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Estimating the number of traffic crash-related cervical spine injuries in the United States; An analysis and comparison of national crash and hospital data

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ABSTRACT

Background: Cervical spine injury is a common result of traffic crashes, and such injuries range in severity from minor (*i.e.* sprain/strain) to moderate (intervertebral disk derangement) to serious and greater (fractures, dislocations, and spinal cord injuries). There are currently no reliable estimates of the number of crash-related spine injuries occurring in the US annually, although several publications have used national crash injury samples as a basis for estimating the frequency of both cervical and lumbar spinal disk injuries occurring in lower speed rear impact crashes.
Purpose: To develop a reliable estimate of the number of various types of cervical spine injuries occurring in the US by comparing data from national crash injury to national hospital ED and inpatient samples.
Study Design: Comparative cross-sectional
Methods: Cervical spine injury data were accessed, analyzed, and compared from 3 national databases; the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS), Nationwide Emergency Department Sample (NEDS), and the Nationwide Inpatient Sample (NIS).
Results: It is estimated that there are approximately 869,000 traffic crash-related cervical spine injuries seen in hospitals in the US annually, including around 841,000 sprain/strain (whiplash) injuries, 2800 spinal disk injuries, 23,500 fractures, 2800 spinal cord injuries, and 1500 dislocations. Because of a highly restrictive inclusion criteria for both crash and injury types, as well as a very small sample size, the NASS-CDS underestimated all types of crash-related cervical spine injuries seen in US hospital emergency departments by 84 %. The injury type with the largest degree of underestimation in the NASS-CDS was cervical disk injuries, which were estimated at an 88 % lower frequency than in the NEDS. National insurance claim data, which include cases of cervical disk injury diagnosed both in and outside of the ED, indicate that the NEDS likely undercounts cervical disk injuries by 92 %, and thus the NASS-CDS correspondingly undercounts such injuries by 99 % or more.
Conclusions: Because of a limited sample size and restrictive criteria for both crash and injury inclusion, the NASS-CDS cannot be used to estimate the number of crash-related spinal injuries of any type or severity in the US. The most inappropriate use of the database is for estimating the number of spinal injuries resulting from low speed rear impact collisions, as the NASS-CDS samples fewer than 1 in 100,000 of the cervical spine injuries of any type occurring in low speed rear impact collisions.

1. Introduction

Neck pain is a highly prevalent condition, occurring in approximately 10–21% of the population annually, and often resulting from a traumatic injury event (Hogg-Johnson et al., 2008; Hoy et al., 2010). The most common cervical spine injury mechanism resulting in both acute and chronic neck pain is road traffic crashes (Freeman et al., 2006; Nolet et al., 2019; Quinlan et al., 2004). The frequency of the various types of crash-related cervical spine injuries is inversely proportional to their severity; the most common and least serious are musculoligamentous strains, often referred to colloquially as "whiplash" injuries (Barnsley et al., 1994). Less common are injuries to the spinal disks and vertebral fractures, and the least common injuries are to the spinal cord (DeVivo, 2012; Kreipke et al., 1989; Rizzolo et al., 1991). The frequency at which the various types of cervical spine injuries result from traffic crashes in the United States is not well

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described in the literature, although there are several national data collection systems by which such injuries are surveilled.

The National Highway Traffic Safety Administration (NHTSA) gathers information on traffic crashes and associated injuries in the United States *via* a number of data collection and investigation systems. The largest of these systems is the National Automotive Sampling System, which has 2 data collection arms; the Crashworthiness Data Sample (NASS-CDS) and the General Estimates System (NASS-GES) (Compton, 2002). The NASS-GES samples approximately 50,000 police accident reports from 400 police jurisdictions annually, and uses a numerical multiplier (weight) to estimate the total number of crashes in the country based on the sample (NASS General Estimates System, 2020). The injury information in the NASS-GES is confined to the "KABCOU" ranked system, with K = Killed, A = serious injury, B = nonserious injury, C = possible injury, O = no apparent injury, and U = injury status unknown (Becker et al., 2003). Along with providing no anatomical injury detail, the KABCOU system is a poor discriminator of injury severity, and thus the NASS-GES has no utility for the surveillance of crash-related spine injuries (Farmer, 2003).

The NASS-CDS consists of a much smaller stratified survey sample than the NASS-GES; approximately 5000 police-reported tow-away crashes are selected each year for extensive investigation of the crash and the associated occupant injuries. The NASS-CDS provides a great deal of specificity regarding injury location, type, involved structures, and severity *via* use of the Abbreviated Injury Scale (AIS) (Crashworthiness Data System, 2020; Martin and Eppinger, 2003). The AIS uses a 7 digit number to describe each crash-related injury in detail, and ranks severity in the final digit as follows: 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, and 6 = maximum, based on the mortality risk associated with the injury (Dobbertin et al., 2013). The highest AIS severity injury for an occupant is denoted by the MAIS (maximum AIS) value. Like the NASS-GES, crashes in the NASS-CDS sample are also weighted to provide a national estimate of the number of crashes and related injuries in the US annually, and these data are commonly cited as a basis for such estimates (Compton, 2002).

There are several reasons to use caution when interpreting national estimates of crash-related injury frequency based on NASS-CDS data; one reason is that the 71 % of police-reported crashes that do not result in the disablement of a vehicle are excluded, and thus injuries that occur in such crashes are not captured in the database (Compton, 2002; Digges, 2002). Another important reason is that a large percentage of occupants who are deemed "uninjured" (*i.e.* MAIS = 0) in the NASS-CDS are actually injured, and simply miscategorized (Garthe and Mango, 2011). It has been estimated that approximately 39 % of occupants deemed "uninjured" in the NASS-CDS are in actuality injured, and even, in some cases, deceased (Garthe and Mango, 2011).

Perhaps the greatest limitation NASS-CDS injury data, with regard to surveillance for spinal injuries, is the types of injuries that are eligible for inclusion in the database. The AIS is designed as a "threat to life" scale, meaning that it includes only those injuries that are immediately apparent after a crash (and ranked by their associated mortality risk), and not their sequelae. As an example, an occupant may sustain a major laceration of the scalp (an AIS 2 or moderate severity injury) which produces sufficient hypovolemia to result in a fatal cardiac arrhythmia. The injury would remain AIS 2 in the NASS-CDS regardless of the fatal outcome, as there is no system in place to upgrade injury severity rank for outcome, or to follow-up the subacute or chronic sequelae of injuries beyond the first few days after the crash. Further, there are no means of identifying occupants who are exceedingly fragile at the time of a crash; for example, an occupant with an unstable lumbar spondylolisthesis defect is at increased risk of sustaining an injury leading to the need for surgical stabilization in a crash, but there is no way identify or track such a patient in the NASS-CDS. Most likely such a patient who complains of acute low back pain after a crash would be initially diagnosed with an AIS 1 "sprain/strain" injury at the hospital emergency department, which is how the NASS-CDS would code the injury, and subsequent diagnostic investigations or treatments would not be used to alter the original code. Similarly, spinal injuries that are ultimately attributed to a symptomatic intervertebral disk derangement would not typically be identified as such in NASS-CDS data, as such injuries are nearly always confirmed after MRI examination, which most often does not occur until days, weeks or even months after the original injury.

Because of the limitations in how crashes and associated injuries are included in the NASS-CDS, the database is biased toward immediately apparent and more serious (*i.e.* higher AIS) injuries requiring hospitalization and resulting from higher energy crashes, and away from lesser severity injuries from lower energy crashes which do not require transportation to the hospital or result in vehicle disablement. Specific to the range of traumatic injuries occurring to the cervical spine in traffic crashes, it is reasonable to suppose that the NASS-CDS most comprehensively surveils for spinal cord injuries, fractures, and dislocations, and provides the least coverage of "whiplash" injuries and their sequelae, including intervertebral disk derangements (Pettersson et al., 1997).

Despite these limitations, a number of authors have cited to NASS-CDS data as a measure of the risk of spine injuries in traffic crashes in the United States. Recently, Cormier and colleagues compared the cervical spine injury rate from low speed rear impact volunteer studies to the rate of injuries reported in the NASS-CDS, concluding that the risk of significant injury from low speed real world rear impact crashes was no greater than from experimental crash tests, and that rear impact collisions of less than 16 km/h (9.9 mph) speed change are thus essentially harmless events (Cormier et al., 2018). Other authors have described a similar comparison between low speed volunteer crash testing and injuries to the lumbar spine recorded in the NASS-CDS from rear impact collisions, concluding that the national data indicate that the injury risk to the low back in rear impact collisions is very low because the seat back prevents such injuries, and that epidemiologic (*i.e.* NASS-CDS) data indicates that such crashes do not have the capacity to cause lumbar disk injuries (Lam and Ivarsson, 2017; Yang et al., 2013).

At the present time there are no published studies that have attempted to validate the national estimates of spine injuries from the NASS-CDS *via* comparison with any other databases in the United States that track crash-related injuries. In the present study we investigated the accuracy of the NASS-CDS as a measure of the epidemiology of cervical spine injuries resulting from traffic crashes in the United States by comparing the characteristics and frequency of injuries estimated in the NASS-CDS to the frequency of crash-related spine injuries reported in US national hospital reporting systems.

2. Methods

Three different publicly available national databases were selected for the present study, based upon the advantages and limitations of each database to adequately estimate the frequency of various types of MVC-related cervical spine injuries in the US (*NB* the term "cervical spine" is used in the present investigation to refer to all musculoskeletal and neurological structures of the neck, excluding the organs and great vessels of the throat). A brief description of these databases, along with their key features and drawbacks for crash-related spine injury surveillance, is as follows:

1 2010–2014 NASS-CDS: National sample of police reported crashes and related injuries

The National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) is a database that comprises details of 5000 probability-selected MVCs from 24 geographically unique locations each year. As a weighted sample, the CDS is nationally representative of all police reported MVCs involving passenger cars, light trucks and vans needing to be towed. Each crash is thoroughly reviewed and

Table 1
Injury Definitions.

	NASS Cervical Spine Injury Definitions[a]				NIS, NEDS[b]
	Region	Structure Type	Specific Structure	Injury level	ICD-9
Complete SCI	6	4	2	20, 21, 22, 24, 26, 28, 29, 30, 32, 34, 36, 60, 61, 62, 64, 66, 68, 69, 70, 72, 74, 76	806.01, 806.06, 806.11, 806.16, 952.01, 952.06
Incomplete SCI	6	4	2	10, 12, 14, 16, 18, 40, 42, 44, 46, 48, 50	806.02, 806.03, 806.04, 806.07, 806.08, 806.09, 806.12, 806.13, 806.14, 806.17, 806.18, 806.19, 952.02, 952.03, 952.04, 952.07, 952.08, 952.09
SCI NSF	6	4	2	0, 1, 2, 4, 6, 8	806.00, 806.05, 806.10, 806.15, 952.00, 952.05
FX	6	5	2	16, 18, 20, 22, 24, 26, 28, 30, 32, 34	805.0x, 805.1x
Dislocation	6	5	2	4, 6, 8, 9, 10, 12	839.0x, 839.1x
Disk injury	6	5	2	0, 2, 3, 99	722.0, 722.71
Whiplash	6	4	2	78	847.0

Abbreviations: NASS = National Automotive Sampling System; NEDS = Nationwide Emergency Department Sample; NIS = Nationwide Inpatient Sample; SCI = spinal cord injury; NSF = not specified further; FX = fracture.

[a] The NASS-CDS defines injury location, type, and severity using a 7 digit identifier, which consists of the Region of the body where the injury occurred (6 indicates spine), the affected anatomical Structure Type (4 indicates organs/muscles/ ligaments, and 5 is skeletal), the Specific Structure (2 denotes cervical spine), and Injury Level is the range of specific injuries in the spine (spinal cord injury, fracture, strain, *etc.*).

[b] The years of the NIS and NEDS accessed for this research uses International Classification of Disease Ninth Revision (ICD-9) diagnostic codes. The listed ICD-9 codes correspond to the NASS codes listed for the same injury category.

documented by trained crash investigators who obtain data directly from the crash scene and vehicles involved, and *via* interviews with and medical reviews of the occupants involved. The data collected for each crash is vast and includes details of the nature of the crash, the vehicles involved, safety features of the vehicles, and occupant injury details. More information regarding the NASS-CDS can be found at https://www.nhtsa.gov/national-automotive-sampling-system-nass/crashworthiness-data-system.

Advantages: Provides detailed information regarding crash circumstances and characteristics

Limitations: Very small sample (5–6,000 out of 13 million crashes annually, or ~1 in 2200); does not include crashes without towaway of at least one vehicle, or that were not reported to police; occupant injury data is not collected for non-towed vehicles, nor for towed vehicles more than 10 years old; only includes injuries apparent within the first 2–6 days (no sequelae of acute injury).

2 2010–2014 NEDS: National sample of emergency department visits

The Nationwide Emergency Department Sample (NEDS) is made available through Healthcare Cost and Utilization Project (HCUP) of the Agency for Healthcare Research and Quality (AHRQ). The NEDS is a nationally representative stratified sample of hospital emergency department (ED) records from the United States. Produced annually, it comprises approximately 30 million discharge records from 953 hospitals in 36 states, and represents 20 % of all ED discharges. The NEDS provides information on patient demographics, up to 15 diagnoses, up to 15 procedures, up to 4 E-codes, admission and discharge status, payer characteristics (*e.g.* Medicare, Medicaid, private insurance, private pay), and total ED charges. More information regarding the NEDS is available at https://www.hcup-us.ahrq.gov/db/nation/neds/nedsdbdocumentation.jsp.

Advantages: Large (20 %) sample of all ED visits in the US; not limited to police-reported or towaway crashes.

Limitations: Relies solely on use of external cause ICD-9 codes (E-codes) to indicate crash involvement; no indication of the nature or severity of the crash; in most cases only includes immediately apparent injuries.

3 2010–2014 NIS: National sample of inpatient hospitalizations

The Nationwide Inpatient Sample (NIS) is made available through HCUP (*via* AHRQ). The NIS is a nationally representative stratified sample of hospital inpatient records from the United States. Produced annually, it is comprised of approximately 8 million discharge records, representing 20 % of all hospital stays. As a weighted sample, it estimates roughly 40 million records every year. The NIS provides information on patient demographics, up to 30 diagnoses, up to 15 procedures, up to 4 E-codes, admission and discharge status, payer characteristics (*e.g.* Medicare, Medicaid, private insurance, private pay), length of stay, and total hospital charges. More information regarding the NIS is available at https://www.hcup-us.ahrq.gov/db/nation/nis/nisdbdocumentation.jsp.

Advantages: Large (20 %) sample of all community hospital inpatient stays in the US; not limited to police-reported or towaway crashes; identifies latent spinal disk injuries associated with inpatient procedures performed in the hospital.

Limitations: Relies only on the use of external cause ICD-9 codes (E-codes) to indicate crash involvement; no indication of the nature or severity of the crash; in most cases only includes the most serious immediately apparent injuries requiring inpatient stay.

All occupant injury records in the 2010–2014 NASS-CDS (5 years, inclusive) were utilized for the analysis. The 2010–2014 NEDS and NIS databases were queried for all records with an E-code indicating the patient was a driver or passenger involved in an MVC (E8100, E8101, E8110, E8111, E8120, E8121, E8130, E8131, E8140, E8141, E8150, E8151, E8160, E8161, E8190, E8191).

Next, all injured occupant and patient records were reviewed for the following cervical spine injuries: complete spinal cord injury (SCI), incomplete SCI, SCI “not further specified” (SCI NFS), fracture (FX), dislocation, disk injury NFS, strain or sprain (collectively termed “whiplash”). Finally, records were summarized over individual occupants and patients, such that each subject contributed exactly one record representing all possible cervical spine injuries, with dichotomous (0/1) variables indicating the absence or presence of each injury. Definitions and codes used for the injuries of interest specific to each database are detailed in Table 1.

All analyses were conducted using SAS software, version 9.4. The NASS-CDS, NEDS, and NIS databases were analyzed using the SURVEY procedures, in order to account for their complex sampling structures. For each national database we calculated the total average annual number of MVC-injured people, the number of those people who were diagnosed with cervical spine injuries, and individual cervical spine injury counts, along with 95 % confidence intervals. We present the total number of injured subjects, the total number of people with cervical spine injuries, and the total number of subjects with specific

Table 2
2010-2014 Annual Average National Injury Counts [95 % CI].

	NASS CDS	NEDS	NIS
Total Injury Records	585,123 [473,673, 696,573]	2,721,457 [2,585,227, 2,857,688]	178,249 [168,122, 188,375]
Total with Cervical Injury	140,232 [110,707, 169,756]	869,086 [819,712, 918,460]	23,941 [22,401, 25,480]
Total SCI	1029 [484, 1574]	2773 [2,418, 3129]	2562 [2,356, 2767]
Complete SCI	243 [28, 458]	296 [236, 357]	330 [285, 376]
Incomplete SCI	219 [91, 347]	997 [827, 1166]	1058 [959, 1156]
SCI NSF	568 [29, 1106]	1550 [1378, 1722]	1252 [1138, 1366]
FX	6135 [3,434, 8835]	23,502 [21,105, 25,899]	16,164 [15,028, 17,303]
Dislocation	544 [259, 828]	1545 [1,392, 1698]	1173 [1,070, 1277]
Disc Injury	332 [0, 672]	2791 [2536, 3047]	732 [662, 802]
Whiplash	132,864 [102,984, 162,745]	841,300 [792,761, 889,839]	4669 [4,297, 5042]

Abbreviations: NASS-CDS = National Automotive Sampling System-Crashworthiness Data System; NEDS = Nationwide Emergency Department Sample; NIS = Nationwide Inpatient Sample.

cervical injury types. We also calculated the proportion of each individual injury relative to the total number of injured persons captured in each database. As a final step, we assessed the accuracy of the NASS-CDS data to estimate national cervical spine injuries by calculating the relative frequency of the injuries observed in the NASS-CDS to those found in the NEDS and NIS.

3. Results

3.1. NASS-CDS

For all 5 years (2010–2014) there were a total of 11,527 (unweighted) occupant records in the NASS-CDS (~2305/year). The records represented a weighted total of 2,925,615 occupants and 701,158 individuals with cervical spine injuries among the occupants (~140,232/year). The cervical spine injuries were comprised of 6135 cervical spine FXs, 332 disk injuries, and 132,864 whiplash injuries per year (Table 2). The proportion of all occupants with an SCI, FX, dislocation, disk injury, or whiplash was 0.18 %, 1.05 %, 0.09 %, 0.06 %, and 22.71 % respectively.

3.2. NEDS

Query of the 2010–2014 NEDS databases resulted in an unweighted total of 3,039,590 records (~607,918/year) with an E-code indicating the patient was either a driver or passenger involved in an MVC. There was a weighted total of 13,607,287 MVC-injured patients who were admitted to the ED, with 4,345,431 cervical spine injuries (31.9 % of the total). There was an average annual total of 23,502 cervical spine FXs, 2791 disk injuries, and 841,300 patients diagnosed with a whiplash injury (Table 2). The proportion of total MVC patients with cervical SCI, FX, dislocation, disk injury, or whiplash was 0.10 %, 0.86 %, 0.06 %, 0.10 %, and 30.91 % respectively. Among the disk injury patients, 94.6 % had no additional diagnosis of bony traumatic injury, including fracture or dislocation. The ratio of NEDS to NASS-CDS estimates for the number of injured occupants and each injury type is given in Table 3.

3.3. NIS

In the 2010–2014 NIS, there were 181,968 (~36,394/year) unweighted hospital inpatient discharge records for drivers or passengers injured in an MVC, representing 891,244 drivers or passengers nationally, of which 119,704 suffered cervical spine injuries (13.4 %). Annually, there were 16,164 FXs, 732 disk injuries, and 4669 cases of whiplash injury (Table 2). The proportion of SCI, FX, dislocation, disk injury, or whiplash injury among the total number of patients admitted with an MVC e-code was 1.44 %, 9.07 %, 0.66 %, 0.41 %, 2.62 % respectively. The ratio of NEDS to NASS-CDS estimates for the number of injured occupants and each injury type is given in Table 3.

Table 3
Relative annual injury counts: Ratio of NEDS and NIS *versus* NASS-CDS weighted counts.

	NEDS	NIS
Total Injury Records	4.65	0.30
Total with Cervical Injury	6.20	0.17
Total SCI	2.70	2.49
Complete SCI	1.22	1.36
Incomplete SCI	4.56	4.84
SCI NSF	2.73	2.21
FX	3.83	2.63
Dislocation	2.84	2.16
Disc Injury NSF	8.42	2.21
Whiplash	6.33	0.04

NASS-CDS = National Automotive Sampling System-Crashworthiness Data System; NEDS = Nationwide Emergency Department Sample; NIS = Nationwide Inpatient Sample.

4. Discussion

The results of the comparison between the number of NASS-CDS reported cervical spine injuries and national ED and inpatient hospital data are consistent with the *a priori* expectation that injuries most likely to result from police-reported towaway crashes and to be diagnosed at the ED shortly after the crash are least prone to selection bias and undercounting in this database. Despite this fact, the most serious (*i.e.* AIS 3+) cervical spine injuries are substantially underestimated in the NASS-CDS; the total number of cervical spinal cord injuries estimated for the 5 years in the present analysis only captured 37 % of the total number of diagnosed SCIs in the NEDS. Cervical spine dislocations and fractures were underestimated to an even greater degree in the NASS-CDS; only 35 % and 26 % of NEDS-reported dislocations and fractures, respectively, were estimated in the NASS-CDS.

The acute but less serious cervical spine injuries that are more commonly associated with lower speed/lower damage (*i.e.* non-towaway) crashes, and which often result in evaluation and treatment in an outpatient setting outside of the ED are undercounted at a much greater rate than the most serious injuries. The NASS-CDS estimate of cervical sprain/strain injuries was only 16 % of the number of injuries estimated in the NEDS. [*NB* Cervical sprain/strain injuries are called "whiplash" in the NASS injury coding dictionary, and thus this term is used in the present discussion, despite the fact that the term most appropriately refers to an injury *mechanism* rather than a specific injury]. The cervical injury type that was least likely to be included in the NASS-CDS was to the intervertebral disk, accounting for only 12 % of the crash-attributed cervical disk injuries estimated in the NEDS.

An additional epidemiologic feature of the aforementioned 3 cervical spine injury groups (*i.e.* serious, whiplash, and disk) to consider in the present analysis is the degree of underreporting of the condition in the NEDS. It is reasonable to assume that serious injuries such as SCIs and spinal fracture are nearly all attended to in hospital emergency departments, and thus the NEDS is an accurate representation of the incidence of serious cervical spine injuries in the US crashes. Relatively rare exceptions are when the occupant has died at the scene and the injury is only diagnosed at autopsy (a circumstance that is included in the NASS-CDS but not the NEDS), or when an MVC E-code is not recorded for a crash-related serious cervical spine injury.

In contrast with serious cervical spine injuries, a substantial proportion of crash-related cervical sprain/strain injuries are first diagnosed outside of a hospital emergency department. A wide variety of outpatient healthcare providers, including primary care, chiropractors, specialty medical (*e.g.* physiatry, orthopedics, neurology) and others often serve as the first portal of entry into healthcare for the patient with symptoms of cervical sprain/strain after a traffic crash, and thus a large proportion of the patients who are diagnosed with a crash-related cervical sprain/strain are never seen in a hospital emergency department. Although there is, at present, no system for surveilling for such injuries in the US outside of the hospital databases, it is reasonable to estimate an annual incidence of "whiplash" that is at least 50–100% more than the ~841 K annual injury frequency estimated from the NEDS data in the present study, and thus the actual incidence of MVC-related cervical sprain/strain injury in the US likely exceeds 1.2 million cases per year, at a minimum.

The group of injuries least likely to be surveilled by the NEDS are cervical disk injuries. Although such injuries may be identified *via* CT scan at the hospital emergency department, cervical disk injuries are most commonly diagnosed in an outpatient setting and only confirmed after a cervical MRI has been performed. Three additional factors contribute to a relatively low frequency of NEDS-surveilled cervical disk injuries; the first is that many cervical disk injuries present with symptoms that are initially indistinguishable from uncomplicated cervical sprain/strain injury, and it is only symptoms of persisting neck and upper extremity radiculopathy that leads to the clinical suspicion and ultimately diagnosis of cervical disk injury. The second factor is that radiculopathic symptoms related to a cervical disk injury may only present after days or weeks of axial neck pain, as the condition can present with an evolving symptom profile over time as the degree of disk derangement progresses. Both of these factors tend to increase the chance that a cervical disk injury will initially be represented in the NEDS data as a cervical sprain/strain diagnosis. The final factor is the same source of undercounting described above for the NEDS cervical sprain/strain estimate, which is that many crash-related cervical disk injuries are only diagnosed in an outpatient setting, and thus not represented in the NEDS in any form. If the diagnosis is associated with an inpatient procedure such as a cervical fusion procedure it may be identified in the national inpatient hospital database, however, there is an increased likelihood of E-code nonuse if the surgery is temporally remote to the crash that caused the initial injury.

Epidemiologic study of the distribution of traffic-crash related injuries based on insurance claims demonstrates the inadequacy of both NASS-CDS and NEDS surveillance for crash-related spinal disk injuries. In a review of 21,236 insurance claims for bodily injury occurring over a 2-week period in 2007 among a 57 % sample of all national insurers, the Insurance Research Council (IRC) reported a 4% rate of spinal disk injury diagnosis against a 66 % background rate of cervical strain injuries, or around 1 cervical disk injury for every 17 cases of whiplash. (Insurance Research Council, 2008) In comparison the NEDS recorded an average annual rate of 2791 disk injuries *versus* 841,300 whiplash injuries, or around 1 cervical disk injury for every 301 cases of whiplash. If the IRC disk to whiplash ratio were to be applied to the national count of whiplash diagnosed at the ED, the number of cervical disk injuries occurring in MVCs (but not surveilled by NASS-CDS or national hospital data) is likely closer to 33 – 34 K cases per year. This is approximately 12 and 100 times the number of disk injury cases recorded in the NEDS and NASS-CDS, respectively. Such a degree of underreporting makes sense given the fact that only a small proportion (5%) of disk injuries include an acute bony injury that would require urgent medical evaluation, and disk injuries most often initially present with symptoms that are indistinguishable from a sprain/strain injury.

Part of the explanation for the large discrepancies between the NASS-CDS cervical injury counts and the number of injuries recorded in the NEDS may be the degree of statistical scatter associated with the small sample size utilized in the NASS-CDS database, relative to the national hospital databases. As noted above, the NIS and NEDS databases used for the present analysis consist of a robust 20 % sample of all inpatient and emergency department visits in the US. In comparison, the NASS-CDS sampled approximately 5,000–6,000 crashes per year during 2010 through 2014, out of an estimated 3 million injury producing crashes occurring each year; around 1 in 500–600 crashes. This sampling protocol results in a large amount of statistical scatter; as noted in Table 2, the 95 % confidence interval bounding the 331 annual cervical disk injuries estimated in the NASS-CDS ranged from 0 to 673. In comparison, the 95 % confidence interval bounding the annual 2791 MVC-related cervical disk injuries in the NEDS ranged from 2536 to 3,047.

Based on the sampling protocol of the NASS-CDS and consistent with the findings of the present study, injuries resulting from crashes that are unlikely to result in the disablement of a vehicle, such as a lower speed rear impact collision, will not be included in the database. Despite this fact, Cormier and colleagues concluded that the cervical spine injury rate from carefully controlled low speed rear impact volunteer studies (in which the tested vehicles sustain little to no damage) was the same as the rate of injuries from real world crashes as represented by NASS-CDS data.(Cormier et al., 2018) These authors concluded, based on the absence of cervical disk injuries reported in the NASS-CDS, that low speed rear impact collisions occurring in the real world do not produce such injuries. In this respect Cormier et al. emulated the methods of other authors who have cited to the lack of lumbar disk injuries in NASS-CDS as evidence that low speed rear impact crashes don't cause lumbar disk injuries (Lam and Ivarsson, 2017; Yang et al., 2013). The results of the present study, demonstrating that the NASS-CDS estimated less than 12 % of cervical disk injuries seen in the ED (and likely less than 1% of MVC-related disk injuries overall), in combination with the knowledge that, *by design*, the NASS-CDS would not include any of the injuries occurring in the non-towaway collisions that were the focus of the Cormier et al. paper, demonstrate how misguided and error-prone the efforts of these authors were. It would be difficult to find a database that was less likely to capture spinal disk injuries occurring in minimal damage crashes than the NASS-CDS, and the conclusions regarding the frequency, risk, or cause of such injuries in any part of the spine, based on the analysis of these data, are meaningless.

There were other problems with how Cormier et al. used the NASS-CDS data, as well. In addition to selecting a database that does not surveil for the included crashes and injury types specified by their study protocol, Cormier et al. failed to describe in any significant detail the exact method by which they developed their analytic sample, including, 1) no description of which years of the NASS-CDS that were used for the analysis; 2) no description of the amount of missing occupant data that was in their sample (a substantial problem in the NASS-CDS, as described below); and, 3) the effect of the small sample sizes on the accuracy of their results, particularly given their attempts to subcategorize rear impact crashes based on delta-V and sex of the occupant.

We attempted to re-create the Cormier et al. analysis, based on the authors' description of finding 2058 unweighted and 1,313,136 weighted front-seat, outboard occupants, who were over the age of 16, who were known to be treated, and involved in a single-event rear-impact crash in the NASS-CDS. We thus queried the 1996–2015 NASS-CDS for all occupants using the data description provided by Cormier et al. Although we could not exactly match the Cormier counts, our counts were comparable, with 2176 unweighted and 1,422,009 weighted eligible occupants.

In investigating the data further, we found that more than half (54.7 %, or 1,497,231 out of 2,735,381) of NASS-CDS sampled vehicles fitting the inclusion criteria had no occupant injury information at all, due to the NASS-CDS missing data guidelines, which state that occupant data is not gathered if the vehicle is not towed, a highly common outcome of minimal damage bumper to bumper collisions. In more recent years occupant injury information is also missing for vehicles that are more than 10 years old, even if they were towed. The fact that occupant injury data was missing for more than half of the included vehicles, as well as the reason the information was missing, should have been an obvious sign to Cormier and colleagues that their proposed analysis of cervical disk and whiplash injuries, most of which occur in non-towed vehicles, could not proceed.

The multiple levels of stratification used by these authors (*i.e.* injury and crash severity by sex) resulted in multiple subcategories with miniscule or null counts. The small sample size of the NASS-CDS (< 1 in 500 crashes), combined with the large proportion of missing injury data, *and* the lack of occupant injury follow up, had the effect of further rendering the NASS-CDS data utterly useless for purpose that Cormier et al. put it to. As an example, the authors described the rate of neck strain injuries occurring in crashes with a delta-v of less than 8 kph (5 mph), stratified by sex. We found a total of 26 sampled occupants among 20 years of NASS-CDS data, or an average of 1.3 occupants injured in a rear impact collision of < 5 mph *per year*. Given the aforementioned estimate of 1.2 million or more neck strain injuries occurring in traffic crashes annually, the fact that the majority of neck injuries result from rear impact collisions, and the fact that 1 in 5 (21 %) of neck injuries result from rear impact crashes that are defined as very "low speed" (< US$500 in vehicle damage) (Farmer et al., 1999), it is reasonable to assume that the < 5 mph rear impact NASS-CDS sample of around 1 crash per year used by Cormier et al. undercounted the actual number of injured occupants in a < 5 mph rear impact crash in the US by a likely factor of more than 100,000.

The authors compared the low rate of neck strain injury that they observed in their NASS-CDS subgroups (*i.e.* 12 % at < 5 mph, and 22 % at 5–10 mph delta V), and the rate of neck symptoms reported after healthy volunteer crash testing, concluding that, because the rates were similar between the 2 groups, the lack of serious injury observed in the volunteer crash tests was a reliable indication that similar injuries do not occur in real world crashes. The comparison between the injury frequency observed in volunteer crash testing and in real world collisions of similar severity is entirely improper for a number of reasons, which have been previously described in the biomedical and automotive engineering literature (Freeman et al., 1999; Human Tolerance to Impact Conditions as Related to Motor Vehicle Design, 2020). Perhaps most importantly, the type of injuries that result from low speed crash tests are entirely non-comparable to the injuries reported in the NASS-CDS. The crash testing literature documents volunteer complaints of short-lived symptoms of neck discomfort or headache after low speed experimental rear impacts, typically lasting no more than a few hours to a few days, and with no documented medical treatment or diagnosis (although one volunteer complained of symptoms for 70 days) (Moss et al., 2005). In contrast, 85 % (77,019 out of 91,092) of the occupants with "whiplash" in 20 years of low speed rear impact data from the NASS-CDS (*i.e.* 1–10 mph delta V) were diagnosed in the ED. While short term spinal soreness is a common part of the human experience, spinal injury that requires evaluation in a hospital emergency department is not, and a comparison between the two conditions is misleading.

The net result of using the NASS-CDS for the analysis of the US rate of cervical spine injury in the Cormier et al. study was extraordinarily high levels of uncertainty and no ascertainable degree of accuracy. The failure to acknowledge, much less address the threats to the internal validity of the study render their conclusions meaningless.

5. Conclusions

Based on the findings of the present study it is estimated that there are approximately 869,000 traffic crash-related cervical spine injuries seen in hospitals in the US annually, including an est. 841,000 sprain/strain (whiplash) injuries, 2800 spinal disk injuries, 23,500 fractures, 2800 spinal cord injuries, and 1500 dislocations. These estimates are likely closest to the total number of injuries among surviving occupants with spinal cord injuries and fractures, and least representative of the true number of cervical disk injuries. The NASS-CDS does not provide an accurate count of cervical spine injuries in the US, underestimating all such injuries by 84 %. The database provides the poorest coverage of cervical disk injuries, which it underestimates by at least 88 % and likely as much as 99 %.

Because of a limited sample size and restrictive criteria for both crash and injury inclusion, the NASS-CDS cannot be used to estimate the number of crash-related spinal injuries of any type or severity in the US. The most inappropriate use of the database is for estimating the number of spinal injuries resulting from low speed rear impact collisions, as the NASS-CDS samples fewer than 1 in 100,000 of the cervical spine injuries of any type occurring in low speed rear impact collisions. Prior publications that have inappropriately used these data to draw inferences regarding the frequency, risk, or cause of spinal injuries occurring in low speed rear impact collisions suffer from such fatally flawed methods that their conclusions are meaningless.

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CRediT authorship contribution statement

Michael D. Freeman: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Wendy M. Leith:** Methodology, Formal analysis, Data curation, Writing - original draft, Writing - review & editing.

Appendix A. Supplementary data

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