Risk factors for traumatic blunt cerebrovascular injury diagnosed by computed tomography angiography in the pediatric population: a retrospective cohort study

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OBJECT Computed tomography angiography (CTA) is frequently used to examine patients for blunt cerebrovascular injury (BCVI) after cranial trauma, but the pediatric population at risk for BCVI is poorly defined. Although CTA is effective for BCVI screening in adults, the increased lifetime risk for malignant tumors associated with this screening modality warrants efforts to reduce its use in children. The authors' objective was to evaluate the incidence of BCVI diagnosed by CTA in a pediatric patient cohort and to create a prediction model to identify children at high risk for BCVI.

METHODS Demographic, clinical, and radiographic data were collected retrospectively for pediatric patients who underwent CTA during examination for traumatic cranial injury from 2003 through 2013. The primary outcome was injury to the carotid or vertebral artery diagnosed by CTA.

RESULTS The authors identified 234 patients (mean age 8.3 years, range 0.04–17 years, 150 [64%] boys) who underwent CTA screening for BCVI. Of these, 24 (10.3%) had a focal neurological deficit, and 153 (65.4%) had intracranial hemorrhage on a head CTA. Thirty-seven BCVIs were observed in 36 patients (15.4%), and 16 patients (6.8%) died. Multivariate regression analysis identified fracture through the carotid canal, petrous temporal bone fracture, Glasgow Coma Scale (GCS) score of < 8, focal neurological deficit, and stroke on initial CT scan as independent risk factors for BCVI. A prediction model for identifying children at high risk for BCVI was created. A score of ≤ 2 yielded a 7.9% probability of BCVI and a score of ≥ 3 a risk of 39.3% for BCVI.

CONCLUSIONS For cranial trauma in children, fracture of the petrous temporal bone or through the carotid canal, focal neurological deficit, stroke, and a GCS score of < 8 are independent risk factors for BCVI.

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KEY WORDS cerebrovascular injury; computed tomography angiography; pediatrics; traumatic brain injury; trauma; technique

BLUNT cerebrovascular injury (BCVI) occurs in 1% of all blunt traumatic injuries in adults²¹ and in 3%–4% of patients with identified risk factors.^{4,7,20,21} These injuries may lead to ischemia and significant neurological deficits, especially in the absence of early recognition and treatment.^{8,12} Computed tomography angiography (CTA) of the head and neck has emerged as the principal modality to screen patients for BCVI during the initial trauma evaluation.^{2,7,9,11,28}

Risk factors for BCVI are well established in the adult trauma population,^{4,7,21} and studies have shown that BCVI screening in high-risk adult trauma patients may be cost effective.¹³ The Denver and Memphis criteria established a Glasgow Coma Scale (GCS) score of < 6, basilar skull fracture, diffuse axonal injury, Le Fort Type II or III facial fractures, Horner syndrome, neurological examination results incompatible with brain imaging findings, cervical spine fracture, and neck hematoma as risk factors for

ABBREVIATIONS BCVI = blunt cerebrovascular injury; CTA = computed tomography angiography; EAST = Eastern Association for the Surgery of Trauma; GCS = Glasgow Coma Scale; ICA = internal carotid artery; NPTR = National Pediatric Trauma Registry; ROC = receiver operating characteristic; TBI = traumatic brain injury; VA = vertebral artery.

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BCVI.^{4,21} Previous studies have suggested that BCVI complicates 0.03%–0.9% of traumatic brain injuries (TBIs) in children^{1,12,14,17} and that the risk factors in this population may be similar to those seen in adults;¹⁴ however, recent evidence indicates that patterns of intracranial injury observed on head CT scans in children are significantly different from the patterns observed in adults.²⁴ This relatively low incidence has led to the speculation that children with TBI are inadequately screened,¹ potentially increasing the number of children who undergo CTA.

Exposing children to radiation from CT has been directly linked to an increased risk for the development of future neoplasms, including leukemia and brain cancer.^{6,20,22} Current estimates suggest that 4.25 million CT scans are acquired in children in the United States annually, resulting in an estimated 4870 future cancers directly attributable to CT.²⁰ A retrospective cohort series found a 2.82-fold increased relative risk for brain cancer among children who underwent high-dose CT.²² It has been estimated that as many as 33% of CT scans in children are unnecessary.^{6,10,26} Head CT is the most frequent type of CT imaging performed in children, and trauma is among the most common indications for it.²⁰

Increasing awareness of the risks of radiation exposure from CT for children has led to the As Low As Reasonably Achievable (ALARA) concept,²⁶ as well as to discussion in the lay press.²³ The implementation of evidence-based clinical prediction rules in pediatric head injury has decreased unnecessary head CT scans in children at low risk for clinically significant head injury.^{15,25} We sought to define independent risk factors for BCVI specific to the pediatric population and to develop a clinical prediction rule for identifying and screening high-risk pediatric patients while decreasing potentially unnecessary CT scanning in low-risk patients.^{6,10,26}

Methods

Patient Population

We performed a retrospective review of the records of all patients who underwent CTA of the head or neck for suspected BCVI at a single pediatric Level I trauma center during an 11-year period (January 2003–December 2013). Before data collection, approval for this study was obtained from the institutional review and privacy boards.

Data Collection

The trauma registry at our hospital was queried to identify all patients who had a TBI during the period surveyed. The criteria for inclusion in the registry were at least one ICD-9-CM injury diagnostic code (800–849 for fractures, dislocations, and sprain of joints and adjacent muscles; 850–854 for intracranial injury without skull fracture; 860–869 for internal injury to chest, abdomen, or pelvis; 870–897 for open wounds of head, neck, trunk, or limbs; 900–904.99 for injury to blood vessels; 925–929.99 for crush injuries; and 940–959.9 for burns, injuries to nerves and spinal cord, and traumatic complications and unspecified injuries). In addition, patients had to meet at least one of the following criteria: hospital admission, patient transfer between hospitals via emergency medical services,

death resulting from traumatic injury independent of hospital admission or transfer status, or patient transport via air ambulance from any location. We recorded the total number of patients with TBI examined at our institution during the study period, and we also noted how many of these patients underwent a noncontrast CT of the head as part of their examination.

Next, we queried a radiological database to identify those patients who underwent screening for BCVI via CTA of the head or neck. The CTA was ordered at the discretion of the treating physician. We reviewed all relevant medical records and radiological reports and recorded demographics such as patient age, sex, and race, as well as clinical data, including injury type (penetrating injury, defined as any penetrating component, or blunt-force injury), injury event (motor vehicle accident, pedestrian struck, fall > 1 story, nonaccidental trauma, or other), initial GCS score, presence of focal neurological deficits on initial examination, mode of treatment for TBI (medical or surgical), and associated fractures. Penetrating injury was included to determine whether a penetrating component was an independent risk factor in the event of a combination of penetrating and blunt traumas.

Radiological variables recorded included the year of the CTA, institution where the CTA was performed, presence of a fracture in the petrous temporal bone, presence of a fracture through the carotid canal, fracture type (linear or comminuted), presence of injury to the internal carotid artery (ICA) or vertebral artery (VA), type of brain injury (that is, epidural, subdural, or subarachnoid hemorrhage), presence of hypodensity on images consistent with ischemia, Rotterdam score (a 6-point score, based on findings on initial noncontrast CT, that predicts the mortality rate at 6 months postinjury in moderate and severe TBI and has been validated in the pediatric population),^{18,19} and radiation dose delivered to the patient measured in dose-length product. The primary outcome was ICA or VA injury identified by CTA, classified according to the BCVI scale:³ a Grade 1 injury is characterized by intimal irregularity with < 25% narrowing, Grade 2 injury is a dissection or presence of intramural hematoma with > 25% narrowing, Grade 3 injury is the presence of a pseudoaneurysm, Grade 4 injury is an occlusion, and Grade 5 injury is transection with extravasation.³

Statistical Analysis

Data were summarized as the mean $\pm$ SD for continuous variables and count and frequency for categorical variables. Univariate statistical analysis was performed to identify the unadjusted association of CTA-diagnosed BCVI with basic demographics and with clinical and radiographic risk factors. Between-group comparisons were analyzed with the Fisher exact test and with the chi-square test for categorical variables and with the Student t-test for continuous variables. Colinearity was determined with Pearson correlation coefficients.

Multivariate logistic regression analysis was performed with 2 categories of variables: 1) those satisfying statistical entry criteria ($p < 0.2$) in the univariate analysis and 2) independent risk factors for traumatic BCVI previously identified in large adult studies, regardless of univariate

TABLE 1. Basic demographic information and results of the univariate analysis of risk factors for patients who underwent CTA screening for BCVI*

Variable	All Patients	Patients w/ BCVI	Patients w/o BCVI	p Value
Patient demographics				
No. of patients	234 (100)	36 (15.4)	198 (84.6)	NA
Mean age in yrs $\pm$ SD	8.3 $\pm$ 4.9	8.5 $\pm$ 5.1	8.3 $\pm$ 4.9	0.77
Male sex	150 (64.1)	23 (63.9)	127 (64.1)	0.98
White race	163 (69.7)	24 (66.7)	138 (69.7)	0.70
Death	16 (6.8)	5 (13.9)	11 (5.6)	0.08
Injury factors				
Injury type				0.50
Penetrating	11 (4.7)	2 (5.6)	9 (4.6)	NA
Blunt, high energy	181 (77.4)	30 (83.3)	151 (76.3)	NA
Blunt, low energy	42 (18.0)	4 (11.1)	38 (19.2)	NA
Injury event				0.33
Motor vehicle accident	60 (25.6)	11 (30.6)	49 (24.8)	NA
Struck pedestrian	37 (15.8)	8 (22.2)	29 (14.6)	NA
Fall >1 story	18 (7.7)	0 (0.0)	18 (9.1)	NA
Nonaccidental trauma	4 (1.7)	0 (0.0)	4 (2.0)	NA
Ground-level fall	42 (18.0)	4 (11.1)	38 (19.2)	NA
Penetrating	11 (4.7)	2 (5.6)	9 (4.6)	NA
Hanging	18 (7.7)	0 (0.0)	18 (9.1)	NA
Other	62 (26.5)	11 (30.6)	51 (25.8)	NA
Clinical examination				
GCS score $\leq$ 8	108 (46.2)	26 (72.2)	82 (41.4)	<0.001
Focal neurological deficit	24 (10.3)	10 (27.8)	14 (7.1)	<0.001
Imaging				
Rotterdam score >3	10 (4.3)	4 (11.1)	6 (3.0)	0.05
Any hemorrhage on CT	153 (65.4)	27 (75.0)	126 (63.6)	0.25
Cerebral infarct on CT	14 (6.0)	6 (16.7)	8 (4.0)	0.01
Epidural hematoma	31 (13.3)	5 (13.9)	26 (13.1)	0.90
Subdural hematoma	65 (27.8)	11 (30.6)	54 (27.3)	0.69
Traumatic SAH	54 (23.1)	11 (30.6)	43 (21.7)	0.28
Contusion	66 (28.2)	14 (38.9)	52 (26.3)	0.16
Associated fractures				
Petrous temporal bone fracture	18 (7.7)	5 (13.9)	13 (6.6)	0.17
Fracture through carotid canal	60 (25.6)	16 (44.4)	44 (22.2)	0.007
Other skull base fracture	37 (15.8)	6 (16.7)	31 (15.7)	0.80
Associated spine fracture	18 (7.7)	2 (5.6)	16 (8.1)	0.60
Surgical management				
Any surgical management	65 (27.8)	14 (38.9)	51 (25.8)	0.11
ICP monitoring	31 (13.2)	7 (19.4)	24 (12.1)	0.29
External ventricular drain	36 (15.4)	10 (27.8)	26 (13.1)	0.08
Craniotomy	32 (13.7)	7 (19.4)	25 (12.6)	0.30

ICP = intracranial pressure; NA = not applicable; SAH = subarachnoid hemorrhage.

* Values are presented as the number of patients (%), unless indicated otherwise.

statistical association in our data set.^{4,21} Calibration was examined using the Hosmer-Lemeshow goodness-of-fit test, and the accuracy of the multivariate model was determined by using the receiver operating characteristic (ROC) c-statistic.¹⁶ Statistical significance was established

at $p < 0.05$. We created a prediction model by converting odds ratios into integers while maintaining their individual numerical relationships.²⁷ The prediction score was dichotomized into high- and low-risk strata, using the technique described by Weinstein and Fineberg.²⁹ False-

FIG. 1. Line graph showing changes in the number of patients with TBI and of CT examinations performed during the period surveyed. While the number of patients evaluated (*dashed line*) and the number of head CT scans obtained (*dotted line*) at our institution were largely stable over time, the number of CTA studies increased dramatically during this period (*solid black line*).

positive and false-negative misclassifications were analyzed using the same method. Data were analyzed using SAS (version 9.2) software.

Results

Incidence and Diagnosis of BCVI

During the 11-year period surveyed, 6753 pediatric patients were examined for TBI, and 3782 TBI patients underwent a head CT. Among these patients, we identified 234 (mean age 8.3 years, range 0.04–17 years, 150 boys [64%]) who underwent CTA screening for a BCVI (Table

1); these patients represented 3.5% of all patients examined for trauma and 6.2% of all TBI patients who underwent a noncontrast head CT during this period. Figure 1 shows that while the number of TBI patients and head CT scans remained relatively stable over time, the frequency of CTA examinations increased during that period.

The mean radiation dose-length product in the CTA images was 649 ± 642.5 mGy-cm. Figure 2 shows the indications for a CTA; the most common indication was fracture through the carotid canal (23.5%). Twenty-four patients (10.3%) had a focal neurological deficit, and 153 (65.4%) had an intracranial hemorrhage on a head CT (Ta-

FIG. 2. Bar graph showing the various indications for CTA examination and the number of patients for each indication. CVA = cerebrovascular accident.

FIG. 3. Bar graph showing the distribution of BCVI grades of the injuries among the patients in this series. In total, 36 children had 37 BCVIs, of which 33 were injuries of the ICA and 4 of the VA.

ble 1). Thirty-seven BCVIs were identified in 36 patients, representing 15.4% of patients who underwent a CTA, 1% of patients with TBI who underwent a head CT, and 0.5% of all patients with TBI. Of these 36 patients with BCVI, 33 (91.7%) had an ICA injury and 4 (11.1%) had a VA injury (1 patient had both); 22 (59.5%) of the BCVIs were Grade 1, 11 (29.7%) were Grade 2, 2 (5.4%) were Grade 3, and 1 (2.7%) each were Grade 4 and Grade 5 (Fig. 3). Five of the 36 patients died in the hospital (representing 13.9% of patients with a BCVI identified by CTA) as did 11 (5.6%) of 198 patients who underwent CTA without an identified BCVI. Only 9 (24.3%) of the 37 BCVIs required management, consisting of antiplatelet therapy, anticoagulation, or an endovascular or open surgical procedure. All decisions to treat and on the mode of treatment were made on a case-by-case basis and involved a multidisciplinary team, including pediatric surgeons, pediatric neurosurgeons, pediatric neurologists, and endovascular surgeons.

Univariate analysis indicated that several clinical variables were significantly or almost significantly associated with a BCVI identified on CTA, including death ($p = 0.08$), a GCS score of ≤ 8 ($p < 0.001$), and a focal neurological deficit on initial examination ($p < 0.001$) (Table 1). No ICA or VA injuries were observed in patients who had hanging injuries ($p = 0.08$). Among radiographic variables, a Rotterdam score of 4–6 ($p = 0.05$), presence of a hypodensity on CT scans consistent with ischemia ($p = 0.01$), and fracture through the carotid canal ($p = 0.007$) were all significantly associated with BCVI. High-energy blunt trauma and some Memphis and Denver criteria,^{20,21} including temporal bone fracture, other skull base fractures, and spine fracture, were not significantly associated with BCVI but were included in a multivariate regression model because of their association with BCVI in adult trauma patients.

The variables and their statistical significance in multivariate regression analysis are shown in Table 2. The independent risk factors statistically significantly associated with BCVI were fracture through the carotid canal, pe-

TABLE 2. Multivariate analysis of risk factors for patients who underwent CTA screening for BCVI*

Variable	p Value	Adjusted OR (95% CI)
GCS score ≤ 8	0.020	2.9 (1.2–6.9)
Focal neurological deficit	0.004	4.6 (1.6–13.0)
Cerebral infarct on CT	0.010	5.8 (1.5–21.8)
Fracture through the carotid canal	0.002	4.3 (1.7–10.8)
Petrous temporal bone fracture	0.004	6.8 (1.9–24.6)

* Risk factors that were also analyzed but were not statistically significant ($p > 0.05$) included high-energy blunt injury, Rotterdam score > 3 , skull base fracture, spine fracture, and hanging.

trous temporal bone fracture, GCS score of ≤ 8 , focal neurological deficit, and hypodensity consistent with ischemia on initial CT scan. The area under the ROC curve for the model was 0.81, indicating a high degree of accuracy. The Hosmer-Lemeshow statistic was not significant, consistent with adequate model calibration.

Development of a Clinical Prediction Score

The results from this study cohort were used to create a prediction model (Table 3) and included the 5 variables identified as being independently associated with BCVI in our cohort (that is, a GCS of ≤ 8 , focal neurological deficit, ischemia on CT scan, fracture through the carotid canal, and petrous temporal bone fracture). According to the results of the multivariate logistic regression model, we developed the pediatric BCVI prediction score by rounding the odds ratios to the nearest integer while maintaining their relative numerical distance to one another. The newly developed score ranged from 0 (least likely to have BCVI) to 11 (most likely to have BCVI) (Table 4). The data dichotomized the cohort into a high-risk group and a low-risk group; the division into 2 groups may assist the clinician in the binary decision to screen a patient for BCVI during the initial trauma evaluation. The group of patients with a pediatric BCVI prediction score of ≤ 2 had a 7.9% probability of BCVI, whereas patients with a score of 3–11 had a 39.3% probability of BCVI. The pretest probability of BCVI identified by CTA screening

TABLE 3. Variables in the prediction model for BCVI and their assigned scores*

Variable	Score
GCS score ≤ 8	1
Focal neurological deficit	2
Carotid canal fracture	2
Petrous temporal bone fracture	3
Cerebral infarct on CT	3
All	11

* Total possible scores range from 0–11. In our study cohort, a patient with a score ≤ 2 had a 7.9% probability of BCVI, and a patient with a score ≥ 3 had a 39.3% probability.

TABLE 4. The pediatric BCVI prediction score

Score	No. of Patients	Probability of BCVI* (%)
0	92	6.5
1	56	10.7
2	30	6.7
3	37	32.4
4	9	44.4
5	7	57.1
6	2	50.0
7	0	—
8	1	100.0
9	0	—
10	0	—
11	0	—

* The probability in the study population of having a BCVI with this score; dashes in this column denote missing data due to no patients with this score (the statistical significance of the model was $p < 0.001$).

was 0.154 (15.4%). For the low-risk group (comprising patients with a score of ≤ 2), we observed a likelihood ratio of 0.47, and using likelihood ratios, a posttest probability of 0.079 (7.9%). Similarly, the likelihood ratio for the high-risk group was 3.59, and the posttest probability was 0.395 (39.5%). Practitioners should have a high level of suspicion of BCVI in patients who have a hypodensity on CT scans suggesting infarction, a petrous temporal bone fracture, a carotid canal fracture coinciding with a GCS score of ≤ 8 , a focal neurological deficit coinciding with a GCS score of ≤ 8 , or a carotid canal fracture coinciding with a focal neurological deficit.

Discussion

In this study, we retrospectively identified 234 patients who underwent head or neck CTA after a traumatic injury. A BCVI was reported in 36 (15.4%) of these patients. Multivariate regression analysis identified fracture through the carotid canal, petrous temporal bone fracture, GCS score of ≤ 8 , focal neurological deficit, and ischemia on non-contrast head CT as independent risk factors for BCVI. We created a prediction model that successfully identified children at high risk for BCVI.

Pediatric BCVI

Few previous studies have investigated BCVI in the pediatric trauma population.^{1,12,14,17} Lew and colleagues¹⁷ reviewed the National Pediatric Trauma Registry (NPTR) over a 10-year period and identified 15 cases of blunt injury to the ICA among 57,659 individuals < 19 years of age, but did not examine injuries to the VA. Two (13.3%) of the 15 patients died. Skull base fracture, intracranial hemorrhage, chest trauma, clavicle fracture, and head and chest trauma were all significantly associated with blunt ICA injury. Because the NPTR relies on ICD-9 codes, the imaging modalities used to establish the diagnoses are unknown.¹⁷

More recently, Kopelman et al.¹⁴ retrospectively reviewed cases of BCVI among more than 1200 pediatric

patients younger than 15 years examined for blunt traumatic injury at a Level I trauma center during a 5-year period. The authors analyzed risk factors according to the Eastern Association for the Surgery of Trauma (EAST) guidelines,⁷ incidence and method of evaluation, management, and outcome. Fewer than 40% of 127 patients who met the EAST criteria were screened with CTA during their initial examination; BCVI was identified in 11 (21%) of the patients who were screened.¹⁴ Overall, BCVI was identified in 0.9% of the entire cohort. This observation is in contrast with those in our study, in which BCVI was identified in 15.4% of the patients with TBI who were screened with CTA. The observed differences in these variables between our study and that of Kopelman et al.¹⁴ are small and likely reflect variation between centers in the indications for screening CTA.

Kopelman and colleagues¹⁴ concluded that the risk factors for BCVI in children are similar to those in adults and recommended applying the EAST guidelines also to the pediatric trauma population. In contrast, after retrospectively reviewing findings on intracranial CT scans in 870 adults and 336 children examined after blunt trauma at a single center, Sarkar and colleagues²⁴ reported that despite having similar GCS scores on admission, the 2 groups significantly differed in some findings. Specifically, the pediatric group was significantly more likely to present skull fracture and epidural hematoma and less likely to have a cortical contusion, subdural hemorrhage, or subarachnoid hemorrhage than the adult group.²⁴

These observations may partly be explained by divergent mechanisms of injury; however, age-specific anatomical factors may also contribute to these differences between children and adults. These findings suggest that children and adults may also have different risk factors for BCVI. Jones et al.¹² identified 45 children who had sustained blunt BCVIs and were examined after presenting at a single institution over a period of approximately 15 years. Although 72% of asymptomatic injuries met adult screening criteria, more than two-thirds of the patients who presented with acute neurological findings did not meet adult screening guidelines. The authors concluded that their data suggest that screening guidelines may need to be modified to account for the specific risk factors for BCVI in children.¹²

Lastly, in a large multicenter retrospective cohort study of 5829 children younger than 15 years who were examined for blunt traumatic injury, only 89 (16.5%) of 538 patients who met adult criteria actually underwent screening for BCVI, and 23 BCVIs were identified in these patients.¹ These data again highlight the importance of identifying specific BCVI risk factors and implementing a pediatric-specific scoring system.

In summary, we identified several independent risk factors for BCVI in a pediatric trauma cohort undergoing CTA screening for BCVI. Using these risk factors, we developed a clinical prediction rule to guide the use of CTA for evaluating pediatric patients at the highest risk for BCVI (Tables 3–4). While our results implicating petrous temporal bone fracture associated with an increased risk for BCVI in children are comparable with those from the adult population,^{4,21} we also determined that fracture

through the carotid canal was an independent risk factor in children. Our data indicate that in children, a higher GCS score cutoff should be used than in adults and highlight the significance of focal neurological deficit and ischemia on noncontrast CT, both of which are strongly and independently associated with BCVI.⁴ We did not identify patients with a BCVI attributable to spine fractures, but the external validity of this finding is limited by the small number of VA injuries in our data set.

Limitations

The limitations of this study are that we conducted a retrospective single-center study with inherent recall bias. We included only patients who underwent CTA imaging, representing only 6.2% of children with TBI who underwent a head CT. Therefore, we did not know how many patients with identified BCVI risk factors did not undergo CTA for examination. In total, 15.4% of screened patients had BCVI diagnosed on CTA scans. Patients with fractures of the petrous temporal bone and through the carotid canal were not included in our cohort if they did not undergo CTA imaging. This was especially likely during the first half of the period surveyed, when the frequency of screening was significantly lower than during the second half (Fig. 1). Further, with the exception of carotid canal fractures, we did not separately analyze different subtypes of petrous bone fracture, such as horizontal and longitudinal fractures. Le Fort II or III facial fractures, an independent risk factor for blunt BCVI in adults,^{4,21} were not analyzed in our data set and may be an important risk factor for BCVI in pediatric trauma as well. In addition, other possible risk factors including cervical soft-tissue injury and cervical pain or tenderness on examination were not included; the latter could not be assessed in the 46.2% of the study population who had GCS scores of ≤ 8 .

We developed a clinical prediction score to stratify patients to high-risk and low-risk groups. Patients with a score ≤ 2 had a 7.9% risk of BCVI, whereas patients with a score > 2 had a 39.3% risk of BCVI. A risk of 7.9% for a potentially lethal injury is still significant, and if there is strong clinical suspicion of BCVI despite a low prediction score, delayed MR angiography may be considered as an alternative screening modality that avoids radiation in lower-risk patients.^{5,28} Risk modeling in large adult populations is commonly used to guide BCVI screening in practice (with the Denver criteria);⁴ patients with no risk factors for blunt ICA injury and for whom screening is not recommended have a 20% risk for BCVI. By comparison, we have defined a pediatric population at much lower risk. We did not include patients with a vascular injury detected in a delayed fashion by another imaging modality in our data set, as it is not clear the injury would have been detected by CTA screening during the patient's initial trauma examination.

We identified only a small number of VA injuries in our series, so we cannot make definitive conclusions about the risk factors involved in these specific injuries. In our pediatric trauma registry during the period assessed, symptoms of TBI and cervical spine injury (fracture or ligamentous injury) were documented in 257 patients, of whom only 27 (10.5%) underwent CTA. Because we could not

retrospectively determine the incidence of vascular injury among patients who were not screened and whose injury may have been detected by the screening and because we did not evaluate ligamentous injury as a separate variable, our data set may have underestimated the association between spine injury and BCVI. Further, the findings of ICA or VA injury had varying clinical significance, in that only 24.3% of the BCVIs identified required management. Because our score has not been externally validated, we cannot recommend its widespread implementation; however, the risk factors used to create the score were strongly associated with BCVI in our trauma population and may be generally useful to identify children at high risk for BCVI who may benefit from CTA screening.

Conclusions

In a retrospective review of the records of 234 patients who underwent CTA screening after TBI at a single Level I pediatric trauma center in an 11-year period, we identified 5 risk factors for BCVI, including initial GCS score of ≤ 8 , fracture of the petrous temporal bone or through the carotid canal, ischemia on noncontrast head CT, and focal neurological deficit. On the basis of these data, we developed a clinical prediction rule to classify patients according to these risk factors as at low or high risk for BCVI. The prediction rule requires validation on an independent population and further prospective study.

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Author Contributions

Conception and design: Bollo, Riva-Cambrin. Acquisition of data: Ravindra, Sivakumar. Analysis and interpretation of data: Riva-Cambrin. Drafting the article: all authors. Critically reviewing the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Bollo. Statistical analysis: Riva-Cambrin. Administrative/technical/material support: Metzger. Study supervision: Bollo, Riva-Cambrin.

Supplemental Information

Proceedings

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