# Blunt Cerebrovascular Injury Screening With 32-Channel Multidetector Computed Tomography: More Slices Still Don't Cut It

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**Objective:** We sought to determine the diagnostic accuracy of computed tomographic angiography (CTA) using 32-channel multidetector computed tomography for blunt cerebrovascular injuries (BCVIs).

**Background:** Unrecognized BCVI is a cause of stroke in young trauma patients. Digital subtraction angiography (DSA), the reference standard, is invasive, expensive, and time-consuming. Computed tomographic angiography has been rapidly adopted by many institutions because of its availability, less resource intensive, and noninvasive nature. However, conflicting results comparing CTA and DSA have been reported. Studies with 16-channel CTA report a wide range of sensitivities for BCVI diagnosis.

**Methods:** From January 2007 through May 2009, patients with risk factors for BCVI underwent *both* CTA and DSA. All CTAs were performed using a 32-channel multidetector CT scanner. Using DSA as the reference standard, the diagnostic accuracy of CTA for determination of BCVI was calculated.

**Results:** There were 684 patients who met the inclusion criteria. Ninety patients (13%) had 109 injuries identified; 52 carotid and 57 vertebral injuries were diagnosed. CTA failed to detect 53 confirmed BCVI, yielding a sensitivity of 51%.

**Conclusion:** Given the devastation of stroke, and high mortality from missed injuries, this study demonstrates that even with more advanced technology (32 vs 16 channel), CTA is inadequate for BCVI screening. Digital subtraction angiography remains the gold standard for the diagnosis of BCVI.

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Before widespread screening for blunt cerebrovascular injury (BCVI), many patients suffered stroke because of unrecognized injuries. This complication is particularly devastating, because trauma disproportionately occurs in the young people. Now, with more aggressive screening, BCVI is identified in up to 2% of blunt trauma patients.[1–4] Screening for BCVI allows for early detection and prompt intervention. Untreated BCVI results in stroke rates of 30% to 50%. However, early intervention improves the prevalence of stroke to less than 10% in many series.[1,5–8] Despite the apparent benefits of early screening, there continues to be much debate regarding the optimal screening modality for BCVI.

Digital subtraction angiography (DSA) has long been the reference standard for screening, identifying, and treating BCVI. However, it is invasive and requires a substantial investment of personnel and time. Risks of DSA include access-site hematomas and injuries, complications from sedation, renal failure due to contrast, and the potential to cause strokes. These complications are rare, and the incidence in the trauma population is not well-defined. Complication rates for DSA are generally reported in elderly populations that undergo the study after neurologic symptoms develop. These patients have widely distributed atherosclerotic disease, which increases both cerebral and access-site complications. In 2005, Cothren et al[9] demonstrated that DSA screening for BCVI is appropriate and cost-effective because of the high stroke and death rate with undetected BCVI.

Many institutions have adopted computed tomographic angiography (CTA) to replace DSA for BCVI screening. The reasons for this rapid acceptance of CTA are due to several perceived advantages. Computed tomographic angiography is less invasive than DSA and can be performed in nearly every hospital. It is less resource-intensive and can be performed during the initial trauma evaluation resulting in a decreased time to diagnosis of BCVI.[10] However, the potential benefits of CTA are negated if it is inaccurate.

In the past year, both the Eastern Association for the Surgery of Trauma (EAST) and Western Trauma Associations (WTA) have made recommendations regarding BCVI screening.[11,12] Both organizations acknowledge the role of DSA as the reference standard, but suggest that 16-channel CTA may be an acceptable screening modality. These recommendations are based on 6 reports using 16-channel CTA, which reported a wide range of sensitivity.[3,13–17] Only 2 of those studies performed both DSA and CTA on the majority of screened patients, with somewhat disparate sensitivities of 74% and 98%.[13,14] Two subsequent reports, not considered in the EAST or WTA guidelines, that use 16- and 64-channel CTA and perform DSA on all patients, report 41% and 64% sensitivities.[2,18] Concerns regarding CTA as the sole screening modality for BCVI are highlighted in literature reviews. Anaya et al[19] reported an overall sensitivity of only 76.8% for detecting BCVI. Those reports are difficult to interpret because not all patients underwent both CTA and DSA, and they include many generations of CT scanner technology.

Sensitivity is the key feature of a screening test that determines the capability to replace the reference standard. Sensitivity can only be determined when CTA and DSA are performed on all patients. Many studies that support CTA as an adequate screening test did not perform DSA on all patients and therefore cannot accurately determine sensitivity. Despite this, many institutions have adopted CTA to replace DSA. In this study, we sought to determine the diagnostic accuracy of CTA using 32-channel multidetector computed tomography (MDCT) in a large series of trauma patients at risk for BCVI.

## METHODS

Institutional review board approval from the University of Tennessee Health Science Center was obtained for this retrospective study. Patients admitted to the Presley Memorial Trauma Center between January 2007 and May 2009, screened for BCVI using DSA, were identified by Current Procedural Terminology (CPT) codes (37215, 37216, 75650, 75662, 75671, 75680, and 75685).

### Data Collection

Hospital records were reviewed to obtain patient demographics, mechanism of injury, indications for BCVI screening, results of CTA and DSA, complications, strokes, and in-hospital mortality.

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Attending neuroradiologist interpretations of CTA and DSA were used to determine BCVI or other abnormalities. Computed tomographic angiography studies with a compromised examination because of a poor contrast load, timing, or patient factors were noted. Location and severity of BCVI on CTA and DSA were recorded. Digital subtraction angiography reports were used to assign injury grade based on established grading criteria.[8,13,20] *Grade I injuries* are defined as vessel wall irregularity or dissection/hematoma with less than 25% lumen stenosis. Grade II injuries include an intimal flap, intramural thrombus, or dissection with greater than 25% narrowing. Grade III and IV injuries are pseudoaneurysms and occlusions, respectively. Grade V injuries are transections or arteriovenous fistulas. Digital subtraction angiography complications including puncture site bleeding or hematoma, groin vessel injury, or iatrogenic cerebrovascular injury were identified in nursing, operative, and radiology notes. Ischemic and hemorrhagic strokes diagnosed by CT or magnetic resonance imaging (MRI) were recorded.

Patient creatinine levels at admission, after angiography, in-hospital maximum, and at discharge were recorded. N-acetylcysteine, 4 doses of 600 mg every 12 hours, was given to patients at high risk for contrast-induced nephropathy with one of the following: age greater than 55, creatinine greater than 1.4 mg/dL, glucose greater than 175, history of diabetes treatment, blood transfusion, nonrami pelvis fracture, or more than 1 long bone fracture. *Renal insufficiency* was defined as a creatinine increase of 0.5 mg/dL or 25% compared to admission in patients with any value greater than 1.0 mg/dL that survived to discharge.[21,22]

## Blunt Cerebrovascular Injury Screening

Blunt cerebrovascular injury screening was performed for the following indications: cervical spine fracture, neck soft tissue injury, basilar skull fracture, Le Fort II or III fracture, Horner syndrome, or an unexplained neurologic deficit, as previously described.[6] Patients underwent CTA at the time of initial trauma evaluation for suspected head, face, or neck injuries. Digital subtraction angiography was generally performed in the morning after overnight trauma evaluations or at the earliest available time. Digital subtraction angiographies were performed by interventional neuroradiologists. Neurosurgery consultation was obtained when a BCVI was diagnosed on DSA or suspected on CTA. Management of BCVI, with consideration of coexistent injuries, was performed by the multidisciplinary team of trauma surgery, neurosurgery, and interventional radiology. The general treatment algorithm was antiplatelet therapy for occluded vessels or small dissections. Patients with pseudoaneurysms and complex dissections were anticoagulated with heparin (partial thromboplastin time PTT goal, 40–60 seconds) followed by endovascular stenting. Patients were loaded with clopidogrel 300 mg the day before stenting. Aspirin (325 mg) and clopidogrel (75 mg) were given daily after stent placement.

## Computed Tomography

Toshiba Aquilion 32-channel computed tomography scanners (Tokyo, Japan) were used for all trauma evaluations. The sequence of examinations was performed to minimize contrast load. Patients were positioned with arms down to the side. Patients underwent head and cervical spine studies without contrast. Scout images were obtained and the carotid vessels identified. Ioversol injection (74%) at 4 mL/sec was given. When a contrast blush was noted at the origin of the carotids, the CTA scan was initiated from the clavicles and continued to the apex of the calvarium. The data were acquired at 1.0-mm thick slices at 0.5-mm intervals. Patients requiring body imaging had their arms raised and the body imaging completed. Digital reconstruction was performed immediately after completion of CT scans. Axial and coronal images were reconstructed at 2-mm by 2-mm intervals whereas sagittal images were at 1 mm by 1 mm. Typical contrast volume of 120 mL was administered when both body and CT scans were performed.

## Digital Subtraction Angiography

Digital subtraction angiography of the head and neck was performed using Siemens AXIOM Artis biplane system (Malvern, Pennsylvania, PA). The common femoral artery was accessed using the Seldinger technique. Angiography of each carotid and vertebral vessel was performed. Ioversol injection (68%) contrast was used for DSA, with typical volumes of 50 to 100 mL. Attending neuroradiologists performed all DSA.

## Statistics

Digital subtraction angiography results were evaluated for BCVI in each of the vessels: right carotid, left carotid, right vertebral, and left vertebral. Each vessel on CTA was categorized as true positive, true negative, false positive, or false negative depending on the correlation with DSA. Abnormalities on CTA that were not clearly called an injury by the radiologist (eg, nonvisualization of vertebral artery) were considered indeterminate for BCVI. Poor quality CTA due to movement, artifact, or inadequate contrast was also considered an indeterminate study. As this was an evaluation of a screening test, indeterminate CTA results were considered an injury for calculation of sensitivity, specificity, and accuracy. All data were analyzed using PASW statistics 18.0 (SPSS Inc, Chicago, IL) and Microsoft Excel 2008 (Microsoft, Redmond, WA). $\chi^2$ tests were performed on categorical variables and student $t$ test was performed on continuous variables, a $P$ of less than 0.05 was considered significant.

# RESULTS

## Study Population

Approximately, 20,000 blunt trauma patients underwent evaluation by the trauma service during the 29-month study period. There were 684 patients who met one or more criteria for BCVI screening and underwent both CTA and DSA. Ninety patients had 109 injured vessels: 52 carotid artery injuries and 57 vertebral artery injuries. Overall, BCVI occurred in 0.5% of blunt trauma patients and 13% of screened patients. Comparisons of patients *with* and *without* BCVI are displayed in Table 1. The gender ratio of the screened population mirrors the general trauma population, with males 2- to 3-fold greater than females. Notably, 41% of the patients with BCVI were women ($P = 0.022$). Motor vehicle collisions and pedestrians struck by vehicles were the most common mechanisms associated with BCVI ($P = 0.007$). The mean length of stay and intensive care unit (ICU) days were greater for patients with BCVI ($P < 0.001$). In addition, the median length of stay also increased from 7 to 13 days and the median ICU days increased from 3 to 7. Table 2 demonstrates the indications for screening and the incidence of BCVI by indication. More than half of the patients were screened for cervical spine fractures, which were more strongly associated with vertebral injuries. The other indications were more associated with carotid injuries (Fig. 1). One hundred of the patients had 2 or more indications for screening for BCVI.

The grade and location of the 109 injuries are demonstrated in Table 3. There was a relatively even distribution among the 4 vessels. The vast majority of injuries were grade II to IV. Pseudoaneurysms (grade III) generally occurred in carotid arteries and occluded vessels (grade IV) predominately in vertebral arteries.

## Diagnostic Accuracy of CTA

The sensitivity of CTA, with DSA as the reference standard, is demonstrated in Table 4. Of the 2736 vessels evaluated (684 patients, each with 4 vessels), there were 128 misdiagnosed on CTA. Some

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**TABLE 1.** Patient Characteristics and Outcomes With and Without Blunt Cerebrovascular Injury (BCVI)

| Patient Characteristics | No BCVI n = 594 | BCVI n = 90 | *P* |
|---|---|---|---|
| Average age | 39 (14–90)* | 39 (15–92)* | 0.900 |
| Gender | | | |
| Male | 421 (71) | 53 (59) | 0.022 |
| Female | 173 (29) | 37 (41) | |
| Race | | | |
| White | 324 (55) | 52 (58) | 0.315 |
| African American | 227 (38) | 36 (40) | |
| Hispanic | 29 (5) | 2 (2) | |
| Other | 14 (2) | 0 (0) | |
| Injury mechanism | | | |
| Motor vehicle collision | 385 (65) | 76 (84) | 0.007 |
| Fall | 64 (11) | 2 (2) | |
| Motorcycle collision | 41 (7) | 2 (2) | |
| Assault | 38 (6) | 3 (3) | |
| Pedestrian struck | 23 (4) | 6 (7) | |
| All terrain vehicle | 22 (4) | 0 (0) | |
| Hanging | 13 (2) | 1 (1) | |
| Crush | 3 (0.5) | 0 (0) | |
| Other | 5 (1) | 0 (0) | |
| Injury severity score | 22 (1–75)* | 28 (9–75)* | <0.001 |
| Admission GCS | 12 (3–15)* | 12 (3–15)* | 0.440 |
| **Outcomes** | | | |
| Length of stay—average days | 13 (0–203)* | 19 (0–81)* | <0.001 |
| Intensive Care Unit—average days | 7 (0–105)* | 13 (0–78)* | <0.001 |
| Average no. of angiograms | 1 (1–2)* | 2 (1–4)* | <0.001 |
| Angiogram complications | 7 (1) | 1 (1) | 0.566 |
| Renal insufficiency | 23 (4) | 4 (4) | 0.795 |
| Stroke | 8 (1) | 13 (14) | <0.001 |
| In-hospital mortality | 31 (5) | 9 (10) | 0.072 |

Values in parenthesis are percents.
*Designates a range.

patients had a CTA that indicated an injury in 1 vessel and were found on DSA to have a different vessel injured. Therefore, the CTA findings were incorrect in both locations, a false positive and a false negative. The CTA sensitivity for individual vessels is 51% overall, 50% and 53% for carotid and vertebral vessels, respectively. The specificity, positive predictive value, negative predictive value, and accuracy are 97%, 43%, 98%, and 95%, respectively.

Table 5 details the BCVI grade and location(s) for the 42 patients with any false-negative result on CTA. There were 53 injuries not identified on CTA. More than half of these patients received an endovascular intervention and 1 patient died before definitive therapy. In total, 6% of the patients with a normal CTA had a BCVI found on DSA. Women had more missed injuries (false negatives) on CTA than men ($P = 0.003$), with a sensitivity of 45% compared to 56% for men.

Thirty-eight CTA studies (6%) were noted to have inadequate quality when evaluated by a staff radiologist. Reasons for inadequacy included poor contrast bolus or timing, patient habitus or movement, and artifact. Figure 2 shows the CTA and DSA finding of the 646 patients with good quality CTAs. Only 3 patients with a false-negative CTA had an inadequate study. When the poor quality examinations are censored, the sensitivity only improves to 52%, compared to 51% when all patients are included.

**TABLE 2.** Frequency of Digital Subtraction Angiography Proven Blunt Cerebrovascular Injury by Screening Indication

| Screening Indication* | Patients Screened (n) | Patients With BCVI (n) | Patients With BCVI (%) |
|---|---|---|---|
| Cervical spine fracture | 398 | 57 | 14 |
| Neck soft tissue injury | 133 | 19 | 14 |
| Skull base fracture | 117 | 16 | 14 |
| Le Fort fracture | 76 | 8 | 11 |
| Horner syndrome | 45 | 9 | 20 |
| Other neurologic deficit | 29 | 7 | 24 |
| Total | 684 | 90 | 13 |

*Some patients had more than one indication for screening.

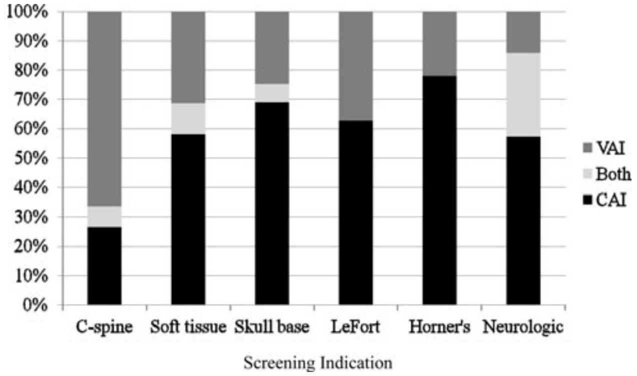

**FIGURE 1.** The relative ratio of carotid and vertebral injuries by screening indication.

## Digital Subtraction Angiography–related Complications

There were 764 DSA performed in the 684 patients for diagnosis, treatment, and follow-up of BCVI. There were 8 procedure-related complications of DSA (1.0%) in all patients; 4 were puncture site hematomas. No hematomas progressed to pseudoaneurysm or arteriovenous fistula. The 4 major complications (0.5%) include 3 femoral vessel occlusions due to closure devices, which required surgical repair. One iatrogenic dissection of a vertebral artery occurred and was subsequently stented. There were no strokes attributable to DSA. No allergic reactions to contrast administration were identified.

Renal insufficiency occurred in 27 patients and none required hemodialysis. Patients with renal insufficiency were older and more severely injured than the screened population as a whole. The average age for patients with renal insufficiency was 49 years and the median LOS and ICU days were 28 and 20 days, respectively. Of the 27 patients with renal insufficiency, only 7 were discharged with a creatinine that was higher than admission. In these patients mean discharge creatinine was only 1.2 (range, 0.8–1.7). The other 20 patients had a transient rise in creatinine but were discharged with a lower creatinine than admission.

## Treatments and Outcomes of Blunt Cerebrovascular Injury

In the 90 patients with BCVI, treatment was dependent on location and severity. Four patients died before definitive treatment with significant coexisting injuries. Fifty percent of patients had only

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**TABLE 3.** Blunt Cerebrovascular Injury by Grade and Location

| | Grade I Small dissection | Grade II Dissection>25% | Grade III Pseudoaneurysm | Grade IV Occlusion | Grade V Transection/Fistula | Total |
|---|---|---|---|---|---|---|
| Right CAI | 6 | 5 | 13 | 0 | 1 | 25 |
| Left CAI | 2 | 8 | 13 | 2 | 2 | 27 |
| Right VAI | 2 | 10 | 2 | 13 | 0 | 27 |
| Left VAI | 3 | 8 | 3 | 16 | 0 | 30 |
| Total BCVI | 13 | 31 | 31 | 31 | 3 | 109 |

CAI indicates carotid artery injuries; VAI, vertebral artery injuries.

**TABLE 4.** Sensitivity of Computed Tomography Angiography

| | | No Injury (DSA−) | | Injury (DSA+) | | |
|---|---|---|---|---|---|---|
| | No. of Vessels | (CTA−) TN | (CTA+) FP | (CTA−) FN | (CTA+) TP | Sensitivity (%) |
| Overall | 2736 | 2552 | 75 | 53 | 56 | 51 |
| Carotid | 1368 | 1286 | 30 | 26 | 26 | 50 |
| Vertebral | 1368 | 1266 | 45 | 27 | 30 | 53 |

TN indicates true negative; FP, false positive; FN, false negative; TP, true positive.

medical treatment with anticoagulation or antiplatelet therapy (Fig. 3). Forty-one patients (46%) had endovascular interventions with coils, stents, or both. Thirteen patients with BCVI developed a stroke, for a stroke rate of 14% (Table 1). Nine strokes were present on arrival, 3 developed secondary to anticoagulation, and 1 was an ischemic stroke in a patient with all 4 vessels injured, who later progressed to brain death. Five of the strokes occurred in patients with multiple vessels injured. All 3 patients that developed hemorrhagic strokes while on anticoagulation had associated closed head injuries. Nine patients with BCVI did not survive to hospital discharge. The mortality rate for a single BCVI was 7% and nearly doubled to 13% when 2 or more vessels had a BCVI.

## DISCUSSION

Digital subtraction angiography has long been the reference standard for BCVI diagnosis. Many studies have been done that compare CTA to DSA. However, most do not use both diagnostic modalities in all patients; therefore, true sensitivities cannot be determined. Reports comparing DSA to CTA that focus on the overall accuracy and specificity of CTA do not address the fundamental issue. Only sensitivity measures the adequacy of a screening test. Low sensitivity corresponds to high levels of false-negative test results, leaving many patients at risk of preventable sequelae. Some publications report excellent sensitivity but obtain the gold standard test only on patients with a positive result on CTA. This falsely elevates sensitivity, and confidence in the test, which misses many injuries. If patients with a negative CTA do not undergo DSA, missed injuries cannot be identified. Reports of high sensitivity may also be falsely elevated because of retrospective review of CTA. For example, one study reports that CTA was originally read as negative but after the patient had a massive posterior stroke and DSA confirmed BCVI, the CTA was reread and the injury could be seen. Therefore, this was not reported as a missed injury.[23] That patient progressed to death.

Several smaller studies report sensitivity when CTA and DSA were performed on the majority of patients. Eastman et al[14] reported 98% sensitivity in 146 patients screened using 16-channel scanners. Malhotra et al[13] also performed CTA and DSA on 92 patients and found a sensitivity of 74%. The authors noted that when the study was divided in 2 eras, CTA in the second half did not miss any BCVI, theorizing that there was a learning curve by the radiologists reading the CTAs.[13] A diagnostic examination with 98% to 100% sensitivity would be an excellent screening tool. Unfortunately, subsequent studies have failed to reproduce these results.

Two more recent studies, which performed both CTA and DSA, were not taken into account in the EAST or WTA guidelines for BCVI screening. These demonstrate disturbingly low sensitivities. Sliker et al[18] reported that 77 patients screened with sensitivity 64%. Goodwin et al[2] screened 158 patients with 16- and 64-channel CT scanners. These authors found that with the improvements in technology, sensitivity increased from 29% to just 54%.[2] The 4 studies that performed both DSA and CTA total less than 500 patients screened and have an averaged sensitivity of 73%.

In the current study with nearly 700 patients, 49% of BCVI were not detected with CTA. The exclusion of poor quality CTA examinations did not change the accuracy of the test. The location and severity of the missed injuries makes it unlikely that all would have remained asymptomatic (Table 5). Seventy-nine percent of the missed injuries were grade II and above. Many studies that selectively use DSA only for positive CTA, report no "in-hospital" symptoms as a surrogate for detecting missed injuries.[3,15–17,23] However, many patients with BCVI tend to be severely injured in which neurologic deficits may be attributed to concomitant head injury, rather than a missed BCVI. Alternately, patients who develop neurologic complications after discharge are not captured with that study design. Some patients may be discharged within hours and therefore the window to detect symptoms from missed BCVI is very small. This underscores the importance of having a reliable screening tool for serious injures.

Because the rapid adoption of CTA as a screening tool, several centers have begun to treat patients on CTA diagnosis of BCVI. There are 2 important considerations with treating patients on the basis of CTA results. First, many patients will be missed because of the low sensitivity. Second, there were 75 false positives in this study. Some patients had a false positive in 1 vessel and a false negative in another. By treating patients on the basis of CTA results and not doing a confirmatory DSA, many patients will be missed all together and others would have inappropriate therapy.

All diagnostic modalities should be evaluated to ensure that the benefits of the test outweigh the risks of the procedure. Digital subtraction angiography may be perceived as an invasive test, with too many complications, to be used for screening. In this series, with 764 DSA performed, there was a 1.0% complication rate. Half of the complications were minor, access-site hematomas, where no intervention was necessary. The major complication rate was only 0.5%. Weighed against the potential for devastating stroke or death because of an unrecognized BCVI, we believe that the risks of DSA are acceptable. There were no strokes attributable to DSA and no allergic reactions to contrast medium found in nearly 700 patients. The additional contrast needed for DSA did not appear to have any significant impact on renal

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**TABLE 5.** Injury Location, Severity, and Treatments of the 42 Patients With 53 False-negative Computed Tomography Angiograms

| Patient | | Injury Grade | | | | Missed Injuries (n) | Treatment |
|---|---|---|---|---|---|---|---|
| Age | Gender | R CAI | L CAI | R VAI | L VAI | | |
| 40 | F | 2 | 3 | — | 2 | 3 | Stents X 3 locations |
| 54 | M | 3 | (3) | 2 | 3 | 3 | Stents X 3 locations |
| 21 | M | 1 | — | 1 | — | 2 | Repeat DSA |
| 21 | M | 2 | (2) | — | 2 | 2 | Stents X 2 locations |
| 31 | F | — | 2 | — | 2 | 2 | Stent |
| 38 | F | 3 | 3 | — | — | 2 | Stents X 2 locations |
| 39 | F | 3 | 3 | — | — | 2 | Stents X 2 locations |
| 49 | F | — | — | 2 | 1 | 2 | Stent |
| 63 | F | 3 | 3 | — | — | 2 | Stent |
| 18 | F | — | 3 | — | — | 1 | Stent |
| 18 | F | 3 | — | — | — | 1 | Stent |
| 20 | M | — | — | — | 3 | 1 | Repeat DSA |
| 20 | M | — | — | 4 | — | 1 | Medical |
| 21 | M | — | — | — | 1 | 1 | Medical |
| 21 | F | — | — | 3 | — | 1 | Stent |
| 21 | F | 3 | — | — | — | 1 | Stent |
| 22 | M | — | 3 | — | — | 1 | Stent |
| 22 | M | 1 | — | — | — | 1 | Repeat DSA |
| 26 | M | 1 | — | — | — | 1 | Repeat DSA |
| 30 | F | — | — | 2 | — | 1 | Medical |
| 30 | M | — | 1 | — | (1) | 1 | Repeat DSA |
| 31 | M | 5 | — | — | — | 1 | Coil |
| 32 | F | — | — | 2 | — | 1 | Repeat DSA |
| 32 | M | 1 | — | — | — | 1 | Repeat DSA |
| 32 | M | — | — | 3 | — | 1 | Stent |
| 39 | M | — | — | — | 2 | 1 | Stent |
| 40 | F | — | 1 | — | — | 1 | Medical |
| 43 | M | 2 | — | — | — | 1 | Repeat DSA |
| 44 | F | — | — | 4 | — | 1 | Medical |
| 45 | M | — | — | — | 4 | 1 | Medical |
| 45 | M | — | — | (2) | 2 | 1 | Stents X 2 locations |
| 46 | M | — | — | 1 | — | 1 | Repeat DSA |
| 46 | F | 3 | — | — | — | 1 | Stent |
| 47 | F | — | — | 2 | — | 1 | Repeat DSA |
| 50 | F | 3 | — | — | — | 1 | Deceased |
| 52 | M | — | — | 2 | — | 1 | Stent |
| 54 | F | — | — | — | 2 | 1 | Stent |
| 54 | M | 1 | (3) | — | — | 1 | Stents X 2 locations |
| 59 | M | — | — | — | 4 | 1 | Medical |
| 60 | M | — | — | — | 2 | 1 | Medical |
| 68 | M | — | — | 2 | — | 1 | Repeat DSA |
| 73 | F | — | — | — | 2 | 1 | Stent |
| Total Missed | | 17 | 9 | 13 | 14 | 53 | |

Values in parenthesis indicate an injury detected on CTA.

function. Renal insufficiency occurred in 4% of the screened population. The extent to which contrast-induced nephropathy contributed to this is not clear. Trauma patients are commonly hypovolemic at presentation and can have renal insufficiency for a multitude of reasons throughout their hospitalization. N-acetylcysteine was routinely used for prophylaxis of at-risk patients, which may contribute to the paucity of renal complications seen in this study.

An interesting finding of this study, previously unrecognized in the literature, is the gender differences in BCVI. At our institution, women represent 30% of the blunt trauma patients. The current study found 41% of the BCVI occurred in women, while they were just 31% of the screened population ($P = 0.022$). Females comprise 59% of the BCVI in a weighted average of the 9 studies with available gender data.[8,13,14,16,24–28] It appears that women acquire BCVI at a higher

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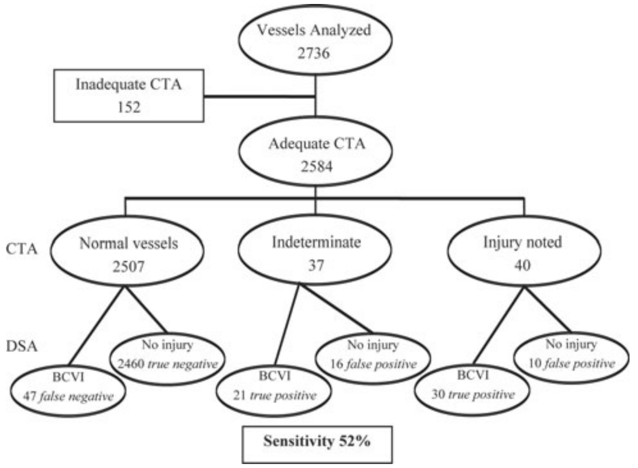

**FIGURE 2.** Adequate quality CTA findings as compared to DSA results.

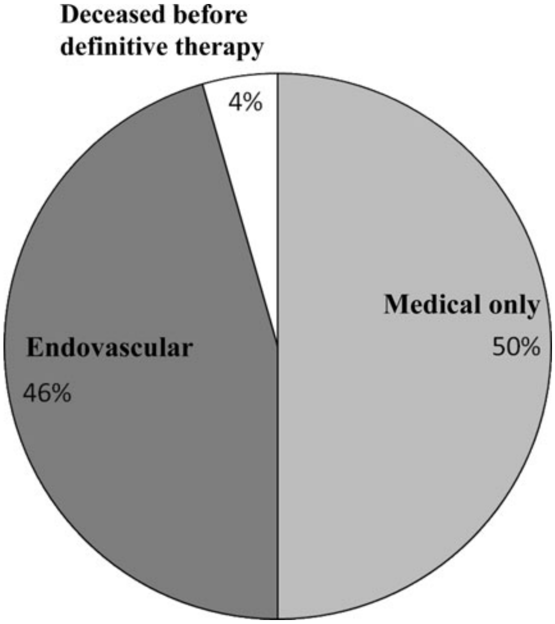

**FIGURE 3.** Treatments utilized for blunt cerebrovascular injuries.

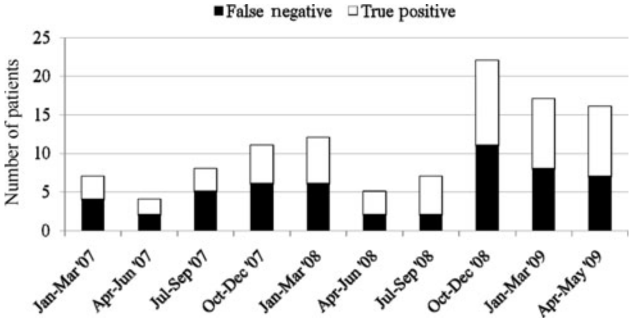

**FIGURE 4.** Time distribution of the 109 blunt cerebrovascular injuries, comparison true positive and false negative.

rate than men. Many studies have small sample sizes that would limit the ability to observe this trend. Women were also more likely to have a false-negative CTA study than their male counterpart, with sensitivities of 45% and 56%, respectively ($P = 0.003$). Nearly 1 in 10 women, compared with 1 in 24 men, with a negative CTA had an injury that would have been undetected, until symptomatic, without routine DSA. The reasons for differences in incidence of BCVI and its detection on CTA in women are unknown but warrant further investigation. Regardless of the reasons, women who present with a potential mechanism should be considered at high risk for BCVI and treated accordingly.

A weakness of this study is the retrospective nature. To minimize the impact of this design, radiologic interpretations used for the clinical management of patients were used to determine sensitivity. No CTA was reviewed to determine whether BCVI could be seen after diagnosis using DSA. Findings of CTA are the result of the acquired radiographic data and the radiologist's interpretation. Malhotra et al[13] speculated that after a learning curve of CTA technology, sensitivity improved.[13] This includes the intuitional establishment of a protocol, including volume and timing of contrast injection, parameters of data acquisition, and the radiologist experience. Acknowledging the potential for a learning curve, the current study began only after acquiring 2 years experience with 32-MDCT technology. The fact that we identified missed injuries throughout the entire 29 months at a relatively constant rate (Fig. 4), demonstrates that these results were not effected by a learning curve. We did not distinguish which factors resulted in the poor sensitivity. Likely, a combination of both inadequate technology and radiographic misinterpretation leads to low sensitivity.

There are several strengths of the study. To our knowledge, this is the largest series published to date. Additionally, it is one of the few studies in which ALL patients received both CTA and DSA, and therefore true comparisons of the tests can be made. The 32-channel MDCT is an improvement over earlier generations and provides many diagnostic advantages. Few studies exist using this advanced scanner technology. Perhaps, as the technology continues to improve, CTA will become adequate for diagnosis of BCVI.

Given the potential for devastating complications after BCVI, one must maintain a high suspicion for these injuries. High-energy mechanisms, such as motor vehicle collisions and pedestrians struck by vehicles, are more likely to result in a BCVI than other mechanisms. In addition, females appear to be at higher risk than their male counterparts and have more missed injuries on CTA. Currently, the sensitivity of CTA (51%) is too low to be used for screening of BCVI. Until sensitivity is consistently greater than 95%, CTA should not be considered a safe alternative. We believe patients at-risk for BCVI should undergo DSA, as the complications associated with this diagnostic modality are less than risks of missed BCVI.

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