Reading the signs in penetrating cervical vascular injuries: Analysis of hard/soft signs and initial management from a nationwide vascular trauma database

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BACKGROUND: Algorithms for management of penetrating cervical vascular injuries (PCVIs) commonly call for immediate surgery with "hard signs" and imaging before intervention with "soft signs." We sought to analyze the association between initial examination and subsequent evaluation and management approaches.

METHODS: Analysis of PCVIs from the American Association for the Surgery of Trauma Prospective Observational Vascular Injury Treatment vascular injury registry from 25 US trauma centers was performed. Patients were categorized by initial examination findings of hard signs or soft signs, and subsequent imaging and surgical exploration/repair rates were compared.

RESULTS: Of 232 PCVI patients, 110 (47%) had hard signs (hemorrhage, expanding hematoma, or ischemia) and 122 (53%) had soft signs. With hard signs, 61 (56%) had immediate operative exploration and 44% underwent computed tomography (CT) imaging. After CT, 20 (18%) required open surgical repair, and 7% had endovascular intervention. Of note, 21 (19%) required no operative intervention. A total of 122 patients (53%) had soft signs on initial examination; 37 (30%) had immediate surgery, and 85 (70%) underwent CT imaging. After CT, 9% had endovascular repair, 7% had open surgery, and 65 (53%) were observed. No difference in mortality was observed for hard signs patients undergoing operative management versus observation alone (23% vs. 17%, $p = 0.6$). Those with hemorrhage as the primary hard signs most often required surgery (76%), but no interventions were required in 19% of hemorrhage, 20% of ischemia, and 24% of expanding hematoma.

CONCLUSION: Although hard signs in PCVIs are associated with the need for operative intervention, initial CT imaging can facilitate endovascular options or nonoperative management in a significant subgroup. Hard signs should not be considered an absolute indication for immediate surgical exploration. (*J Trauma Acute Care Surg.* 2022;93: 632–638. Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic/Epidemiological; Level IV.

KEY WORDS: Penetrating neck; trauma; vascular trauma; hard signs.

Penetrating neck trauma is a relatively common injury in both military and civilian trauma, which can present with significant vascular, airway, and/or digestive tract involvement.[1–3] Historically, penetrating neck injuries were managed using an anatomically based "zone approach" with injuries to Zone 1 (below the cricoid cartilage) and Zone 3 (above the angle of the mandible) in stable patients requiring employment of bronchoscopy, endoscopy, and invasive angiography because of surgical inaccessibility or morbidity of access to these regions. Penetrating injuries in Zone 2, the area in between, were recommended to undergo operative neck exploration as opposed to pursuing a complex and timely diagnostic evaluation. This led to an unnecessarily high amount of nonoperative neck explorations with retrospective studies showing surgical exploration to be therapeutic in 70% of patients with hard signs but only 40% of patients with soft signs.[4–9] With improvements in the quality and accessibility of computed tomography angiography (CTA), the standard for evaluating most penetrating neck injuries has recently shifted to a "no zone" approach using screening CTA in stable patients and immediate operative exploration in unstable patients or those with hard signs of vascular or aerodigestive injuries.[4,8,10] Many algorithms continue to center on the presence of these "hard signs," which include active hemorrhage, expanding/pulsatile hematoma, neurological deficits for vascular injuries and airway compromise, subcutaneous emphysema, and hematemesis for aerodigestive injuries in addition to hemodynamic stability (Table 1). The current Western Trauma Association algorithm follows this pattern.[10] However, recent literature has begun to question the validity of these hard signs for directing mandatory and immediate operative exploration, particularly for vascular injury. There exists a significant gap in the literature because of the relative infrequency of these injuries in most centers resulting in the majority of published reports having small sample sizes and being underpowered.

The American Association for the Surgery of Trauma began the Prospective Observational Vascular Injury Treatment (PROOVIT) registry in 2013, a multicenter database regarding the diagnosis, management, and outcomes for patients with vascular injury in trauma.[11] This database allows for analysis of modern diagnosis, management, and subsequent outcomes of patients with penetrating cervical vascular injuries (PCVIs). We sought to analyze a large modern sample of patients with PCVIs from the PROOVIT database and to specifically examine the association between hard signs and outcomes including need for operative interventions and mortality.

PATIENTS AND METHODS

The PROOVIT registry is a 31-center vascular injury registry sponsored by the American Association for the Surgery of Trauma (AAST). After obtaining institutional review board approval, enrolled trauma centers submit data directly to the PROOVIT study via an internet-based portal. Approval for this analysis was granted by the PROOVIT study review panel. Deidentified data for admissions occurring between January 29, 2012, and September 30, 2020, were used because this was when accrued data were last reported. The Strengthening the Reporting of

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TABLE 1. Hard Signs as Defined by the Western Trauma Association

Hard Signs in Penetrating Neck Injuries	
Vascular	Active hemorrhage, expanding hematoma, ischemia/ neurological deficits
Airway	Airway compromise, subcutaneous emphysema, air bubbling through wound
Digestive	Hematemesis

Observational Studies in Epidemiology guidelines for cross-sectional studies were followed[12] (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C533).

Patients who sustained any penetrating injury to the external carotid artery (ECA), internal carotid artery (ICA), common carotid artery (CCA), vertebral artery, or jugular vein were included (Fig. 1). Penetrating mechanisms were categorized as gunshot wounds, stabbings, or other. Patients with other penetrating injuries were specified as having a penetrating type of injury but with a specified mechanism of industrial accident, motor vehicle crash, or unspecified. Patients were categorized based on presence of hard signs for any of the previously named vessels. Hard signs were defined as presence of hemorrhage, expanding hematoma, or ischemia, as outlined by the PROOVIT data collection methodology. Patients with multiple hard signs versus singular hard signs were identified and classified accordingly. Soft signs captured by the PROOVIT registry included wound proximity, reduced pulses, and fracture/dislocation pattern. Patients who had multiple cervical vascular injuries were similarly categorized separately to those with a singular vascular injury. Patients were excluded if they had missing data pertaining to diagnostic methods or course of care.

The primary risk factors of interest were preoperative imaging with CTA. For each injured vessel, usage of preoperative CTA or operative exploration was assessed. The primary outcomes were operative management of the vascular injury or observation without surgery. Operative management categories were open operative intervention, endovascular intervention, or observation. Timing of the first intervention used the following categories based on the PROOVIT methodology: <1 hour from admission, within 1 to 3 hours from admission, within 3 to 6 hours from admission, or >6 hours from admission.

Additional risk factors of interest include patient age at admission, sex, presence of concomitant noncervical injuries, Injury Severity Score, Glasgow Coma Scale score, admission systolic blood pressure, adjunctive medical therapy, hospital length of stay, ventilator days, and in-hospital death. Hemodynamic instability was defined as a systolic blood pressure of <90 mm Hg. Severe traumatic injury was defined as an Injury Severity Score of >15. Presence of concomitant nonhead injuries was identified using presence of AIS body region scores for nonhead locations.

Data were managed and analyzed using Stata MP v17.0 (StataCorp LLC, College Station, TX). Descriptive statistics were calculated and displayed as means with SD, medians with interquartile ranges, or proportions, as appropriate. Descriptive analyses included the *t* test, χ^2 test, and rank-sum test to evaluate patient and clinical characteristics by presence of hard signs. χ^2 Tests were used to evaluate differences in the presence of specific hard signs by course of care. Statistical significance was attributable to comparisons with resultant p values of <0.050.

RESULTS

The PROOVIT registry contained 4,618 patients, of which 232 experienced PCVIs with injury to a named cervical vessel. Singular ICA injuries were the most frequent (23.7%), followed by jugular injuries (23.3%), vertebral artery injuries (18.5%), CCA injuries (12.5%), and ECA injuries (6.0%). Multiple vessel injuries were seen in 16.0% of the sample. The most prevalent mechanism of injury was gunshot wounds (59.9%), followed by stabbings (34.9%) and other (5.2%). Overall, 110 (47.4%) presented with hard signs and 122 (52.6%) had soft signs. Between patients with hard signs and soft signs, there were no statistical differences detected regarding patient age, reported sex,

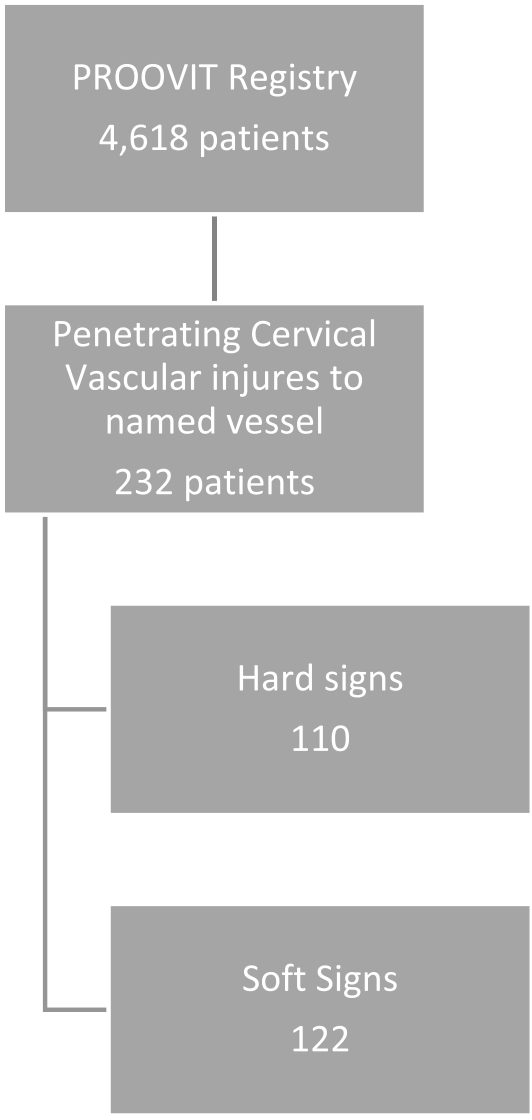

Figure 1. Inclusion criteria.

Injury Severity Score, ICU length of stay, or Glasgow Coma Scale score (Table 2). However, the median hospital length of stay was shorter for patients who had hard signs compared with those with soft signs. Similarly, patients with hard signs were more likely to have presented with a systolic blood pressure of <90 mm Hg, have a stabbing-type mechanism of injury, and to have died during their hospital stay.

Of those with hard signs, 61 (55.5%) underwent immediate operative exploration, and 49 (44.5%) underwent diagnostic computed tomography (CT) imaging. Of those imaged first, 14 (28.5%) had open surgical repair, 11 (22.4%) had endovascular intervention, and 3 (6.1%) had operative exploration without a subsequent repair. The remaining 21 (42.8%) of imaged patients required no intervention and were observed. Ultimately, 19% of all patients who presented with hard signs were managed with observation alone (Fig. 2). There was no statistical difference in mortality between patients with hard signs who underwent operative management versus observation alone (12.5% vs. 26.3%, $p = 0.248$).

The proportion of hard signs at presentation in the sample were 48.2% hemorrhage, 21.8% hematoma, 0.9% ischemia, and 29.1% with multiple. Regarding specific vessels, hard signs comprised 58.7% of CCA injuries, 36.1% of ICA injuries, 40.0% of ECA injuries, 66.2% of jugular injuries, and 33.3% of vertebral artery injuries. Those with a singular hard sign of hemorrhage were more likely to have open repair and endovascular repair of their injury compared with patients who experienced a singular hematoma or ischemia. However, these differences were not statistically significant (Table 3). No interventions were required in 19.4% of hemorrhage or 21.1% of patients with singular expanding hematoma. Among 32 patients with multiple hard signs, 23 (71.9%) received open repair, 1 (3.1%) received open and endovascular repair, and 8 (25.0%) received no intervention.

Of the 122 injured patients who presented with soft signs, 27.1% were ICA, 23.0% were vertebral, 16.4% were jugular, 12.3% were CCA, and 7.4% were ECA. Seventeen (13.9%) of soft sign patients had multiple vascular injuries. Nineteen patients (15.6%) had immediate surgery compared with 89 (73.0%) who underwent CT imaging. Of the 122 patients who presented with soft signs, 14 patients were excluded because of missing diagnostic and management data. After imaging, 10 (11.2%) had open surgery, 12 (13.4%) had endovascular repair, and 66 (74.1%) were observed. Patients who were first imaged were more likely to die compared with patients who received immediate operative intervention, although the difference was not statistically significant (10.3% vs. 0.0%, $p = 0.143$). This cohort of patients when compared with the rest of the patients who presented with soft signs were older and had a higher overall Injury Severity Score and lower Glasgow Coma Scale, making them at a higher overall risk for in hospital mortality. They also had significantly shorter hospital stays, indicating they died within a short interval of injury. What factor these patients' overall prognosis had on decision making in regard to their PCVI is not captured in this database.

Among all patients in our sample, those who had hard signs were more likely to receive their first operative intervention within 1 hour of injury compared with those with only soft signs (45.9% vs. 25.6%, $p = 0.032$). Earlier timing of the first intervention was not directly attributable to a specific vessel injury before or after stratification by presence of hard signs. Similarly, timing of the first intervention was not associated with mortality. Patients who experienced a stabbing-type mechanism of injury were statistically significantly more likely to have had a surgical intervention within 1 hour of injury (50.0% vs. 42.8% for other vs. 28.8% for gunshot, $p = 0.030$). However, after stratification by presence of hard signs, the strength of the associations diminished.

Patients presenting with an admission systolic blood pressure of <90 mm Hg were defined as hypotension on admission. Hypotension was present in 19% of patients with hard signs, compared with 9% for patients without hard signs ($p = 0.026$). Among those with soft signs, zero hypotensive patients had surgery first compared with seven who had been scanned first ($p = 0.206$). Among patients with hard signs, 21 patients were hypotensive and had surgery or imaging. Twenty-six percent had surgery, and 10% had been imaged first ($p = 0.034$).

TABLE 2. Demographics

Characteristic	Any Hard Signs (n = 110)	Only Soft Signs (n = 122)	*p*
Age, mean (SD), y	33.8 (14.8)	35.7 (15.7)	0.360
ISS, median (IQR)	16 (10–25)	16.5 (10–26)	0.840
Male sex, n (%)	95 (86.4)	99 (81.2)	0.284
Hospital LOS, median (IQR)	6 (3–16)	9 (4–18)	0.042
ICU LOS, median (IQR)	3 (1–7)	4 (1–9)	0.429
GCS score, median (IQR)	12.5 (3–15)	15 (3–15)	0.207
Hemodynamic instability, n (%)	21 (19.1)	11 (9.0)	0.026
Mechanism of injury, n (%)			0.026
Gunshot	58 (52.7)	81 (66.4)	
Stabbing	48 (43.6)	33 (27.1)	
Other	4 (3.6)	8 (6.6)	
Vessels injured, n (%)			0.060
Common carotid	14 (12.7)	15 (12.3)	
Internal carotid	22 (20.0)	33 (27.1)	
External carotid	5 (4.6)	9 (7.4)	
Internal jugular vein	34 (30.9)	20 (16.4)	
Carotid artery	15 (13.6)	28 (23.0)	
Multiple vessels	20 (18.2)	17 (13.9)	
In-hospital death, n (%)	23 (21.3)	11 (9.7)	0.016

GCS, Glasgow Coma Scale; IQR, interquartile range; ISS, Injury Severity Score; LOS, length of stay.

DISCUSSION

The evaluation and management of penetrating cervical trauma and particularly cervical vascular injuries have continued to evolve significantly over the past several decades. The historical approaches of extensive imaging and endoscopic workups for zones 1 and 3 neck injuries and mandatory neck exploration for zone 2 trauma have given way to management strategies based primarily on the bedside physical examination and assessment for hard or soft signs of injury, and with CTA as the primary imaging adjunct that can then guide the need for additional diagnostic evaluation or surgical exploration. Although the oft-cited "hard signs" of cervical vascular injury are typically used as an indication to proceed with immediate operative exploration,

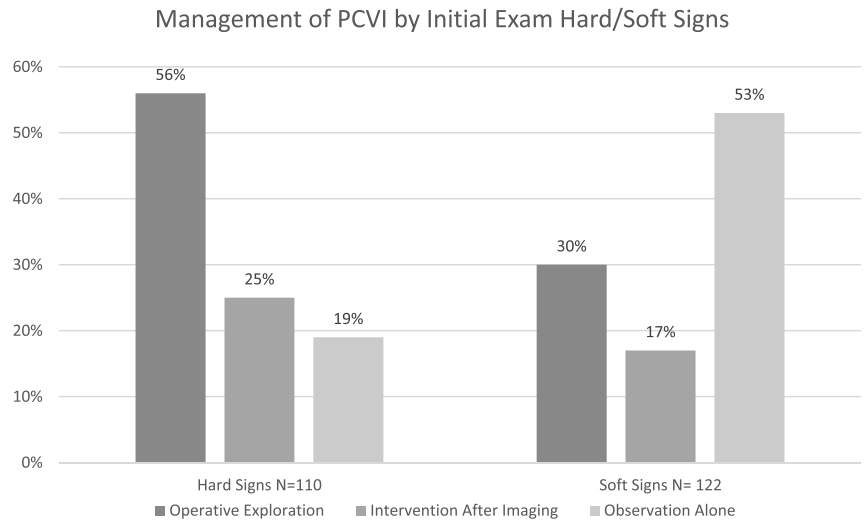

Figure 2. Breakdown of management by hard and soft signs. PCVI, penetrating cervical vascular injuries.

their actual reliability and predictive value has not been well validated in penetrating neck trauma. Here, we report the first analysis of the nationwide PROOVIT database of traumatic vascular injuries by examining these issues for penetrating neck injury. We specifically examined the outcomes and need for operative repair among cohorts with reported hard signs who underwent immediate operation versus those who underwent diagnostic imaging. Our results indicate a significant proportion of patients with hard signs who may benefit from CTA imaging to direct less invasive interventions or to avoid the need for surgery altogether.

The currently used hard signs of vascular injury were initially described in peripheral vascular trauma in the early 1960s and slowly refined and generalized to include cervical vascular injuries.[13] However, few have challenged and verified these signs in the decades since. Recently, Romagnoli et al.,[14] used the PROOVIT database to compare management of hemorrhagic versus ischemic hard signs in traumatic extremity injuries. They concluded that using clinical hard signs had significant limitations in characterizing extremity vascular injury and found that patients who underwent CTA imaging required less operative intervention and had similar outcomes.[14] Our aim was to use this same multicenter database to explore the value of hard signs in penetrating cervical vascular trauma.

After analyzing the PROOVIT database, we found that a significant number of patients presenting with hard signs of vascular injury after PCVI did not require operative intervention and were able to be observed clinically before discharge. Most patients who presented with hard signs underwent immediate operative intervention, although it is unclear whether this was due to a clinical necessity for operative intervention or simply following current local management algorithms. However, of those who were imaged initially, 65.2% were managed without operative intervention (42.8% observation, 22.4% endovascular). Furthermore, 34.6% of imaged patients did undergo operative exploration, but 17.6% of those patients had nontherapeutic operations. The choice to undertake operative exploration after imaging in these patients was likely due to equivocal imaging findings or the necessity to operate on hard signs despite imaging, although the true motivation for these decisions was not captured by the database. However, patients who underwent immediate operative repair did not have worse outcomes than those who were observed alone. Furthermore, the data showed that, although imaging delayed time to operation, there was no significant increase in mortality. Hemorrhage was the most commonly presenting hard sign, followed by multiple hard signs. Hemorrhage was also more likely to be intervened on than other hard signs. Unlike extremity vascular trauma where loss of distal pulses is a reliable hard sign, there is no distal pulse examination in cervical vascular trauma. The closest equivalent is the resultant neurologic sequelae that can occur from occlusion of the carotid and/or vertebral vessels, which would typically manifest as focal neurologic deficits similar to a stroke presentation. However, these can be highly variable depending on the location and type of injury and the presence of collateral vessels, and the neurologic examination can also be compromised by factors like shock, associated brain injury, intoxication, or the need for early intubation and sedation. In this series, neurological deficits or ischemia was the least commonly reported hard sign at less than 1%, and thus, there is little that can be extrapolated about this small subset in terms of the utility of immediate operative intervention versus performing CTA or other

TABLE 3. Hard Signs by Repair Methodology

Hard Sign Category	n	Definitive Open	Definitive Endovascular	Observation	*p*
Hemorrhage only	58	74.1%	13.8%	12.1%	0.048
Hematoma only	29	75.9%	6.9%	17.2%	
Neurologic symptoms only	1	0%	100%	0%	
Multiple signs	15	68.2%	0%	31.8%	

imaging studies. The most injured vessels to present with hard signs were the jugular vein and the CCA. Of note, 30% of patients presenting with hard signs had isolated jugular vein injuries. Current literature shows nonoperative management of isolated internal jugular vein injury to be safe and effective with no increased morbidity or mortality.[15,16] Under current protocols, a significant number of patients with internal jugular injuries would undergo unnecessary neck explorations. Theoretically, hard signs are meant to represent arterial injury that necessitates operative repair. However, given the high preponderance of isolated jugular vein injuries presenting with hard signs, the validity of this interpretation comes into question.

Regarding soft signs, as expected, the majority (54.1%) of these patients underwent diagnostic imaging, and most (75%) were treated with observation alone. A small proportion underwent immediate repair, although it is difficult to ascertain whether this was due to clinical gestalt or provider preference. However, as expected, only 18% of patients required any intervention after imaging. There was no statistically significant difference for patients with soft signs who were observed.

The movement away from a zone approach to penetrating neck injuries was spurred by two things, the advancement and accessibility of CTA but also the unreliability of external zones to correlate with internal injury.[7,8,17–20] Further evaluation of CTA in penetrating neck injuries by Inaba et al.[21] showed that CTA was a highly sensitive and specific screening modality for evaluating vascular trauma. A study by Woo et al.[22] further demonstrated that CTA evaluation reduced the rates of nontherapeutic neck exploration, invasive angiography, and endoscopy. However, these studies still used hard signs as absolute indications for operative intervention, and these patients were excluded from evaluation. Schroll et al.[23] performed a 4-year single-center retrospective analysis of patients with penetrating neck trauma who presented with hard signs and underwent imaging first. Of 183 patients who have penetrating neck injuries, 23 clinically stable patients with Western Trauma Association-defined hard signs were identified. Seventeen of these patients had negative CT findings and did not require neck exploration. The most specific hard signs in their review were hard signs for aerodigestive injury (air bubbling through wound and subcutaneous emphysema). Hard signs for vascular injury were found to be much less specific with patients only requiring neck exploration in 39% to 55%. Their analysis found that hard signs had a sensitivity of 84%, specificity of 84%, positive predictive value (PPV) of 47%, and negative predictive value (NPV) of 97%. In comparison, they found that CTA in the presence of hard signs had 83% sensitivity, 100% specificity, PPV of 100% and NPV of 94%. Ultimately, CTA in this patient population was able to significantly reduce the rate of nontherapeutic neck exploration without increasing risk of missed injury.[23] This study was limited by being a single-center review with relatively low sample size. Another retrospective study done by Madsen et al.,[17] investigated 380 stable patients with penetrating neck injuries who underwent CTA imaging. Although only 13 (3%) of these patients had hard signs, CTA was able to detect arterial injury in 11 (84.6%), and 38.5% were able to be managed nonoperatively. They found no clinically significant delay or increased morbidity associated with imaging first management. They determined hard signs to be only 76.9% effective for predicting arterial injury compared with 93.9% sensitivity of CTA. Furthermore, they demonstrated soft signs to be only 16.4% sensitive.[18] Our study further supports the previous findings, as almost two thirds of patients with hard signs who were imaged were able to avoid a neck exploration despite being associated with a true vascular injury.

Our study does have significant limitations given that the exact indications for operative management are often multifactorial and guided by clinical picture, surgeon judgment, and hospital resources among other variables. These variables are often difficult to capture in a large database, and the exact reasoning behind any captured decision in the data set is unknown. In addition, inclusion in the PROOVIT database requires presence of a named vascular injury and thus, analysis of these data cannot be used to determine sensitivity, specificity, or predictive value of hard signs because of the missing denominator data of all patients who presented with a penetrating neck injury but did not have a vascular injury identified. Further delineation of these variables would require larger prospective studies aimed at analyzing the positive and negative predictive values of hard signs based on CTA findings. However, our study does set the precedent that routine CTA imaging in stable patients is safe and effective.

In conclusion, although hard signs in PCVI are associated with the frequent need for operative intervention, initial CT imaging in select patients (hemodynamically stable, with a secure airway, and manageable hard signs) appears safe and can facilitate endovascular options or nonoperative management in a significant subgroup. There also appear to be variable patterns in the incidence of associated vascular injury, need for operative repair, and outcomes including mortality based on which hard sign is present alone or in combination. Further study with larger sample sizes will be required to achieve the required power to adequately examine these issues among subgroups of individual hard and soft signs following penetrating cervical trauma with associated vascular injuries. Based on the data from this analysis, hard signs should not be considered an absolute indication for immediate surgical exploration in all penetrating cervical trauma patients, and select use of CTA can identify a significant subgroup for alternative interventions or nonoperative management.

AUTHORSHIP

A.M. conducted the literature search. A.M., J.B., A.S.R., R.Y.C., M.S., A.K., V.B., J.D., and M.J.M. participated in the conception or design of the work. A.M., R.Y.C., and M.J.M. acquired, analyzed, or interpreted the data for the work. A.M., J.B., A.S.R., R.Y.C., M.S., A.K., V.B., J.D., and M.J.M. participated in drafting the work or revising it for important intellectual content. All authors approved the final version of the work to be published.

DISCLOSURE

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