



Cervical seatbelt sign is not associated with blunt cerebrovascular injury in children: A review of the national trauma databank



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ABSTRACT

Background: Blunt cerebrovascular injury (BCVI) is a rare consequence of blunt trauma. There appears to be benefit to an aggressive approach to screening for BCVI due to catastrophic sequelae of unrecognized injury. However, screening for BCVI carries extensive cost and oncologic risk to young patients. Foundational BCVI studies examined adults primarily, leaving question to the effectiveness of these criteria in children. We sought to evaluate BCVI screening criteria developed in primarily adult populations using a nationally representative pediatric dataset.

Methods: We queried the 2008–2014 National Trauma Data Bank for patients with BCVI. Patients were stratified by age (adults > 18yrs, pediatric ≤ 18yrs). Screening factors from the Modified Denver Criteria and Modified Memphis Criteria (GCS ≤ 8, C1–C3 cervical fracture, cervical subluxation, seatbelt sign, basilar skull fracture, mid-facial fracture, mandibular fracture, significant blood loss, coma, stroke, and hanging) were examined using univariate analysis and backwards-stepwise logistic regression to verify predictors of BCVI.

Results: Blunt injury occurred in 2,174,244 adults and 422,181 children; 5970 adults and 809 children sustained BCVI. In univariate analysis, all screening factors correlated with BCVI in both groups ($p < 0.001$). When comparing BCVI patients, children more commonly experienced GCS ≤ 8, seatbelt sign, basilar skull fracture, mid-facial fracture, mandibular fracture, and coma ($p < 0.05$). In multivariable analysis, seatbelt sign was not associated with pediatric BCVI.

Conclusion: Many adult-associated BCVI risk factors apply to children. Although children more commonly experience seatbelt sign, it does not independently cause increased BCVI risk. Given the rarity of pediatric BCVI, prospective multi-institutional studies are warranted to establish screening criteria specific to children.

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Introduction

Trauma via motor vehicle collision (MVC) is the most common mechanism of injury for pediatric patients.¹ Blunt cerebrovascular injury (BCVI) is rare in children and can lead to potential catastrophic consequences from ischemic injury or stroke.² Injury occurs through damage to the carotid or vertebral arteries, typically through blunt strike to the cervical region, hyperextension injury of

the neck in MVCs, or falling injury.³ Expedient diagnosis of BCVI is paramount in preventing permanent neurologic impairment due to ischemia or thrombotic complication.⁴ Intervention typically consists of surgical intervention, stenting, and/or anticoagulation.^{5–7}

Foundational studies at large trauma centers established screening criteria for BCVI through identifying injuries and clinical signs related to carotid and vertebral artery injury.^{3,8} The Denver Criteria and Memphis Criteria (along with their subsequent modified forms) serve as the most widely accepted examples of screening metrics for BCVI.^{3,8–13} Recent analysis of children with BCVI using the Utah score (which uses established criteria from the Denver and Memphis Studies) has also gained significant

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attention.^{14,15} The Boston Criteria have emerged, combining several of these factors into an additional screening system, which provides recommendations for triaged screening based on many of the criteria listed by the Denver group.¹⁶ Most recently, the McGovern Screening Score has emerged, as a modified version of the Utah Score which incorporate mechanism of injury into its prediction score. Each criteria system identified factors associated with BCVI through prospective data collection and analysis of comorbid injuries found in patients eventually diagnosed with BCVI. Among those factors identified, specific fractures, signs of soft tissue injury, indicators of neurologic injury, and specific mechanism of injury comprise the vast majority of screening criteria.¹⁷ With several similar prediction criteria there has been noted confusion regarding the best system to implement at a given medical center.

Although screening criteria for BCVI have been largely accepted in adults based on the Denver and Memphis studies, the pediatric population was poorly studied in these reviews due to rarity of the injury in children.^{6,10,18,19} Validation studies for these criteria included small pediatric cohorts,¹³ making it difficult to extrapolate meaningful conclusions to guide treatment for the pediatric population. The Utah Score, the only analysis with the direct intent of examining children, was only able to identify 24 BCVIs within their original cohort and 22 patients with BCVI in their validation cohort.^{14,15} In addition, there has been challenge to the Memphis Criteria which have proposed cervical seatbelt sign as a predictor of BCVI, however, these studies have had small numbers of pediatric BCVI which make large scale multivariable analysis ineffective.¹⁹ Within our own institution we have subjectively found that isolated seatbelt in children has poorly correlated with BCVI. In order to better understand the risk factors for blunt cerebrovascular injury in children, we queried a national trauma registry for incidence and factors associated with their occurrence. Using a large cohort of patients with a large number of BCVIs, we sought to evaluate established screening criteria for BCVI in children and hypothesized that cervical seatbelt sign would not be significantly associated with BCVI on multivariable analysis.

Methods

IRB approval

This retrospective study was approved by the Duke University Institutional Review Board (Pro00051486).

Data source

The National Trauma Data Bank (NTDB) is a database supported by the American College of Surgeons and comprises the largest registry of traumatic injury in the United States. Current participation in this program includes over 800 hospitals contributing cases annually that detail patient demographics, injury information, and patient outcomes.^{20,21} To date over 8 million cases have been recorded within this dataset.

Study population

Blunt trauma patients captured within the NTDB from 2008 to 2014 were included in this analysis. Blunt trauma was defined using ICD E-Codes for fall injury, motor vehicle collisions, struck by motor vehicle injuries, hanging injury, and strike injuries. Patients were stratified by age (adult: age ≥ 18 , pediatric: age < 18). For this analysis we excluded penetrating mechanism of injury in order to more clearly examine BCVI. Patients with missing age and injury data were also excluded from this analysis.

Statistical analysis

We sought to assess previously defined predictors of BCVI that were identified in established screening criteria (either the Denver Criteria or Memphis Criteria) using univariate analysis. These factors are well summarized in a recent review by Fenton et al.²² We evaluated factors available in the NTDB as appropriate in a series of analyses described below, specifically evaluating: Glasgow Coma Scale (GCS), Cervical fractures or Cervical Subluxation, Soft Tissue Injury or “Seatbelt Sign,” Basilar Skull Fractures, Le Fort or Mid-Facial Fractures, Mandibular Fractures, Significant Blood Loss or Hemorrhage, Coma, Stroke on CT, and Hanging Mechanism of Injury. We were unable to examine diffuse axonal injury, Horner's syndrome, cervical bruit in patients over 50, focal neurologic deficit, and neurologic exam incongruous with CT imaging due to absence of specific diagnostic codes or lack of a categorical variable for these injuries within the NTDB. Several factors identified in the 2012 study by Burlew et al. were not included in this study, namely blunt cardiac rupture, thoracic vascular injury, fracture of ribs 1–3, scalp degloving, and TBI in the presence of thoracic injury.

Screening factors were compared between pediatric patients with BCVI and those without using univariate analysis to determine the relative significance of each associated sign or injury. Univariate analysis was conducted using non-parametric tests including Pearson's Chi-squared test for categorical variables and Kruskal-Wallis test for continuous variables. A p-value < 0.05 was considered to be significant for all statistical analyses in this study. This analysis utilized R statistical programming software (Version 3.3.0, Vienna, Austria).

For the purpose of this study we sought to identify the incidence of BCVI in overall, adult, and pediatric populations. This was accomplished by comparing diagnosed BCVI to the respective blunt traumatic injury populations.

We then sought to highlight variations in presentation between adults and children with the intent of identifying factors that may be more useful clinically when evaluating pediatric blunt trauma patients with suspected BCVI. We used univariate analysis (as previously described) to compare adults and children with BCVI in order to demonstrate significant variations in patient presentation between these two populations.

Injury patterns associated with carotid and vertebral artery injuries were then examined in children in an attempt to highlight variations in injury patterns between these two injury patterns. We separated BCVI into the respective injury components of carotid artery or vertebral artery injury. We then compared these two groups using univariate analysis (as previously described) to identify trends in presentation associated with each injury type. We hypothesized that while these injuries are often considered together as BCVI, they would have unique presentations identifiable on univariate analysis.

Finally, we used backwards-stepwise multivariable logistic regression analysis to identify independent factors associated with blunt cerebrovascular in the overall population, the adult population, and the pediatric population. This was done controlling for GCS ≤ 8 , cervical fracture in C1–C3, cervical subluxation, cervical seatbelt sign, basilar skull fracture, mid-facial fracture, mandibular fracture, significant blood loss, coma, stroke, and hanging mechanism of injury.

Results

Incidence

Our query identified 2,596,425 patients who had sustained blunt traumatic injuries. Of these patients, 2,174,244 were adults

and 422,181 were children. BCVI occurred in 5970 adult cases and 809 pediatric cases (6779 total). Incidence of BCVI in the overall population was 26.1 per 10,000 cases of blunt trauma, 27.4 per 10,000 cases in the adult population, and 19.2 per 10,000 cases in the pediatric population. Median age (in years) was 39 in the adult patients and 16 in pediatric patients. Histograms of occurrence of BCVI by age demonstrate increase in incidence beginning at approximately age 13 in pediatric patients and dramatic increases in incidence at approximately 16 years of age in the general population (Fig. 1).

Examination of screening criteria

On review of univariate analysis of the predictors of BCVI described in the Denver and Memphis studies, all associated injuries were statistically significant for the overall population, the adult population, and the pediatric population. Those factors available within the NTDB for validation are listed in Table 1. Of note, each of these factors was associated with a significant p-value ($p < 0.001$) in each subgroup univariate analysis.

Assessment of injury patterns in pediatric patients compared to adults revealed higher proportional incidence of carotid artery injury in children and higher proportional incidence of vertebral artery injury in adults (Table 2). Children were more likely to experience GCS <8 , cervical seatbelt sign, basilar skull fracture, mid-facial fracture, mandibular fracture, and coma (all $p < 0.05$). Notably, adults were more likely to experience cervical fracture of C1–C3, and cervical subluxation. Significant blood loss, stroke documented on CT, and hanging mechanism were not statistically different between the two groups (all $p > 0.05$).

In examination of unique signs for vertebral artery injury and carotid artery injury, it was noted that GCS ≤ 8 , basilar skull fracture, and mid-facial fracture were most commonly associated with carotid artery injury (all $p < 0.05$) (Table 3). No significant difference was noted between vascular injury types for cervical subluxation, cervical fracture, cervical seatbelt sign, mandibular fracture, significant bleeding, coma, stroke, or hanging mechanism (all $p > 0.05$).

On multivariable analysis, the overall population and adult population maintained significant association with each of the identified factors from the Denver and Memphis studies. Pediatric

patients did not experience significant correlation between BCVI and soft tissue injuries or, “Cervical seatbelt sign,” (OR = 1.0002 [95% CI 0.9998–1.0006], $p = 0.212$) (Table 4).

The weak association between individual predictors and BCVI prompted creation of a histogram of pediatric patients diagnosed with BCVI organized by the number of positive screening criteria present. This demonstrated 153 patients presented without a single screening criterion. Further, likelihood of BCVI tended to increase with the presence of additional screening criteria (Table 5).

Discussion

Cervical seatbelt sign has historically been associated with BCVI^{9,10,23} however, there has been controversy surrounding the utility of this sign. Desai et al. demonstrated in a single-institution retrospective review that cervical seatbelt sign is a poor predictor of BCVI in children.¹⁸ This study was limited by a small sample size, with only eight pediatric patients with BCVI. Other studies have challenged the use of this criterion in adults.^{19,24} Despite recent skepticism regarding use of this sign in isolation, cervical seatbelt sign remains within the Memphis Criteria, Boston Criteria, and Denver Criteria as well as many institutional screening protocols. Notably, the Utah Score and McGovern Screening Score do not incorporate cervical seatbelt sign into their predictive calculations.^{15,25} Lew et al. have noted incidence of BCVI as low as 0.03% of patients in their study of the National Pediatric Trauma Registry.²⁶ Due to the rarity of this injury and lack of large cohort studies, cervical seatbelt sign has not been well studied in children with suspected BCVI. Given the weak association between BCVI and cervical seatbelt sign, we have concern in using this exam finding alone to justify subsequent investigation with computed tomographic angiography (CTA), due to the small but present cancer risk in children.²⁷ Our current metrics for identifying BCVI in children may be insufficient and cost-ineffective. Based on our data, we advise against using the cervical seatbelt sign as an independent risk factor for radiologic screening. Isolated injuries should also be viewed with caution, as children presenting with a single positive screening criterion had very low incidence of injury, as demonstrated by Ravindra et al. in their creation and validation of the Utah Score.^{14,15} However, children with multiple positive screening

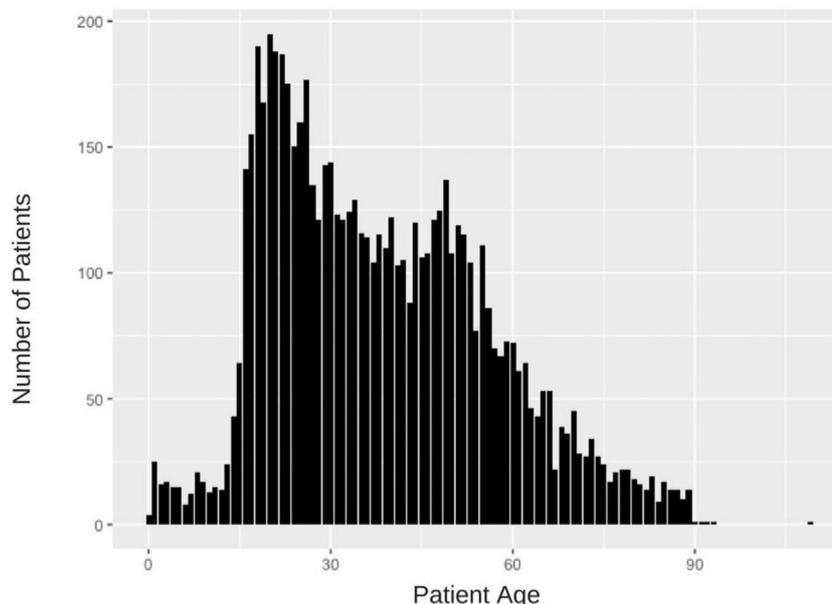


Fig. 1. Histogram of patients with blunt cerebrovascular injury organized by age in years.

Table 1
Variables used to assess Modified Denver Criteria and Modified Memphis Criteria.

Name of Criterion	Means of Assessment through NTDB
Memphis Criteria	
Base of Skull Fracture with Involvement of the Foramen Lacerum	ICD-9 Codes and AIS Codes
Cervical Spine Fracture	ICD-9 Codes and AIS Codes
Neurological Exam Findings not Explained by Neuroimaging	Unable able to assess within NTDB
Horner Syndrome	Unable able to asses within NTDB
Le Fort II or III Fracture Pattern	ICD-9 Codes and AIS Codes
Neck Soft Tissue Injury (Seatbelt Sign, Hanging, Hematoma)	ICD-9 Codes and AIS Codes
Denver Criteria	
Signs and Symptoms	
Arterial Hemorrhage	Unique Variable Present Within NTDB
Cervical Bruit in Patient under 50	Unable to Assess Within NTDB
Expanding Cervical Hematoma	Unable to Assess Within NTDB
Focal Neurologic Deficit (TIA, hemiparesis, vertebrobasilar symptoms, Horner Syndrome)	Unable to Assess Within NTDB
Neurological Exam Incongruous with CT Scan Findings	Unable to Assess Within NTDB
Stroke on Secondary CT Scan	Unique Variable Present Within NTDB
Risk Factors for BCVI: High Energy Mechanism of Injury with the Following	
Displaced mid-face fractures (Le Fort Type II or III Fractures)	ICD-9 Codes and AIS Codes
Mandibular Fracture	ICD-9 and AIS Codes
Complex skull fracture, basilar skull fracture, or occipital condyle fracture	ICD-9 Codes and AIS Codes
Severe TBI with GCS<6	Unable to Assess TBI Within NTDB; GCS available as unique continuous variable
Cervical Spine Fracture, Subluxation, or ligamentous injury at any level	ICD-9 Codes and AIS Codes
Near Hanging Mechanism of Injury with Hypoxic Ischemic Brain Injury/Strangulation Especially with Loss of Consciousness	ICD-9 Codes and AIS Codes
Clothesline-type injury or seatbelt abrasion with significant swelling, pain, or altered mental status	ICD-9 Codes and AIS Codes
Fracture of Ribs 1-3	Not evaluated
Blunt Cardiac Rupture	Unable to assess specifically with ICD-9/AIS codes. Unable to examine in this analysis.
Scalp Degloving	Not evaluated
TBI with Thoracic Injury	Unable able to assess within NTDB
Thoracic Vascular Injury	Not evaluated

criteria appear to have a higher risk for BCVI and should be observed with increased clinical suspicion. We believe more extensive examination in the pediatric population through multi-institutional reviews is necessary to establish appropriate scoring criteria to support clinical judgment. An effort of this kind can also provide further clarification on the degree to which blunt pediatric trauma patients are screened, and the radiologic burden incurred in children during BCVI screening.

Children and adults present with different injury patterns related to their cerebrovascular injuries. As seen in our comparison of adult

and pediatric BCVI, children are diagnosed with proportionally more carotid artery injuries and are more likely to present with a $GCS \leq 8$, seatbelt sign, basilar skull fracture, facial fracture, and mandibular fracture than their adult counterparts are. In our multivariable analysis, all of the evaluated screening factors for BCVI were significantly associated with BCVI, with the exception of cervical seatbelt sign. The notable differences in presentation between adults and children, such as variations in anatomical injury, and a more efficient cardiovascular system in younger patients, signify the importance of a unique approach to pediatric trauma patients. Examination of the screening factors' relevance in relation to age may highlight age specific injuries associated with BCVI. It may be possible that age itself should be considered when screening children for BCVI. The low frequency of BCVI demonstrated within the pediatric population signal the need for more robust investigation into this injury as well as more vigilant attention to defining screening criteria in children.

Identifying clear predictors of BCVI in children remains a challenging proposition. The Eastern Association of Surgery in Trauma (EAST) has endorsed using adult screening guidelines in children due to lack of substantial evidence to direct screening criteria specific to children.² Rossidis et al. recently published a 10-year retrospective analysis finding that adult screening criteria of $GCS \leq 8$, basilar skull fracture, cervical spine fracture, cervical ligamentous injury, Le Fort II and III fractures, and Diffuse Axonal Injury were sufficient in identifying 100% ($n = 11$) of their pediatric patients who had sustained BCVI, finding these screening criteria sufficient.²⁸ However, the authors of the EAST document note that a significant number of patients who are eventually diagnosed with BCVI have no signs indicating this injury, which is corroborated by a 2011 study by Burlew et al. in their attempts to examine broadened Denver screening criteria.⁹ After uniform screening of blunt trauma patients with CT at their institution, Bruns et al. noted 30% of patients who had sustained BCVI and had zero positive screening

Table 2
Comparison of adults and children with BCVI.

	Adult (N = 5970)	Pediatrics (N = 809)	P-value
Age	39 (27–53)	16 (13–17)	<0.001
Gender			0.096
Female	37.1% (2217)	41.5% (336)	
Male	62.8% (3749)	58.5% (473)	
Carotid Artery Injury	81.4% (4860)	93.8% (759)	<0.001
Vertebral Artery Injury	20.4% (1217)	7.2% (58)	<0.001
GCS-Total	13 (3–15)	6 (3–15)	<0.001
GCS ≤ 8	40.4% (2409)	56.5% (457)	<0.001
Cervical Fracture C1–C3	11.4% (678)	5.9% (48)	<0.001
Cervical Subluxation	5.4% (323)	3.3% (27)	0.012
Cervical Seatbelt Sign	14.4% (859)	17.3% (140)	0.028
Basilar Skull Fracture	20.6% (1228)	35.7% (289)	<0.001
Mid-Facial Fracture	26.6% (1590)	32.6% (264)	<0.001
Mandibular Fracture	9% (537)	11.2% (91)	0.038
Significant Blood Loss	0.9% (53)	1% (8)	0.775
Coma	0.4% (24)	1% (8)	0.022
Stroke on CT	6.3% (375)	6.6% (53)	0.767
Hanging Mechanism	1.6% (93)	1.4% (11)	0.667

Univariate analysis. Categorical tests complete with Pearson's Chi-Squared test, listed as percentage (N). Continuous variables assessed with Kruskal-Wallis test, listed as mean (IQR).

Table 3
Comparison of children with BCVI by vessel injury type.

	Carotid Artery Injury (N = 759)	Vertebral Artery Injury (N = 50)	P-value
Age	16 (13–17)	17 (15–18)	0.068
Gender			0.715
Female	41.4% (314)	44.0% (22)	
Male	58.6% (445)	56.0% (28)	
Race			0.042
Asian	1.2% (9)	6.0% (3)	
Black or African American	10.8% (82)	12.0% (6)	
Other	17.0% (129)	20.0% (10)	
White	71.0% (539)	62.0% (31)	
GCS-Total	6 (3–15)	14 (3–15)	0.003
GCS≤8	58% (440)	34% (17)	<0.001
Cervical Fracture C1–C3	5.5% (42)	12.0% (6)	0.061
Cervical Subluxation	3% (23)	8% (4)	0.058
Cervical Seatbelt Sign	17.3% (131)	18.0% (9)	0.893
Basilar Skull Fracture	37.4% (284)	10.0% (5)	<0.001
Mid-Facial Fracture	33.9% (257)	14.0% (7)	0.004
Mandibular Fracture	11.6% (88)	6.0% (3)	0.225
Significant Blood Loss	1.1% (8)	0.0% (0)	0.466
Coma	0.9% (7)	2.0% (1)	0.456
Stroke on CT	6.9% (52)	2.0% (1)	0.179
Hanging Mechanism	1.3% (10)	2.0% (1)	0.686
LOS (Days)	10 (3–21)	8 (4–17)	0.697

Univariate analysis. Categorical tests complete with Pearson's Chi-Squared test, listed as percentage (N). Continuous variables assessed with Kruskal-Wallis test, listed as mean (IQR).

Table 4
Backwards stepwise logistic regression analysis of criteria factors associated with BCVI in children with blunt trauma. Odds ratios for each factor as well as significance value are listed.

Variables	Odds Ratio	Lower 95% CI	Upper 95% CI	P-value
GCS≤8	1.0113	1.0108	1.0118	<0.001
Cervical Fracture or Cervical Subluxation	1.0058	1.0052	1.0066	<0.001
Cervical Soft Tissue Injury	1.0002	0.9998	1.0006	0.212
Basilar Skull Fracture	1.0072	1.0066	1.0078	<0.001
Mid-Facial Fracture	1.0040	1.0035	1.0045	<0.001
Hemorrhage	1.0079	1.0035	1.0124	<0.001
Stroke on CT	1.0879	1.0838	1.0919	<0.001
Hanging Mechanism	1.0118	1.0083	1.0153	<0.001

Table 5
Table of pediatric patients with blunt cerebrovascular injury organized by the number of positive screening criteria present.

Number of Screening Criteria	Number of Total Patients	Number of Patients with BCVI	Percentage of Patients with BCVI
0 Criteria	322898	153	0.0%
1 Criterion	74965	224	0.3%
2 Criteria	18344	210	1.1%
3 Criteria	4872	157	3.2%
4 Criteria	979	57	5.8%
5 Criteria	115	6	5.2%
6 Criteria	8	2	25.0%
Total	422,181	809	0.2%

criteria at presentation.⁴ In a retrospective review of BCVI cases from the Denver group, Jones et al. noted absence of adult screening criteria in only 28% of patients with BCVI.²⁹ Within our study, 153 patients with BCVI presented without screening criteria (Table 5).

There appears to be benefit for an aggressive approach to screening for BCVI.^{8,30} Several studies support the efficacy of CTA use in screening for BCVI.^{31,32} However, current guidelines have not conclusively demonstrated effective utilization of healthcare resources or accounted for potential risks related to radiation exposure, as children are at higher lifetime risk for radiation-related malignancy.^{27,33–35} Studies examining the use of M-mode transcranial Doppler ultrasound show promise for the ability to safely evaluate BCVI in children, given absence of radiation risk.^{36,37} However, these studies are limited by small sample sizes and

require further examination in a broader population before large-scale implementation. Due to limitations in available data, we were unable to effectively evaluate the utilization of radiologic imaging for patients within the NTDB.

This study is limited by its retrospective nature and lack of granularity. Specifically, we are not able to define how many patients underwent radiographic imaging as a result of their injuries. However, we believe that the ability to examine the signs that are relied on for utilization of initial radiographic imaging will help providers who are deciding whether children should undergo a CTA. We hope that clarifying the poor utility of seatbelt sign in pediatric patients will increase to more judicious use of CTA and may aid in the development of better guidelines for screening children with suspected BCVI.

Conclusion

Cervical seatbelt sign is not significantly associated with blunt cerebrovascular injury in children. Many other predictors of BCVI established in adults are relevant in children. However, the clinical utility of these injuries, individually, is low. More extensive examination of clinical predictors of BCVI in children is needed to effectively identify factors more directly associated with carotid and vertebral artery injury.

Level of evidence

Level III, Retrospective Comparative Study.

Conflicts of interest

Our group has no conflicts of interest to declare.

Additional disclosure

This project was presented as an Oral Poster as part of the Rosenkrantz Competition at the American Association of Pediatrics Section on Surgery on September 16th, 2017 in Chicago, IL.

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