study. Injury 2022;53:3663-72.
21. Lyons JG, Hudson TL, Krishnamurthy AB. Epidemiology of patellar dislocations in the United States from 2001 to 2020: Results of a national emergency department database. Phys Sportsmed 2022. p. 1-10.
22. NEISS Coding Manual. U.S. Consumer Product Safety Commission Division of Hazard and Injury Data Systems; 2007. Available from: http://www.cpsc.gov/library/neiss.html. [Last accessed on 2007 Jan 20].
23. U.S. Consumer Product Safety Commission Division of Hazard and Injury Data Systems. The National Electronic Injury Surveillance System: A Tool for Researchers; 2000. Available from: http://www.cpsc.gov/LIBRARY/neiss.html. [Last accessed on 2007 Jan 20].
24. U.S. Census Bureau. Population and Housing Unit Estimates. Available from: https://www.census.gov/data/datasets/time-series/demo/popest/2020s-national-detail.html. [Last accessed 2023 Feb 06].
25. Rao JN, Scott AJ. On Chi-squared tests for multiway contingency tables with cell proportions estimated from survey data. Ann Stat 1984;12:46-60.
26. Rao JN, Thomas DR. The analysis of cross-classified categorical data from complex sample surveys. Sociol Methodol 1988;18:213.
27. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. Stat Med 2000;19:335-51.
28. Duffin E. Median Age of the Resident Population of the United States from 1960 to 2021. Statista; 2022. Available from: https://www.statista.com/statistics/241494/median-age-of-the-us-population/. [Last accessed on 2023 Apr 2].
29. Srivastava M, Deal C. Osteoporosis in elderly: Prevention and treatment. Clin Geriatr Med 2002;18:529-55.
30. Coughlan T, Dockery F. Osteoporosis and fracture risk in older people. Clin Med (Lond) 2014;14:187-91.
31. Khosla S, Oursler MJ, Monroe DG. Estrogen and the skeleton. Trends Endocrinol Metab 2012;23:576-81.
32. Mirza FS, Prestwood KM. Bone health and aging: Implications for menopause. Endocrinol Metab Clin North Am 2004;33:741-59.
33. Cullen P, Möller H, Woodward M, Senserrick T, Boufous S, Rogers K, *et al.* Are there sex differences in crash and crash-related injury between men and women? A 13-year cohort study of young drivers in Australia. SSM Popul Health 2021;14:100816.