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ABSTRACT

BACKGROUND AND PURPOSE: Screening patients with trauma for blunt cerebrovascular injury with neck CTA is a common practice, but there remains disagreement regarding which patients should be screened. We reviewed adult blunt cerebrovascular injury data from a level 1 trauma center to investigate whether screening is warranted in low-mechanism trauma.

MATERIALS AND METHODS: We reviewed all neck CTAs performed on adult trauma patients in the emergency department during the 2019 calendar year. Clinical and imaging risk factors for blunt cerebrovascular injury, trauma mechanism, initial neck CTA interpretations, results from subsequent CTA and DSA studies, antiplatelet and anticoagulant treatments, and outcome data were recorded.

RESULTS: One thousand one hundred thirty-six neck CTAs met the inclusion criteria, of which 965 (85%) were interpreted as having negative findings; 125, as having indeterminate findings (11%); and 46, as having positive findings (4%). Review of subsequent imaging and clinical documentation led to classification of 40 indeterminate studies (32%) as true-positives and 85 (68%) as false-positives. Blunt cerebrovascular injury was identified in 77 (12.6%) cases meeting and in 9 (1.7%) cases not meeting the expanded Denver criteria. The subset of 204 low-mechanism trauma cases (ground-level falls, blunt assaults, and low-impact motor vehicle collisions) not meeting the expanded Denver criteria (18% of the entire data set) could have been excluded from screening with 1 questionable injury and 0 ischemic strokes missed and 12 false-positive cases prevented.

CONCLUSIONS: We advocate reservation of blunt cerebrovascular injury screening in low-mechanism trauma for patients meeting the expanded Denver criteria. Further research is needed to determine the behavior of indeterminate cases and to establish criteria for separating true-positive from false-positive findings.

ABBREVIATIONS: BA = blunt assault; BCVI = blunt cerebrovascular injury; FP = false-positive; GLF = ground-level fall; MVC = motor vehicle collision; TP = true-positive

Blunt cerebrovascular injury (BCVI) is a rare but increasingly recognized injury to the carotid or vertebral arteries, which may lead to ischemic stroke in trauma patients. These injuries are estimated to occur in 0.2%–3% of blunt trauma cases[1-6] and are most often asymptomatic at the time of presentation.[3,5,7] The risk of ischemic stroke may be as high as 30%,[8] though this risk significantly decreases with antiplatelet therapy.[3,5,6,8,9] The large percentage of asymptomatic cases and the margin for preventable morbidity and mortality make appropriate screening for BCVI a critical component of trauma evaluation.

Since Biffl et al,[3] in 1998, raised awareness of BCVI, it has been consistently demonstrated that a standardized approach to screening improves detection and patient outcomes, with CTA widely accepted as the preferred screening modality.[3,6,10,11] Screening criteria generally rely on clinical risk factors, such as soft-tissue injuries to the neck and neurologic symptoms worrisome for ischemic stroke, and imaging risk factors such as skull base and cervical spine fractures.[10] However, recent research has shown that accepted screening paradigms such as the expanded Denver and Memphis criteria miss 20%–50% of cases of BCVI. Therefore, more liberal and even universal screening for BCVI has been implemented at many institutions.[12-15] At our institution (Atrium Health Wake Forest Baptist), a more liberal approach to screening including all patients with "above the clavicle" injuries was implemented in 2010.[16]

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From the Wake Forest School of Medicine (K.S.H., R.A., C.S.O., N.P.P., C.P.G., S.Q.W., M.E.Z.). Winston-Salem, North Carolina; Departments of Radiology (K.D.H., C.P.G., S.Q.W., M.E.Z.), and Neurological Surgery (C.S.O., S.Q.W.), Atrium Health Wake Forest Baptist, Winston-Salem, North Carolina; and Department of General Surgery (E.C.J.), Virginia Commonwealth University Health, Richmond, Virginia.

Please address correspondence to Kevin D. Hiatt, MD, Atrium Health Wake Forest Baptist, Medical Center Blvd, Winston-Salem, NC 27157; e-mail: kehiatt@wakehealth.edu; @kdhiatt

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Table 1: The expanded Denver criteria[a]

Signs/Symptoms	Risk Factors
Potential arterial hemorrhage from face or neck	High-energy trauma mechanism with:
Cervical bruit in patient <50 yr	LeFort II or III facial fracture
Expanding cervical hematoma	Mandible fracture
Neurologic deficit inconsistent with head CT	Complex skull or skull base fracture
Stroke on CT or MRI	Severe TBI with GCS < 6
	Cervical spine fracture, subluxation, or ligamentous injury at any level
	Near hanging with anoxic brain injury
	Clothesline type injury or seat belt abrasion with significant swelling, pain, or altered mental status
	TBI with thoracic injuries
	Scalp degloving
	Thoracic vascular injury
	Blunt cardiac rupture
	Upper rib fractures

Note:—TBI indicates traumatic brain injury; GCS, Glasgow Coma Scale.
[a] Adapted from Nagpal et al.[37]

Table 2: Additional clinical risk factors recorded specific to trauma mechanism

Mechanism-Specific Risk Factors	
MVC	**Motorcycle/ATV**
Vehicle speed	Vehicle speed
Head-on collision	Head-on collision
Ejection	No helmet
Rollover	
No seat belt	
Air bags deployed	

Note:—ATV indicates all-terrain vehicle.

Inclusive screening approaches have been shown to be clinically advantageous and cost-effective[17] if the injuries identified are true injuries. However, in the case of BCVI, there is a recognized risk for false-positive (FP) results using screening CTA,[18] meaning that screening more patients may lead to more unnecessary treatment. Digital subtraction angiography (DSA) is the criterion standard test for diagnosing BCVI, but it is not performed on most trauma patients due to risk and cost;[18] therefore, neck CTA is widely relied on to determine the presence or absence of BCVI in clinical practice and in the existing literature.[10,11,19] To date, there has been little discussion of the potential for CTA findings to be ambiguous or misleading, particularly in the push for universal screening. Concerned by the frequency of CTAs ordered for low-mechanism trauma and of indeterminate CTA findings in our practice, we reviewed all adult trauma neck CTAs performed at our institution for 1 calendar year to investigate the occurrence, management, and outcomes of BCVI among patients with low-mechanism trauma and the rate at which CTA yielded ambiguous and FP results.

MATERIALS AND METHODS

We retrospectively reviewed all neck CTAs performed for traumatic indications on adult patients in the emergency department at a level 1 academic trauma center during the 2019 calendar year. This study was written in accordance with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[20] Our institutional review board approved a waiver of informed consent for this study, given its deidentified nature. Patient age and sex, study time and date, the CT scanner used, the name of the interpreting radiologist, and the times and dates of additional CT and MR imaging studies performed for the trauma evaluation were recorded for each patient. Clinical documentation and imaging reports were searched to determine whether each of the expanded Denver criteria was met (Table 1). In addition, trauma mechanism and mechanism-specific risk factors were recorded (Table 2).

For more precise classification of the mechanism of injury, we divided the ground-level fall (GLF), blunt assault (BA), and motor vehicle collision (MVC) groups into subgroups that met (GLF+, BA+, MVC+) and did not meet (GLF-, BA-, MVC-) the expanded Denver criteria. An additional, "low risk" MVC subgroup (MVC_{low}) was created, including patients who did not meet the expanded Denver criteria or other high-risk trauma attributes (vehicle speed ≥ 40 miles per hour, head-on collision, rollover, patient ejection, air bag deployment, or lack of appropriate seat belt use).

Each initial CTA was classified as negative, indeterminate, or positive on the basis of the radiology report. Indeterminate studies were further classified as having FP or true-positive (TP) findings on the basis of the interpretation of subsequent imaging studies and review of the clinical documentation. On the basis of imaging reports, an indeterminate study was labeled FP if a subsequent study determined the initially described findings unlikely to represent an acute BCVI (eg, if the finding resolved or if it persisted but the appearance favored an alternate diagnosis such as atherosclerotic disease, fibromuscular dysplasia, or remote injury) and if the report resulted in the clinical team resolving the BCVI as an active patient problem. On the basis of clinical documentation, an indeterminate study was labeled FP if the clinical team decided against assigning or treating for a diagnosis of BCVI, citing either clinical suspicion or a neurosurgery overread as grounds for reaching this decision. Studies with positive and indeterminate findings were classified using the Biffl grading system as grades I, II, III, IV, or V. For each study with indeterminate or positive findings, the timing and results of subsequent CTA and catheter angiography studies were recorded. Follow-up imaging findings were classified as improved, the same, or worse in comparison with the initial study.

Table 3. Classification of trauma mechanisms

Trauma Mechanism	No.	%
MVC	443	39.0
GLF	149	13.1
Fall down stairs	101	8.9
BA	93	8.2
MVC	88	7.8
Fall from higher than ground level	61	5.4
Penetrating injury	52	4.6
Pedestrian struck by motor vehicle	50	4.4
All-terrain vehicle or dirt bike	22	1.9
Hanging	8	0.7
Other	69	6.1

For each indeterminate and positive CTA finding, treatment and outcome data were also recorded. The starting date, dose, and duration of therapy were recorded for each antiplatelet or anticoagulant medication administered. Outcome data included notation of neurologic deficits on the discharge summary or follow-up clinic visits, the detection of emboli on transcranial Doppler ultrasound, new or worsening intracranial hemorrhage after initiation of drug therapy, extracranial bleeding complications after initiation of drug therapy (eg, gastrointestinal hemorrhage), ischemic stroke, and death.

Statistical analysis was performed using JMP software (JMP Pro Version 15; SAS Institute) with pair-wise data mean comparison performed using the Student t test. Statistical significance was defined as $P < .05$.

RESULTS

One thousand one hundred ninety-six neck CTAs were performed on adult patients in the emergency department during the 2019 calendar year, of which 1136 (95.0%) were performed for traumatic indications and were included in the analysis. Four hundred eighteen patients were women (36.8%), and the mean patient age was 51.6 years. The most common trauma mechanism was MVC ($n = 450$, 38.9%) followed by GLF ($n = 152$, 13.1%). Trauma mechanisms are further detailed in Table 3. Neck CTA was ordered as part of the initial trauma imaging bundle in 809 (71.2%) patients and was ordered after the imaging report was available for other cross-sectional imaging studies in the remainder of cases.

Neck CTAs were interpreted by a total of 12 subspecialty neuroradiologists, with each interpreting at least 50 studies. The individual rates of reporting studies with positive findings ranged from 2.0% to 7.4%, and the rates of reporting indeterminate studies ranged from 6.2% to 18.5%.

Nine hundred sixty-five neck CTAs were interpreted as having negative findings (85.0%); 125, as having indeterminate findings (11.0%); and 46, as having positive findings (4.0%) for BCVI. Of the indeterminate studies, 40 (32.0%) were classified as TPs and 85 (68.0%) were classified as FPs. The determination of a study with FP findings was made by a subsequent imaging study interpretation in 67 of 85 cases (78.9%), clinical documentation in 13 cases (15.3%), and neurosurgery overread in 5 cases (5.9%). Including the indeterminate TP cases, grade I injuries were most common, followed by grade II (Table 4).

In the 171 cases with positive and indeterminate findings, an ICA injury was reported in 114 (66.7%) and a vertebral artery injury

Table 4: Number of Biffl grade I–V injury assignments in patients with positive and indeterminate findings on neck CTAs

Group	I	II	III	IV	V
Positive studies	9	16	10	8	3
Indeterminate studies	114	6	1	3	0
TP	36	3	0	1	0
FP	78	3	1	2	0
Positive + TP	45	19	10	9	3

was reported in 82 (48%). Injury to 1 vessel was reported in 96 (56.1%), to 2 vessels in 60 (35.1%), to 3 vessels in 11 (6.4%), and to all 4 vessels in 4 (2.3%) cases. Sixty-four of the ICA injuries (56.1%) and 29 of the vertebral artery injuries (35.4%) were subsequently classified as FPs. ICA injuries were more likely to be reclassified as FPs than vertebral artery injuries ($P < .005$). There was no significant correlation between the number of vessel injuries reported in a patient and the likelihood of the patient being classified as a having FP findings.

Five hundred twenty-three cases (46%) did not meet expanded Denver criteria. Within these, 9 BCVIs (positive and indeterminate TP findings) were identified (1.7%), in addition to 30 indeterminate FPs (5.7%). Among the 613 cases meeting expanded Denver criteria, 77 BCVIs were identified (12.6%), in addition to 55 indeterminate FP findings (9%). Subgroup analysis of the GLF, BA, and MVC low-risk groups revealed 0 BCVIs and 7 indeterminate FPs in the GLF group, 1 BCVI and 2 indeterminate FPs in the BA group, and 0 BCVIs and 3 indeterminate FPs in the MVC_{low} group. The single BCVI identified in the BA group was interpreted as indeterminate and had no follow-up imaging or treatment because the patient was lost to follow-up. The patient re-emerged about 1 year later, at which time neuroimaging showed no evidence of prior ischemic infarct. Repeat vascular imaging was not performed. Due to the case ambiguity and the documented intent to treat the patient, it was classified as a TP, but it remains unclear whether this was a true injury. Altogether, 204 of 1136 cases (18%) or 39% of the cases not meeting the expanded Denver criteria could have been excluded from screening neck CTA with only 1 questionable injury missed and 12 indeterminate FPs prevented (Online Supplemental Data).

At least 1 follow-up CTA was performed for 130 of the 171 studies with positive and indeterminate findings (76%), with the first follow-up CTA performed at a median of 2.1 days following the initial study. Seventy-nine studies (60.8%) showed improvement in the initial imaging finding, 49 (37.7%) demonstrated no change, and 2 (1.5%) showed progression. The 2 cases demonstrating progression were both initially classified as having grade IV injuries. DSA was performed in 13 cases (7.6%), with stenting performed in 4, angioplasty in 1, and vessel sacrifice in 2 cases.

Fifty-seven of the 86 cases with positive and TP findings (66.3%) were treated with aspirin (28 with 81 mg daily, 11 with 162 mg daily, and 18 with 325 mg daily) and 9 (10.5%) were additionally treated with clopidogrel (75 mg daily). Eighteen of the 85 indeterminate FP cases (21.2%) were treated with aspirin, and zero were treated with clopidogrel, with aspirin typically discontinued once the injury was determined to be a FP unless aspirin was required for a separate indication. The median duration of aspirin therapy in the cases in which it was discontinued was 3 days.

In the 86 cases with positive and TP findings, ischemic stroke occurred 3 times (3.5%) compared with 0 times in the cases with 85 FP findings ($P = .08$). Death occurred in 18 of the patients with positive and TP findings (20.9%) and in 3 of the cases with FP findings (3.5%; $P < .005$). Worsening intracranial hemorrhage after admission was observed in 5 patients with positive and TP findings (5.8%) and in 2 patients with FP findings (2.4%; $P = .26$). No instances of bleeding outside the CNS (eg, gastrointestinal bleeding) were reported to have developed after initiation of antiplatelet therapy in any of the patients studied.

DISCUSSION

High-sensitivity screening for BCVI is important in adult trauma patients because of the high percentage of patients who are initially asymptomatic and the potential to decrease the rates of ischemic stroke, permanent disability, and death with appropriate management.[3-6,8,9,11] The reported high rate of BCVI missed by established screening algorithms such as the expanded Denver criteria has led many to advocate for universal screening.[12-15,17,21,22] In our data set, 10.5% of BCVIs were not captured by the expanded Denver criteria, even after excluding cases determined to be FPs. However, the potential benefit from expanded screening should be balanced against the risks, which include the potential adverse effects of antiplatelet or anticoagulant treatment, extended hospital stays, iodinated contrast material–related reactions and renal injuries, radiation exposure, and increased cost to patients and health care systems.[23-26]

Trauma mechanism is a useful consideration in the selection of patients for BCVI screening because high-mechanism trauma portends an increased risk for BCVI, even in the absence of other identifiable injuries.[7,27,28] Conversely, low-mechanism trauma confers a very low risk for BCVI, particularly in the absence of other risk factors. We focused on GLF, BA, and low-impact MVC as low mechanism injuries due to concern from our practice that patients presenting with these mechanisms are overscreened. First, we defined low-risk GLF injuries as those not meeting the expanded Denver criteria. In a retrospective review of >1.2 million trauma cases in elderly patients (65 years of age or older), Anto et al[29] discovered the overall incidence of BCVI among patients with GLFs to be 0.15%. Among the subset of patients with ≥1 risk factor, the incidence was significantly higher at 0.86%. Although not directly reported, the incidence of BCVI among elderly patients with GLFs with no risk factors calculated from their data set was 0.07%. Anto et al and others have reported low rates of screening in elderly patients with GLFs as well as increased morbidity and mortality in elderly compared with young patients with GLFs with BCVI,[29-32] but there is little justification for screening patients with GLFs without risk factors for BCVI in the existing literature. Second, in the absence of a literature precedent for uniquely classifying BA injuries to define BCVI risk, we chose to define low-risk BA injuries as those not meeting the expanded Denver criteria. Finally, stratifying MVCs into high and low impact can be challenging, particularly when history is lacking, but when possible, we defined low-impact MVCs as those with a vehicle speed of <40 miles per hour, no airbag deployment, appropriate seatbelt use, and no head-on collision, rollover, or patient ejection, mirroring the criteria outlined by Farhat-Sabet et al[27] (though we selected 40 miles per hour instead of 40 km/hour as our speed threshold).

In support of trauma mechanism as a useful discriminator in selecting patients for BCVI screening, we identified 204 cases of low-mechanism trauma (GLF, BA, and low-impact MVC) not meeting the expanded Denver criteria, among which 1 questionably TP and 12 FP BCVIs were encountered. In other words, 18% of our data set could have been excluded from BCVI screening with only 1 questionable injury missed. The cost savings of excluding these 204 studies would have been $51,571.20 US dollars (at our calculated institution-specific price for performing and interpreting a neck CTA of $252.80), though the savings are likely much greater when considering the elimination of unnecessary follow-up imaging studies, neurosurgical consultations, patient treatment, and prolonged in-hospital patient evaluation. A future dedicated cost analysis would be useful to better determine the expense of overscreening.

The existing literature largely accepts confirmation of BCVI on CTA, given that catheter angiography is not commonly performed. However, the weaknesses of CTA are well-established in studies comparing CTA with DSA. Several have reported a mediocre sensitivity of CTA in comparison with DSA ranging from 51% to 74%.[33-35] While the same studies have reported the high specificity of CTA for BCVI ranging from 86% to 95%, a separate study by Grandhi et al[18] reported a CTA FP rate of 48% compared with DSA. Because DSA was not available for most of our data set and was only performed to further evaluate or treat cases with positive findings, we cannot determine our CTA false-negative rate. However, 68% of CTA studies interpreted as indeterminate in our study were determined to be FPs based on clinical documentation and follow-up imaging results. Certainly, the reporting of indeterminate BCVI may vary widely among institutions, across levels of radiologists' experience and training, and even in the same interpreting radiologist across time. Reporting variability is demonstrated by the approximately 3-fold variability in rates of reporting cases positive for BCVI (2%–7.4%) and indeterminate for BCVI (6.2%–18.5%) among our 12 neuroradiologists. The importance of indeterminate interpretations is in the subsequent practice of repeating a follow-up neck CTA to confirm resolution or the need for ongoing treatment, which doubles the cost and risk exposure to contrast material and radiation.

There is, unfortunately, a paucity of literature addressing indeterminate BCVI. Crawford et al[36] identified 59 indeterminate BCVIs from a set of 138 non-negative neck CTAs obtained for trauma (43%). Of these indeterminate cases, 23 resolved, 21 remained indeterminate, and 15 were reclassified as true BCVIs on subsequent imaging, though it is unclear from their research whether this reclassification necessarily resulted from a worsening of imaging findings. Our rate of indeterminate studies was higher than what they reported (73% of our non-negative cases were indeterminate), highlighting a likely wide variability in the reporting of BCVI among radiologists. The new implementation of standardized wording for indeterminate BCVI at our institution just prior to the time period of the data set we studied may have also led to an increased rate of reporting indeterminate injuries. None of our indeterminate cases demonstrated progression on follow-up imaging studies, with at least 1 follow-up CTA obtained in 76% of cases.

Ischemic infarct and death are commonly reported outcome measures in patients with BCVI. The stroke rate among patients with positive and TP findings in our study of 3.5% is comparable with rates reported in the literature.[1,5,8,9] Among patients with FP findings, the stroke rate was 0%. The mortality rate among patients with positive and TP findings in our study of 20.9% represents an all-cause mortality rather than mortality directly attributable to BCVI. There was a significantly lower mortality rate in patients with FP compared with those with positive/TP findings, though the small number of observed ischemic infarcts and deaths in this data set limits cross-group comparisons.

Our study has several limitations. Due to its retrospective nature, the set of cases obtained reflects the ordering biases of a heterogeneous group of emergency and trauma surgery physicians. Although standardized algorithms aim to make practice more uniform, differing approaches among ordering physicians breed heterogeneity. Additionally, the interpreting radiologists had access to data about the trauma mechanism and were aware of the presence or absence of injuries predisposing to BCVI, such as cervical spine fractures. These data likely impacted study interpretation. Unfortunately, even in a blinded study environment, it would be difficult to shield interpreting radiologists from imaging risk factors for BCVI including cervical, skull base, facial, and upper rib and thoracic vertebral fractures because these are often apparent on the neck CTA. Finally, our division of indeterminate cases into TP and FP relied on the opinions of interpreting radiologists and clinical teams, which are not immune to error. However, all cases benefited from subspecialty neuroradiologists' interpretations and patient assessment by a dedicated trauma surgery service at a level 1 trauma center.

CONCLUSIONS

More inclusive approaches to BCVI screening offer greater sensitivity at the expense of increased cost to the medical system, increased radiation and contrast media exposure to patients, and an increased number of FP results leading to unnecessary treatment. Within a liberal screening system using "above the clavicle" injuries as the inclusion criterion, we identified 204 low-mechanism trauma cases not meeting the expanded Denver criteria during 1 calendar year, among which only 1 questionable BCVI and 12 studies with FP findings were identified and no ischemic strokes occurred. We, therefore, advocate reservation of BCVI screening for low-mechanism trauma patients (including GLFs, BAs, and low-impact MVCs) to those meeting the expanded Denver criteria, meaning that neck CTA should not be routinely included as part of the initial trauma imaging bundle in these patients. Additionally, we found a high rate of indeterminate studies (73% of all non-negative studies in our data set), among which 68% had FP findings. More research is needed to better elucidate the behavior of indeterminate injuries and to establish standards for distinguishing studies with TP from those with FP findings.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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