Original Research Article

Cervical spine fracture in geriatric blunt trauma: are the NEXUS criteria sensitive enough?

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ABSTRACT

Background: The NEXUS criteria lack an age consideration. This study characterizes NEXUS sensitivity for significant cervical fracture (CF) in non-geriatric (18-64 years) and geriatric (≥65 years) patients.
Methods: This was a single-institution, retrospective review of blunt trauma patients (admitted between January 1, 2011 and December 31, 2016). Significant CF was an acute injury requiring surgery/orthosis. Propensity matching was used.
Results: Overall, 353 patients had significant CF and notably 101 (28.6%) denied neck pain and tenderness at presentation. There were 162 geriatric patients with 17 patients who failed to meet any NEXUS criterion (sensitivity: 89.5%). The remaining 191 patients were non-geriatric, only six failed to meet any NEXUS criterion (sensitivity: 96.8%). NEXUS sensitivity was reduced among geriatric patients (89.5% vs. 96.8%, p=0.01), even after propensity matching (n=73/group; 86.3% vs. 97.3%, p=0.02).
Conclusions: Alarmingly, 28.6% of patients with significant CF denied pain and tenderness. NEXUS demonstrated reduced sensitivity in the geriatric cohort, even after propensity matching. Liberal imaging is recommended for geriatric patients.

Keywords: Geriatric blunt trauma, Cervical fracture, NEXUS criteria

INTRODUCTION

Since their landmark publication in 2000, the criteria validated by the National Emergency X-Radiography Utilization Study (NEXUS) have been widely adopted to identify blunt trauma patients at low risk for cervical spine injury.[1] The criteria exclusively utilize information present on the initial clinical examination, including neurological status, intoxication, physical examination of the cervical spine, and distracting injury. Notably, the criteria do not account for patient age in the recommendation for imaging. The NEXUS study was conducted in adults with only 8.6% of patients over the age of 65. To confirm the utility of the criteria in this minority, the NEXUS study group published a subset analysis of the geriatric patients (age ≥65 years) that reported 100% sensitivity for clinically significant injury.[2]

The development and validation of the NEXUS criteria, however, occurred in the era of plain film.[1-3] The paradigm shift to computed tomography (CT) as the standard imaging modality warrants reassessment of the NEXUS criteria secondary to the enhanced cervical spine injury detection provided by CT.[4-13] Recent external validations have raised concern regarding the use of the NEXUS criteria in geriatric trauma, though the existing literature offers little consensus with NEXUS sensitivity ranging from 65.9% to 94.8%.[14-16] One considerable confound in this literature, however, is the frequent

exclusion of non-geriatric patients.[15,16] Without the appropriate population of younger counterparts, it is difficult to ascertain whether the findings in the geriatric population are truly age-specific. The existing literature is also limited by an inconsistent consideration for whether missed injuries were clinically significant.[14,16] Additionally, some investigations restricted the scope to low- or high-energy mechanisms of injury.[14,15]

To enhance the current understanding of the relationship between the NEXUS criteria and patient age, the present study aimed to compare the NEXUS criteria's sensitivity in identifying individuals with significant cervical spine fracture (CF) between non-geriatric (age <65 years) and geriatric (age ≥65 years) patients sustaining injury from any blunt trauma mechanism. It was hypothesized that NEXUS sensitivity would be significantly reduced in the geriatric population.

METHODS

This was a retrospective study approved by the Institutional Review Board of Geisinger Health System who granted a waiver of informed consent due to the retrospective design. Data on blunt trauma patients who were admitted to a single Level I adult trauma center (Geisinger Medical Center, Danville, PA) between January 1, 2011 and December 31, 2016 were reviewed. Evaluable adults (age ≥18 years) were eligible for inclusion if there was CT evidence of acute CF according to the final report issued by the board-certified attending radiologist at the time of image acquisition. To ensure that documentation reflected the initial physical examination and to eliminate the potential analysis of patients arriving with known CF, any patient who was admitted via inter-hospital transfer was excluded.

The NEXUS criteria are routinely documented at presentation in accordance with the institutional standard for the evaluation of patients sustaining blunt trauma. Trauma team personnel (general surgery resident and board-certified trauma attending) performed the clinical examination, which was intended to be used for the NEXUS criteria. Trauma attendings provide training for residents in the use of the NEXUS criteria, though no specific certification process is used. For patients undergoing cervical imaging, CT scanning of the head and cervical spine is executed from the vertex to the second thoracic vertebrae utilizing spiral axial imaging of the spine with sagittal and coronal reconstructions from a 64-slice scanner (Aquilion, Toshiba American Medical Systems, Tustin, CA).

The studied population was composed of patients who were found to have clinically significant CF, which was assessed during the hospitalization by a board-certified attending surgeon from one of the institutional spine specialist teams (neurosurgery or orthopedic spine). Significant CF was defined as injury requiring surgery, halo immobilization, or cervicothoracic orthosis,

excluding bracing for comfort. Individuals with significant injury were further classified as non-geriatric (age <65 years) or geriatric (age ≥65 years) according to the generally-accepted definition of advanced age in the trauma literature.

Each NEXUS criterion must have been fully documented during the initial clinical examination at presentation. The criteria were evaluated according to the NEXUS study group definitions, as briefly outlined below.[17] Any patient with incomplete documentation was excluded.

NEXUS criterion: altered neurological function

Patients were considered to have altered neurological function if they met any of the following criteria: disorientation to person, place, time or events; delayed or inappropriate response to external stimuli; focal motor or sensory deficiency.

NEXUS criterion: intoxication

Intoxication was a clinical assessment because diagnostic decision making is done before the results of toxicology reports, if performed, are available. Patients arriving with a known, recent history of ingesting intoxicating substances were considered to be intoxicated.

NEXUS criterion: positive physical examination

Patients were considered to have a positive physical examination if they demonstrated any of the following criteria: neck pain; tenderness to palpation (TTP) to the cervical midline or spinous processes.

NEXUS criterion: distracting injuries

Patients were considered to have a distracting injury if they demonstrated any of the following criteria: long bone fracture, excluding metacarpals, metatarsals and phalanges; visceral injury requiring immediate surgical intervention; large laceration, degloving, burn or crush injury. Additionally, any patient who was documented to display acute functional impairment following subjective assessment was also considered to have a distracting injury complex.

Data relating to demographics, injury profile and clinical course were extracted from the institutional trauma registry. Additional details regarding the physical examination and radiography were collected from the electronic health record, noting that odontoid fractures were classified using the Anderson and D'Alonzo classification scheme as previously described.[18] Results are reported as frequency or median with interquartile range. Univariate analysis of categorical variables was performed using Pearson's chi-squared test or Fisher's exact test. Continuous variables were evaluated using the Wilcoxon rank-sum test.
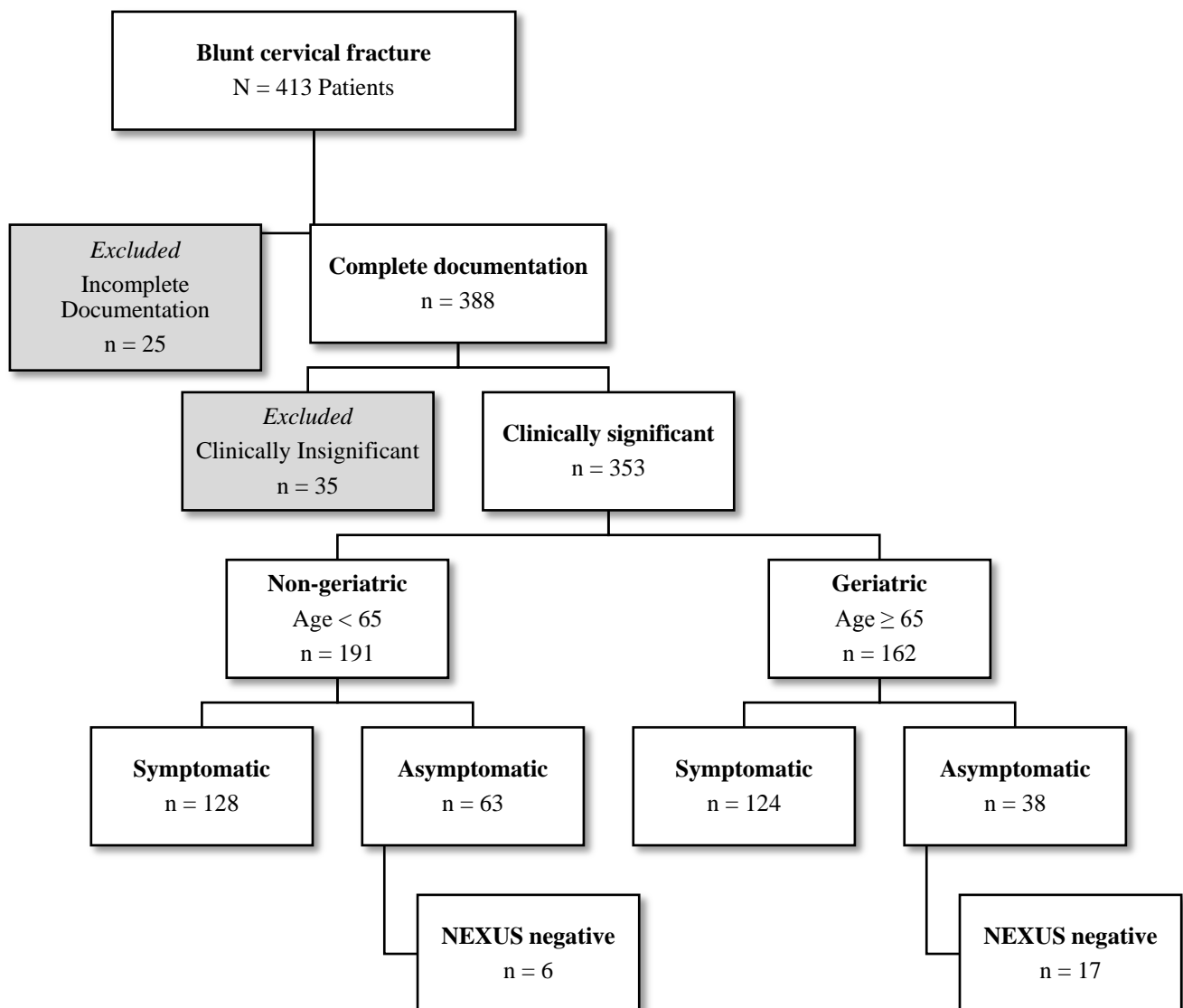
The sensitivity of the NEXUS criteria in predicting the presence of clinically significant CF served as the primary outcome. To evaluate the hypothesis that the performance of the NEXUS criteria is affected by patient age, the sensitivity of NEXUS was compared among non-geriatric and geriatric patients using Pearson's chi-squared test.

To assess the sensitivity of the NEXUS criteria after controlling for inter-group differences, the sensitivity comparison among age groups was repeated following propensity matching, which was modeled for the geriatric population and executed using an eight-to-one greedy matching algorithm. Matching was performed on a one-to-one patient basis; the quality of which was assessed using standardized mean difference (SMD <0.10 indicated sufficient match). Patients were matched by sex, evidence of osteoporosis and/or degenerative joint disease, mechanism of injury (fall, motor vehicle collision, other), injury severity score, atlanto-axial fracture (C1 and/or C2), and subaxial fracture (C3-C7). All analyses were performed using SAS software, Version 9.4 (Copyright 2013 SAS Institute Inc. Cary, NC). All statistical tests were two-sided and $p<0.05$ was statistically significant.

RESULTS

In total, 999 blunt trauma patients presented with at least one acute vertebral fracture. There were 413 patients sustaining CF, and 388 of these patients had complete NEXUS documentation at presentation (Figure 1). From this population, 353 patients had clinically significant CF, and most of these patients were less than 65 years old (191 patients, 54.1%).

Figure 1: Clinical presentation of patients sustaining blunt cervical fracture.

Table 1: Demographics and baseline characteristics of patients with significant cervical fracture.

Characteristics	Non-geriatric (age <65 years) n=191		Geriatric (age ≥65 years) n=162		P value
	N	%	N	%	
Age, years [median (IQR)]	42 (26, 55)		81 (73, 86)		<0.0001
Sex, female	62	32.5	85	52.5	0.0001
Comorbidities					
Osteoporosis	15	7.9	63	38.9	<0.0001
Degenerative joint disease	13	6.8	67	41.4	<0.0001
Glasgow coma scale					
Mild, GCS (13, 14, or 15)	191	100.0	162	100.0	Not tested
Mechanism					
Auto vs pedestrian	7	3.7	2	1.2	
Fall, ground level	10	5.2	81	50.0	
Fall, height	32	16.8	33	20.4	
MVC	48	25.1	31	19.1	<0.0001
MVC, ejection or roll over	52	27.2	10	6.2	
MVC, unenclosed vehicle	27	14.1	5	3.1	
Other	15	7.9	0	0	
ISS [median (IQR)]	14 (9, 17)		10 (9, 17)		0.01

IQR-Interquartile range; ISS-Injury severity score; MVC-Motor vehicle collision.

Table 2: Cervical spine injury characteristics.

Characteristics	Non-geriatric (age <65 years) n=191		Geriatric (age ≥65 years) n=162		P value
	N	%	N	%	
Presentation					
Symptomatic	128	67.0	124	76.5	0.048
Asymptomatic	63	33.0	38	23.5	
Level[a]					
C1	24	12.6	52	32.1	<0.0001
C2	31	16.2	30	18.5	0.57
Odontoid process	12	6.3	60	37.0	<0.0001
C3	21	11.0	16	9.9	0.73
C4	13	6.8	15	9.3	0.40
C5	30	15.7	35	21.6	0.15
C6	63	33.0	37	22.8	0.04
C7	87	45.5	32	19.8	<0.0001
Classification[a]					
C1					
Arch	15	7.9	40	24.7	<0.0001
Burst, Jefferson	5	2.6	11	6.8	0.06
Odontoid type I	0	0.0	1	0.6	0.46
Odontoid type II	4	2.1	44	27.2	<0.0001
Odontoid type III	8	4.2	15	9.3	0.05
Vertebral body					
Burst, C2-C7	4	2.1	2	1.2	0.53
Teardrop	9	4.7	4	2.5	0.26
Other	60	31.4	52	32.1	0.89
Facet	69	36.1	24	14.8	<0.0001
Lamina	44	23.0	23	14.2	0.03
Pedicle	18	9.4	15	9.3	0.96
Spinous process	45	23.6	14	8.6	0.0002
Transverse process	58	30.4	39	24.1	0.19

[a]Most patients had multiple fractures. Percentages exceed 100%.

Table 3: Outcomes of patients with significant cervical fracture.

Outcome	Non-geriatric (age <65 years) n=191		Geriatric (age ≥65 years) n=162		P value
	N	%	N	%	
Treatment					
Brace	154	80.6	143	88.3	
Halo	3	1.6	2	1.2	0.15
Surgery	34	17.8	17	10.5	
Morbidity					
Acute respiratory failure	2	1.0	8	4.9	0.048
Acute cardiac event	3	1.6	15	9.3	0.001
Acute kidney injury	1	0.5	1	0.6	0.99
Pneumonia	7	3.7	8	4.9	0.55
Venous thromboembolism	2	1.0	3	1.9	0.66
Requirement of intubation	23	12.0	19	11.7	0.93
Duration, days [median (IQR)]	2 (1, 5)		5 (2, 9)		0.11
ICU hospitalization	42	22.0	36	22.2	0.96
LOS, days [median (IQR)]	4 (2, 8)		5 (3, 8)		0.43
LOS, days [median (IQR)]	4 (2, 7)		4 (3, 7)		0.14
Discharge [a]					
Home	126	66.7	41	27.0	
Rehabilitation	48	25.4	44	28.9	
Skilled nursing facility	13	6.9	63	41.4	<0.0001
Long term acute care	0	0	3	2.0	
Against medical advice	2	1.1	1	0.7	
Inpatient mortality	2	1.0	10	6.2	0.008
Comfort care	(0/2)		(8/10)		

[a]Patients alive at discharge. ICU- Intensive care unit; IQR- Interquartile range; LOS- Length of stay.

The demographics and baseline characteristics of patients with complete documentation and clinically significant CF are presented in Table 1. As expected, the geriatric group had a significantly higher rate of osteoporosis and degenerative joint disease (38.9% vs. 7.9% and 41.4% vs. 6.8% respectively; all p<0.0001). The mechanism of injury also differed significantly with most non-geriatric patients injured in a motor vehicle crash (66.4%), whereas most geriatric patients were injured during a fall (70.4%). The higher incidence of a high-energy mechanism corresponded to a higher severity of injury in non-geriatric patients (median [interquartile range] Injury severity score: 14 [9, 17] vs. 10 [9, 17], p=0.01).

Within the studied population, 101 patients (28.6%) with significant injury presented without cervical pain and denied TTP (Table 2). Non-geriatric patients demonstrated a higher rate of asymptomatic fracture than their older counterparts (33.0% vs. 23.5%, p=0.048). Overall, the most common fracture location was the seventh cervical vertebrae, accounting for over 45% of the fractures in younger patients. Geriatric patients demonstrated a significantly higher incidence of fractures at the odontoid process, in addition to the first cervical vertebrae (37.0% vs. 6.3% and 32.1% vs. 12.6%, respectively, all p<0.0001). Younger patients had a higher incidence of fractures to the facets and spinous

processes (36.1% vs. 14.8%, p<0.0001 and 23.6% vs. 8.6%, p=0.0002, respectively).

The outcomes of patients with clinically significant CF are presented in Table 3. Most patients were treated with bracing, resulting in no significant difference in the management of CF (p=0.15). While there was no difference in the duration of intubation, the length of stay in the intensive care unit or the length of hospitalization, older patients had a significantly higher incidence of an adverse cardiac event (9.3% vs. 1.6%, p=0.001). Geriatric patients also demonstrated a higher inpatient mortality rate (6.2% vs. 1.0%, p=0.008), though most of the geriatric patients were transitioned to comfort care before expiring.

Table 4 details the characteristics among patients with significant CF who did not meet a single NEXUS criterion to recommend imaging. Among the non-geriatric patients, only six failed to meet any of the NEXUS criteria. Notably, 3 patients (50.0%) remained asymptomatic during the subsequent physical evaluation by the spine specialists after radiographic CF diagnosis. In the 162 geriatric patients, 17 patients failed to meet a single NEXUS criterion. Eleven patients (64.7%) continued to deny neck pain and TTP during the physical evaluation by the spine specialists after radiographic CF

diagnosis. Among the NEXUS-negative geriatric patients, the predominant mechanism was a ground level fall (13 patients, 76.5%) with injury most commonly located at the level of C1 (6 patients, 35.3%). Younger patients were again noted to be injured in high-energy

mechanisms (motor vehicle collisions: 4 patients, 66.7%) and most patients sustained low-level fractures (C6-7: 5 patients, 83.4%). Regardless of patient age, bracing served as the principle treatment modality.

Table 4: Characteristics of NEXUS negative patients.

Characteristics	Non-geriatric (age <65 years) n=6		Geriatric (age ≥65 years) n=17	
	N	%	N	%
Age [median (IQR)]	48 (25, 55)		82 (76, 85)	
Sex, female	3	50.0	10	58.8
Comorbidities				
Osteoporosis	0	0	5	29.4
Degenerative joint disease	0	0	7	41.2
Mechanism				
Fall, ground level	0	0	13	76.5
Fall, height	1	16.7	1	5.9
MVC	2	33.3	2	11.8
MVC, ejection or roll over	1	16.7	0	0
MVC, unenclosed vehicle	1	16.7	1	5.9
Other	1	16.7	0	0
ISS [median (IQR)]	14.5 (9, 17)		9 (5, 14)	
Fracture level [b]				
C1	1	16.7	6	35.3
C2	0	0	2	11.8
Odontoid process	0	0	3	17.6
C3	1	16.7	1	5.9
C4	0	0	1	5.9
C5	0	0	5	29.4
C6	1	16.7	5	29.4
C7	4	66.7	1	5.9
Fracture classification[a]				
C1				
Arch	1	16.7	4	23.5
Burst, Jefferson	0	0	2	11.8
C2				
Odontoid type II	0	0	2	11.8
Odontoid type III	0	0	1	5.9
Vertebral body				
Teardrop	1	0	3	17.6
Other	1	16.7	3	17.6
Facet	1	16.7	4	23.5
Spinous process	2	33.3	1	5.9
Transverse process	2	33.3	2	11.8
Treatment				
Brace	5	83.3	16	94.1
Surgery	1	16.7	1	5.9

[a]Most patients had multiple fractures. Percentages exceed 100%. IQR: Interquartile range; ISS- Injury severity score; MVC- Motor vehicle collision.

Overall, the NEXUS criteria demonstrated a sensitivity of 96.8% (Table 5) in the younger population, whereas NEXUS sensitivity was significantly reduced in geriatric patients (89.5%, p=0.01).

Propensity matching was executed to further assess the sensitivity of the NEXUS criteria after controlling for differences in comorbidities, mechanism of injury and fracture location. Ultimately, 73 patients in each group

were well-matched (all covariates with SMD <0.10; Table 6). Among the non-geriatric patients, 2 patients (2.7%) failed to meet a single NEXUS criterion, whereas 10 geriatric patients (13.7%) were NEXUS-negative (Table 7). Thus, in this propensity matched subset, the NEXUS criteria continued to demonstrate a significantly reduced sensitivity among geriatric patients compared to the younger counterparts in detecting clinically significant CF (86.3% vs. 97.3%, p=0.02; Table 5).

Table 5: Sensitivity of nexus criteria among patients with significant cervical fracture.

	Total patients	NEXUS negative	NEXUS sensitivity (%)	P value
Per age group (years)				0.01
Age <65	191	6	96.8	
Age ≥65	162	17	89.5%	
Per age group: propensity matched [b] (years)				0.02
Age <65	73	2	97.3	
Age ≥65	73	10	86.3	

[b]Matched variables: sex, osteoporosis and/or degenerative joint disease, mechanism of injury (fall, motor vehicle collision, other), injury severity score, atlanto-axial fracture (C1 and/or C2), subaxial fracture (C3-C7).

Table 6: Propensity matched demographics and baseline characteristics.

	Non-geriatric (age <65) n=73		Geriatric (age ≥65) n=73		SMD
	N	%	N	%	
Age, years [median (IQR)]	46 (25, 57)		76 (69, 83)		Not tested
Sex, female	32	43.8	29	39.7	0.083
Comorbidities					0.072
Osteoporosis	12	16.4	14	19.2	
Degenerative joint disease	10	13.7	10	13.7	
Glasgow coma scale					Not tested
Mild, GCS 13-15	73	100	73	100	
Mechanism					0.056
Auto vs. pedestrian, other	2	2.7	2	2.7	
Fall	34	46.6	36	49.3	
MVC	37	50.7	35	47.9	
ISS [median (IQR)]	14 (8, 17)		12 (9, 17)		0.043
Level[a]					
C1–C2	36	49.3	33	45.2	0.082
C3–C7	48	65.8	51	69.9	0.088
Presentation					Not tested
Symptomatic	54	74.0	51	69.9	
Asymptomatic	19	26.0	22	30.1	

Matched variables: sex, osteoporosis and/or degenerative joint disease, mechanism of injury (fall, motor vehicle collision, other), injury severity score, atlanto-axial fracture (C1 and/or C2), subaxial fracture (C3-C7). IQR: interquartile range; ISS: injury severity score; MVC: motor vehicle collision; SMD: standardized mean difference.

Table 7: Characteristics of NEXUS negative patients after propensity matching.

	Age	Sex	Mechanism of injury	ISS	Fracture	Treatment
Non-geriatric						
Patient A	44	Female	MVC without RO/E	22	C1 Arch	Brace
Patient B	62	Female	Fall from height	9	C3 Endplate, C3 Transverse Process, C4 Facet	Brace
Patient C	69	Male	MVC without RO/E	9	C1 Arch, C5 Spinous Process	Brace
Patient D	70	Male	GLF	4	C4-5 Endplate	Brace
Patient E	76	Female	GLF	14	C2-3 Teardrop	Brace

Continued.

	Age	Sex	Mechanism of injury	ISS	Fracture	Treatment
Patient F	81	Male	GLF	5	C5 body, C5 transverse process	Brace
Patient G	81	Female	GLF	5	Jefferson	Brace
Patient H	82	Male	GLF	5	C5 Teardrop	Brace
Patient I	82	Female	MVC without RO/E	22	Odontoid type III	Brace
Patient J	83	Male	GLF	14	C1 Arch, Odontoid Type II	Brace
Patient K	85	Female	GLF	6	C2 Endplate, C7 Facet	Brace
Patient L	91	Female	GLF	14	Odontoid Type II	Brace

Matched variables: sex, osteoporosis and/or degenerative joint disease, mechanism of injury (fall, motor vehicle collision, other), injury severity score, atlanto-axial fracture (C1 and/or C2), subaxial fracture (C3-C7). GLF: ground level fall; MVC: motor vehicle collision; RO/E: rollover or ejection.

DISCUSSION

In this retrospective study, more than one-in-four patients with a significant CF presented without neck pain and denied TTP during examination, indicating that these patients failed to meet one of the core NEXUS criteria to recommend cervical spine imaging. When the remaining NEXUS criteria were applied, the clinical decision rule demonstrated high sensitivity among non-geriatric patients in identifying significant injury. NEXUS sensitivity was significantly reduced in geriatric trauma, missing 10.5% of patients with CF requiring surgery, halo immobilization, or cervicothoracic orthosis. Even after propensity matching, the NEXUS criteria remained significantly less sensitive among geriatric patients compared to their younger counterparts.

The rapid identification of cervical spine injury is essential to the safe treatment of patients sustaining blunt trauma as serious, potentially catastrophic complications can result from delayed diagnosis or missed injury.[19-21] Several validated clinical decision-making rules have been developed to identify patients at risk of cervical spine injury, and the NEXUS criteria remain one of the predominant tools used in trauma centers around the United States. The sensitivity of the criteria, however, requires re-examination as prospective and retrospective studies have questioned the reliability of NEXUS,[22] particularly in the geriatric population.[14-16]

While no significant CF was undetected after radiographic evaluation, 28.6% of patients with significant CF presented without subjective pain or TTP. The present rate of asymptomatic CF is slightly higher than a previous study of adults (≥55 years) that reported 21% of patients denying pain or TTP, which was extrapolated to 18.3% among patients sustaining injury requiring treatment.[23] While confirming the suspicion that the absence of pain and TTP does not reliably exclude significant injury in geriatric patients (23.5% asymptomatic), the present work also extends this conclusion to non-geriatric patients (33.0% asymptomatic).

In this population, a ground-level fall was the most common mechanism of injury among geriatric patients, particularly in the individuals failing to meet a single NEXUS criterion. The high incidence of ground-level falls among older adults is consistent with previous reports, which also similarly report high incidence of fracture at the level of the second cervical vertebrae, including the odontoid process.[16,24] This predominance of ground-level falls may have contributed to the similar sensitivity reported between the present work (89.5%) and a previous investigation exclusively examining geriatric ground-level falls, which reported an 88.9% sensitivity in detecting clinically significant injury.[15]

An investigation of high-energy mechanisms requiring trauma team activation reported even lower sensitivity in the geriatric population, which was significantly reduced compared to the already inadequate sensitivity demonstrated in the younger adults (65.9% vs. 84.2% P<0.0001).[14] These results support prior findings indicating insufficient NEXUS sensitivity in severe blunt trauma,[22] while also demonstrating that NEXUS has significantly worse performance in the geriatric cohort. This previous study is the only available work that compared sensitivity between geriatric patients and their younger counterparts within the same population; however, the clinical significance of the CF was not assessed.[14] Similar findings are reported in the present work which examined clinically significant injury resulting from any blunt trauma mechanism, suggesting that the NEXUS criteria may not be adequately sensitive even in geriatric patients without severe trauma or high-energy mechanisms of injury. This conclusion is supported by another retrospective study, which reported insufficient sensitivity among geriatric trauma resulting from any blunt mechanism, though the clinical significance of the injury was not considered and younger counterparts were not studied.[16]

Recently, a modified version of NEXUS (distracting injury limited to any external head/neck trauma, baseline rather than normal mentation) was applied to geriatric ground level falls not triaged to the trauma bay and reported 100% sensitivity for CF, though the clinical significance of the injury was not considered.[25] In the present population, 11 of the 17 NEXUS-negative geriatric patients presented with a minor sign of trauma (small and superficial laceration, small ecchymosis) to

the face or head, which the admitting clinician did not assess to be a painful or distracting injury. Though encouraging, the modified criteria still require dedicated validation of sensitivity and specificity before implementation in this highly specific subset of patients. Nonetheless, the optimal guidelines for the remaining mechanisms of geriatric injury remain controversial.

The present study enhances the current understanding of the relationship between patient age and the use of the NEXUS criteria in evaluating the cervical spine following blunt trauma. First, it supports the notion that the absence of pain and TTP does not reliably exclude significant CF in geriatric or non-geriatric patients. Secondly, this work suggests that even though an alarming rate of patients, regardless of age, will fail to meet the criterion for a positive physical examination, the NEXUS criteria in entirety are significantly more sensitive in identifying significant injury in non-geriatric patients. Nonetheless, the NEXUS criteria still failed to identify 3.2% of younger adults with significant injury in the overall population and 2.7% of non-geriatric patients after propensity matching. The high-energy mechanism of injury (motor vehicle collision, fall from second story onto concrete, mine collapse) sustained by all six of these NEXUS-negative patients contributed to the decision to scan the head and cervical spine during the initial evaluation. Ultimately, this pattern of NEXUS-negative patients is consistent with previous reports criticizing the reliability of the NEXUS criteria in severe blunt trauma.[22]

While there were young patients with significant injury who failed to meet a single criterion, there was a threefold increase in the incidence of NEXUS-negative injury among geriatric patients in the overall population. Correspondingly, the significant reduction in sensitivity in the geriatric patients, which persisted even after propensity matching, suggests that this cohort may need an even lower threshold for imaging, particularly as they may have a high burden of comorbid disease, chronic pain that could mask acute injury, and age-related musculoskeletal decline, which may predispose them to sustaining severe injuries. The present study's recommendation towards imaging, regardless of NEXUS status, is consistent with the best practice guideline released by the American College of Surgeon's Trauma Quality Improvement Project that recommends the liberal use of CT in geriatric patients citing the possibility of occult injury and recognizing that radiation exposure poses minimal risk in this cohort.[26]

The results of the present study, however, should be interpreted in the context of its limitations. Though rigorous documentation standards were applied, this work was critically limited by the retrospective nature of data collection and the single institution's small sample size, particularly after propensity matching. Additionally, this work was a focused, first-step study and restricted its scope to patients with CT evidence of acute CF in order to examine sensitivity. The imperfect sensitivity reported in this study supports further reassessment, and future work must expand the population to all blunt trauma patients to comprehensively assess the NEXUS criteria's performance, including specificity and negative predictive value. The present findings help justify the considerable investment necessary to examine all evaluable blunt trauma patients, irrespective of a retrospective or ideally prospective study design. Despite these limitations, this work should serve as a preliminary first-step study to further define the need to rigorously evaluate the optimal cervical spine guidelines, particularly among geriatric patients. Future prospective, multicenter studies may further elucidate specific sub-groups most in need of liberal imaging.

CONCLUSION

Geriatric patients demonstrated a threefold increase in the incidence of significant injury despite NEXUS-negative status compared to non-geriatric patients. Correspondingly, the NEXUS criteria demonstrated a significantly reduced sensitivity among geriatric patients, which persisted even after propensity matching. Liberal imaging is therefore recommended, particularly in the geriatric population following blunt trauma.

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