Clinical and radiographic outcomes following traumatic Grade 1 and 2 carotid artery injuries: a 10-year retrospective analysis from a Level I trauma center. The Parkland Carotid and Vertebral Artery Injury Survey

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OBJECT Proper screening, management, and follow-up of Grade 1 and 2 blunt carotid artery injuries (BCIs) remains controversial. These low-grade BCIs were analyzed to define their natural history and establish a rational management plan based on lesion progression and cerebral infarction.

METHODS A retrospective review of a prospectively maintained database of all blunt traumatic carotid and vertebral artery injuries treated between August 2003 and April 2013 was performed and Grade 1 and 2 BCIs were identified. Grade 1 injuries are defined as a vessel lumen stenosis of less than 25%, and Grade 2 injuries are defined as a stenosis of the vessel lumen between 25% and 50%. Demographic information, radiographic imaging, number of imaging sessions performed per individual, length of radiographic follow-up, radiographic outcome at end of follow-up, treatment(s) provided, and documentation of ischemic stroke or transient ischemic attack were recorded.

RESULTS One hundred seventeen Grade 1 and 2 BCIs in 100 patients were identified and available for follow-up. The mean follow-up duration was 60 days. Final imaging of Grade 1 and 2 BCIs demonstrated that 64% of cases had resolved, 13% of cases were radiographically stable, and 9% were improved, whereas 14% radiographically worsened. Of the treatments received, 54% of cases were treated with acetylsalicylic acid (ASA), 31% received no treatment, and 15% received various medications and treatments, including endovascular stenting. There was 1 cerebral infarction that was thought to be related to bilateral Grade 2 BCI, which developed soon after hospital admission.

CONCLUSIONS The majority of Grade 1 and 2 BCIs remained stable or improved at final follow-up. Despite a 14% rate of radiographic worsening in the Grade 1 and 2 BCIs cohort, there were no adverse clinical outcomes associated with these radiographic changes. The stroke rate was 1% in this low-grade BCIs cohort, which may be an overestimate. The use of ASA or other antiplatelet or anticoagulant medications in these low-grade BCIs did not appear to correlate with radiographic injury stability, nor with a decreased rate of cerebral infarction. Although these data suggest that these Grade 1 and 2 BCIs may require less intensive radiographic follow-up, future prospective studies are needed to make conclusive changes related to treatment and management.

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KEY WORDS blunt cervical vascular injury; carotid artery injury; cerebral infarction; trauma

THE management of blunt cerebrovascular injuries (BCVIs), including low-grade blunt carotid artery injuries (BCIs), remains controversial; however, antiplatelet agents or anticoagulation continue to be first-line treatments, with endovascular stenting typically re-

served for symptomatic or higher-grade injuries.^{5,7,8,16,19,26} Whereas our earlier reports explored blunt vertebral artery injuries (BVIs), this current report presents our evaluation of Grade 1 and 2 BCIs. Imaging, progression of injury, and outcomes of these lower-grade BCIs were analyzed to

ABBREVIATIONS ASA = acetylsalicylic acid; BCI = blunt carotid artery injury; BCVI = blunt cerebrovascular injury; BVI = blunt vertebral artery injury; CTA = CT angiography; DSA = digital subtraction angiography; MVC = motor vehicle collision.

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gain a better understanding of their natural history and to assist in establishing a rational management plan based on their progression and the risk of cerebral infarction.

Methods

A retrospective review of a prospectively maintained database of all traumatic carotid and vertebral artery injuries has been maintained at our Level I trauma center (Parkland Memorial Hospital, Dallas, TX). Analysis for this study focused on the Grade 1 and 2 BCIs. We suspect that lower-grade injuries may exhibit a more benign behavior compared with higher-grade injuries; therefore, our aim for the Parkland Carotid and Vertebral Artery Injury Survey was to categorize and report on these injuries separately.

Screening for BCVIs at our institution occurs through a modification of the Denver Criteria. Any patient found to have cervical spine fractures of the vertebral body or pedicle, basilar skull fractures involving the carotid canal or petrous bone, Le Fort II or III fractures, Glasgow Coma Scale score < 7 without obvious cerebral injury on head CT, and/or near hanging/strangulation with a ligature mark/contusion receives a screening cervical CT angiography (CTA) scan to rule out a vascular injury.

Grade 1 injuries are defined as a vessel lumen stenosis of less than 25%, Grade 2 injuries are defined as a stenosis of the vessel lumen between 25% and 50%, Grade 3 injuries are defined as stenosis of the vessel greater than 50% or the development of a pseudoaneurysm, and Grade 4 injuries are defined as vessel occlusion.³ Grade 5 injuries are complete transections of the artery. All CTA scans were read by personnel in our department of neuroradiology. A staff neurosurgeon confirmed all injuries and decided on the desired follow-up and treatment. Only blunt injuries were evaluated. Any vascular injuries secondary to penetrating trauma were not included in this analysis.

Data including age, sex, mechanism of injury, presence or absence of cervical fractures, and other traumatic injuries within the proximity of the neck (e.g., occipital condyle fracture, first rib fracture, and so on) were recorded. Radiographic imaging was reviewed (e.g., CTA, digital subtraction angiography [DSA]), as was the number of imaging sessions performed per individual, the length of time between sessions, and radiographic outcomes at the end of follow-up. Information on the treatment(s) provided was recorded. The presence of cerebral infarction was confirmed by clinical presentation and neuroimaging.

Results

From August 2003 through April 2013, there were 537 BCVIs. This included 241 (45%) BCIs and 296 (55%) BVIs. From this cohort, there were 175 Grade 1 and 2 BCIs in 132 patients. This comprised 33% of all BCVIs and 73% of all BCIs. Of these 132 patients, 100 patients with 117 Grade 1 and 2 BCIs were available for follow-up and were analyzed further in this study. There was a nearly equal amount of right-sided and left-sided injuries, and in 20 cases there were bilateral Grade 1 and 2 BCIs. There were 71 males and 29 females in the study. The mean age for Grade 1 and 2 BCIs was 35 years (range 16–85 years).

Of the 32 patients who were excluded, 9 individuals with a mean age of 35 years (range 21–60 years) were either dead on arrival or died shortly after admission. Of the 5 individuals who died shortly after admission, the reason was severe traumatic brain injury (3 cases from motor vehicle collision [MVC] and 2 from falls). The other 4 individuals died of other nonneurological traumatic injuries. One patient was transferred to another facility due to cardiac contusions. There were 22 patients who were lost to follow-up. The patients who were lost to follow-up were discharged at a mean of 6.3 days (range 1–17 days) after hospital admission.

The mechanism of injury of Grade 1 and 2 BCIs was MVC in 61 patients (61%), fall in 16 patients (16%), motorcycle collision in 11 patients (11%), and motor–pedestrian collision in 6 patients (6%). Other less common mechanisms included assault, all-terrain vehicle accidents, and crush injuries in the remaining 6 patients (6%).

Of the Grade 1 and 2 injuries, 48 patients (48%) had a single-sided Grade 1 or 2 BCI, whereas 52 patients (52%) presented with multiple cervical vascular injuries (an additional ipsilateral and/or contralateral BCI and/or a BVI). The distribution of other vascular injuries is shown in Table 1. Skull base fractures were present in 16 patients (16%), with 6 of these patients demonstrating involvement of the carotid canal. First rib fractures were present in 6 patients (6%), and mandible fractures were present in 6 patients (6%). Cervical fractures were present in 37 patients (37%) and, in those with a cervical fracture, the transverse foramen was involved in 16% of cases.

During follow-up, 52 individuals (52%) received only 1 follow-up CTA scan. There were 45 patients who received more than 2 CTA scans: 21 patients received 3 scans, 13 patients received 4 scans, 8 patients received 5 scans, 2 patients received 6 scans, and 1 patient received 7 scans. The reason for obtaining multiple repeated images in this group appeared to be the presence of multiple vascular injuries in nearly all cases, with a higher than Grade 2 injury of either the carotid or vertebral artery included in this majority. There were 3 patients who were followed with angiography, with 2 of them also receiving a CTA scan. The patients receiving angiography were all treated prior to 2009, and the patient followed with angiography only was treated in 2004.

At final imaging of the 117 BCIs, 75 showed complete resolution (64%), 10 showed radiographic improvement (9%), 14 showed radiographic stability (13%), and 16 demonstrated radiographic worsening with subsequent stabilization at a higher grade injury (14%). One case demonstrated radiographic worsening with subsequent improvement. In 80% of cases, a follow-up CTA image was obtained within 7–10 days. During this short timeframe, 39% of injuries were noted to have resolved, 30% of injuries had remained stable, 16% of injuries had improved, and 16% of injuries had radiographically worsened (further narrowing of the vessel to worsened grade). Table 2 shows the status of injuries at 7–10 days and at final imaging. The average duration of follow-up in the Grade 1 and 2 BCIs group was 60 days (7–723 days).

Fifty-four patients (54%) were treated with acetylsalicylic acid (ASA) alone. There were 15 cases treated with a

TABLE 1. Distribution of additional BCVIs in relation to the studied Grade 1 and 2 BCIs

Grade	No. BVIs		No. BCIs	
	Ipsilat	Contralat	Ipsilat	Contralat
1	13	11	6	7
2	4	3	1	3
3	3	2	5	15
4	4	0	0	1

variety of medications and treatments: 2 cases were treated with ASA and clopidogrel; 2 cases with ASA and then heparin transitioned to Coumadin; 1 case with heparin transitioned to ASA; 1 case with ASA transitioned to Coumadin; 1 case with ASA transitioned to heparin and then transitioned to enoxaparin; 1 case with ASA and clopidogrel transitioned to Coumadin; 2 cases with enoxaparin; 2 cases with clopidogrel; and 3 cases were treated with endovascular stenting. In those individuals who underwent a change of medication, the reasons included physician decision, worsened grade of injury, and concern for stroke. In the 3 patients who received stents, the mean age was 53 years (range 22–82 years). One of these endovascular cases was performed in 2005 and 2 were performed in 2007. All 3 patients were subsequently treated with ASA and clopidogrel. The indication for the endovascular procedure was worsening of injury from a low-grade BCI to pseudoaneurysm in all 3 cases. In the 22 individuals lost to BCI follow-up, 60% were discharged on ASA, whereas the remaining individuals were not treated with any medication.

In the patients who received ASA, 80% of the BCIs demonstrated stable, improved, or resolved injuries on final follow-up imaging. Of the remaining patients treated with ASA, 10 injuries demonstrated progression and stabilization to a Grade 3 injury, 1 case worsened and subsequently improved to a Grade 1 injury, and 1 case worsened and subsequently demonstrated complete resolution. There were 18 BCIs in the 15 patients who were treated with various medications. On final follow-up imaging, 12 of these injuries remained stable, improved, or resolved, whereas 6 cases were identified as radiographically worsened. Of the 6 cases that worsened, all were identified as stabilized at the worsened grade. Thirty-one patients (31%) were not treated with any medication(s). In these 31 patients there were 34 Grade 1 or 2 BCIs. All patients who did not receive treatment were found to have stable, improved, or resolved injuries on final imaging. The distribution of individual injuries and respective treatments are reviewed in Tables 3 and 4. In all cases in which clinic follow-up records were available and there was resolution of the vascular injury, the treatment medication was discontinued. In those cases in which the injury remained present at the last available follow-up record, it was recommended that the treatment medication be continued.

Magnetic resonance imaging was performed in 25 patients for evaluation of trauma or suspicion of stroke. There was 1 patient (1% of the follow-up cohort of Grade 1 and 2 BCIs) who was identified as having a cerebral infarction thought to be related to the BCI. This case involved

TABLE 2. Progression of lesion at 7–10 days postinjury

Status	Injuries at 7–10 Days	Injuries at Final Imaging (mean 60 days)
Resolved	39%	64%
Improved	16%	9%
Stable	30%	13%
Worsened	16%	14%

a 44-year-old woman involved in an MVC, who sustained multiple orthopedic injuries including a C1–2 dislocation with rotary subluxation and was identified as having a right-sided Grade 3 BVI in addition to bilateral Grade 2 BCIs. Prior to the initiation of medical management directed toward her vascular injuries, this patient developed nonfocal altered mental status early on hospital Day 2 and an MRI study was performed, which demonstrated bilateral frontal, parietal, and temporal subcortical hemispheric infarcts. In response to these cerebral infarctions in the setting of the BCVIs, heparin therapy was initiated. Her altered mental status improved shortly thereafter, and she was later transitioned to ASA for her vascular injuries. The BCIs showed improvement bilaterally and the Grade 3 BVI resolved on follow-up imaging. She was discharged to inpatient rehabilitation on hospital Day 32. In those individuals who were lost to BCI follow-up, 91% (20 of 22) underwent a noncontrast head CT after hospital admission and prior to hospital discharge. No hypodensities suggestive of stroke were identified in this group. In the other 2 patients, a brain MRI study was performed; one for a mild hemiparesis on hospital Day 1 and the other for an episode of slurred speech on hospital Day 2. Neither MR image in either case demonstrated evidence of cerebral infarction.

Discussion

Research on BCVI conducted since the 1990s has led to an increase in screening protocols and treatment strategies for this injury. Disagreement remains regarding the appropriate screening, treatment, and follow-up of these traumatic vascular injuries. Common parameters for BCVI screening include patients with symptomatic ischemic injuries and patients who are asymptomatic with Le

TABLE 3. Final radiographic progression of stable and unstable Grade 1 and 2 BCIs in 100 patients with 117 injuries

Status	Unchanged	Improved	Resolved
Stable/improved/resolved (98 injuries)			
Treatment	14 (15%)	10 (10%)	74 (75%)
ASA	10	6	37
None	3	1	30
Other	1	3	7
Unstable (19 injuries)			
Treatment	17 (89%)	1 (5.5%)	1 (5.5%)
ASA	10	1	1
None	0	0	0
Other	7	0	0

TABLE 4: Progression of unstable injuries and their respective treatments

Original Grade	Worsened Grade*	Final Outcome	Treatment
1	2	Resolved	ASA
1	2	Stable Grade 2	ASA
1	3A	Stable Grade 3	ASA
1	3A	Stable Grade 3	ASA
1	3A	Stable Grade 3	ASA
1	3A	Stable Grade 3	ASA
1	3A	Stable Grade 3	ASA
1	3B	Stable Grade 3	ASA then Coumadin
1	3B	Stable Grade 3	ASA/clopidogrel
1	3B	Stable Grade 3	Other†
2	3A	Improved to Grade 2	ASA
2	3A	Stable Grade 3	ASA
2	3A	Stable Grade 3	ASA
2	3B	Stable Grade 3	ASA
2	3B	Stable Grade 3	ASA
2	3B	Stable Grade 3	Lovenox
2	3B	Stable	Stent/ASA/clopidogrel
2	3B	Stable	Stent/ASA/clopidogrel
2	3B	Stable	Stent/ASA/clopidogrel

* Grade 3A injuries are defined as > 50% stenosis of the vessel; Grade 3B injuries are defined as harboring pseudoaneurysm.

† Patient treated initially with ASA, then transitioned to heparin, and subsequently to ASA and Lovenox.

Fort II or III fractures, cervical spine fractures, Horner's syndrome, foramen lacerum fractures, neck soft-tissue injury, or unexplained ischemic events.^{4,12} There have also been case reports of BCVI diagnosis from more benign torsion injuries, such as those reported from common activities such as yoga.^{22–24}

At our institution, trauma patients meeting the criteria for BCVI screening undergo CTA studies. Formerly the gold standard, DSA has been supplanted by CTA as the standard in our center due to the compelling evidence on the topic.^{2,6,9,15,21,22} Biffi et al. evaluated the progression of BCVI in a sequential DSA study examining both vertebral and carotid artery injuries together as a cohort.⁵ In this study, DSA was performed immediately on admission and then again 7–10 days after admission, and found that more than 90% of Grade 1 BCVIs and more than 50% of Grade 2 BCVIs were stable or spontaneously resolved. Although this study combined both carotid and vertebral artery injuries for evaluation, it is difficult to make exact correlations to our current study examining isolated low-grade BCIs; however, comparable results were noticed overall. Our study demonstrated 86% of low-grade (i.e., 1 and 2) BCIs were ultimately identified as stable, improved, or resolved; however, because our patients were followed for a comparatively longer duration, these vascular injuries had a potentially longer time to heal. We noticed that the majority (89%) of low-grade BCIs that demonstrated radiographic worsening did not resolve or improve, but stabilized at higher grades.

The greatest concern regarding BCVIs in general, including the low-grade (i.e., 1 and 2) BCIs, is the risk of cerebral infarction; however, reports have suggested that the risk of ischemic stroke may be quite low. Griessenauer et al. looked at the outcomes in 112 patients with BCVI.¹² This study included both carotid and vertebral artery injuries of various grades and identified only 1 case of ischemic stroke caused by BCVI. From the available literature, however, it is difficult to determine the true rate of BCVI-related ischemic strokes; there have been reports as low as 0.05% and as high as 50%.^{10,12,14,16} In this current study examining low-grade BCI, we identified only 1 patient (1%) who presented with a BCI-related stroke, which is not a dissimilar finding from our earlier report on low-grade BVIs.²⁵ A previous study from our institution by Eastman et al. examined 26 patients with either BCIs and/or BVIs (4 of those patients had a Grade 1 or 2 BCI) and found a stroke rate of 3.8% (1 of 26) in patients with BCVI. The cerebral infarction in this study was identified in a patient with a Grade 3 injury.¹⁰ Griessenauer et al. concluded that most ischemic strokes occur before initial screening with CTA, and prior to treatment with an antiplatelet medication, indicating that follow-up imaging may not aid in preventing most ischemic strokes.¹²

We have noticed similar findings thus far in our BCVI analysis, with the majority of strokes presenting soon after admission, and frequently prior to the administration of any medication.²⁵ Similarly, Mayberry et al. retrospectively examined cases treated in 2 major trauma centers and noted that all strokes from BCI happened within 12 hours of admission.¹⁶ Of note, our study lost 22 patients after hospital discharge to appropriate BCI follow-up. This group, however, was evaluated by both our trauma and neurosurgery teams for an average of 6.3 days (range 1–17 days). All patients in this group were identified as being discharged in stable condition, and all of these individuals had undergone a head CT scan without contrast in addition to the CTA for diagnosis of their BCI. There were no clinically or radiographically detected cerebral infarctions identified in this group, suggesting that within the peritraumatic time frame the stroke rate may be closer to 0.8%. This finding represents similar results identified in our earlier report on low-grade BVIs.²⁵

The progression of injury does not seem to be affected by any specific medical treatment(s). Cothren et al. evaluated 422 patients with BCVI; 162 of those patients had a Grade 1 or 2 BCVI.⁸ The majority of patients in this cohort (49%) were treated with heparin, 23% were treated with either ASA or a combination of ASA and clopidogrel, and 28% were untreated. This study concluded that there was no reliable way to alter the progression of injury. Our study found similar results in that the progression of injury was not altered by any specific treatment or absence of treatment. Despite treatment with antiplatelet medication, there were 9 patients in this current study who progressed to pseudoaneurysm, with 3 of those patients receiving endovascular stenting for this radiographic progression. No patient in this subgroup experienced any adverse clinical outcomes despite these radiographic changes. Although there have been prior studies reporting varying efficacy and safety of endovascular treatment of pseudoaneurysms

in these cases,^{1,4,7,11,13,19} Li et al. performed a national trauma bank review and found that there was no difference in the functional outcome between patients treated with endovascular procedures compared with patients treated with medicine alone.¹⁴

Limitations of the Study

The major limitation of this study was its retrospective design. A prospective study is needed to implement various treatment strategies to verify appropriate follow-up protocols. Although some studies have suggested that CTA overestimates vascular injury in these blunt traumatic cases,^{12,18,20,27} we used this imaging modality in the majority of cases due to the comparative ease, accessibility, and safety associated with this procedure compared with DSA, especially in critically ill patients with multiple traumas. Use of CTA may have then produced a falsely elevated incidence rate of vascular injury at our center. Because these low-grade injuries reflect a smaller percentage of vessel diameter disruption, a falsely elevated rate of improvement on follow-up imaging may also be reflected in this study, as compared with older studies that used DSA,^{5,17} especially if there was a potential overestimation of initial injury.

Due to the dynamic nature of our study population, and at times following multiple vascular injuries simultaneously, we experienced a large variability in our follow-up days, which does limit our ability to state timing conclusively as it relates to the healing of these low-grade carotid artery injuries. However, that does not diminish the fact that the majority these injuries proved to be stable and to carry an overall low posttraumatic infarct rate. Another limitation of this retrospective study is that we cannot be entirely sure that some clinically silent strokes were not missed, but we can offer that all individuals included in this study did undergo follow-up evaluations, and thus we are certain that all clinically apparent strokes were both identified and recorded. Although these data accrued across the past 10 years at our institution have yielded valuable information, the data involving low-grade carotid artery injuries alone did not afford much ability for statistical analysis; however, once all of the data across all of the cervical vascular injuries have been analyzed, we look forward to the ability to offer a well-powered analysis across all grades of BVIs and BCIs, specifically as it relates to the stroke risk in the setting of treatment, timing, vessel, and grade.

Conclusions

Results of this study suggest that Grade 1 and 2 BCIs carry a low stroke risk. Although 36% of the studied BCIs appeared unresolved on final imaging, and although the majority of worsened injuries did not show improvement on radiographic studies, this lack of injury resolution did not correlate with adverse clinical outcome or an increased rate of cerebral infarction. The use of ASA or other antiplatelet or anticoagulant medications in these low-grade BCIs did not appear to correlate with radiographic injury stability or with a decreased rate of cerebral infarction, suggesting that in individuals with low-grade carotid artery injuries, its use may not provide a difference in the

progression of injury or eliminate the small but present risk of cerebral infarction. The time and cost allotted for follow-up radiography deserves attention, because continued imaging in these subsets of vascular injury may not prove entirely necessary. Follow-up protocols should be amended, but further prospective studies are needed to make conclusive changes as these relate to management.

As we continue the Parkland Carotid and Vertebral Artery Injury Survey at our institution, we look forward to presenting our entire experience of cervical vascular injuries in sectioned categories as discussed above. After we conclude our reporting on all grades of carotid and vertebral artery injuries, we will at that time consider future plans for prospective research on this topic; specifically, determining which injuries warrant follow-up and which injuries require treatment.

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