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Blunt Cerebrovascular Injuries: Screening and Diagnosis

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Abstract

Purpose of Review This review focuses on the origins of research in blunt cerebrovascular injuries (BCVI) and highlights recent developments in BCVI screening and diagnosis. An emphasis is made on the evolution of screening guidelines and the role for a computed tomography angiography (CTA)-based approach to the diagnosis of BCVI.

Recent Findings The expanded Denver criteria first published in 2012 have been widely adopted in many trauma centers. Increased awareness and broadened screening have led to an increased rate of diagnosis in BCVI among blunt trauma patients. Current research efforts are focused on refining and improving diagnostic algorithms to improve patient selection for screening and to avoid missed injuries among blunt trauma patients.

Summary BCVI complicates between 1 and 3% of all blunt trauma admissions, and clinicians must have a high index of suspicion for this injury. Early and aggressive screening has decreased stroke rates and prevented unnecessary morbidity and mortality in this patient population. Future research will further improve institutional processes of identifying patients and instituting rapid treatment.

Keywords Blunt cerebrovascular injury · Blunt neck trauma · Blunt trauma · Traumatic stroke · Denver criteria

Introduction

The term blunt cerebrovascular injury (BCVI) represents both blunt injuries to the carotid arteries (CAI) as well as the vertebral arteries (VAI). A historically under-appreciated clinical phenomenon, the overall incidence of this injury complex is estimated to affect 1–3% of blunt trauma admissions [1•]. Prompt recognition of this injury and appropriate treatment can reduce the rate of stroke and prevent associated morbidity and mortality [2–5]. Over the past 30 years, there have marked improvements in screening protocols and diagnostic imaging technology, with modern series reporting a BCVI-related stroke rate of under 5% in treated patients [1•, 6•, 7•]. Continued work to refine screening protocols to identify all at-risk patients [8•], and elucidating the ideal treatment regimens [9, 10] and follow-up [1•, 11] are still areas of active investigation.

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Historical Overview

Blunt cerebrovascular injuries (BCVI) were likely first described in the late nineteenth century [12]. Following this description, there is a relative paucity of literature on the subject for the majority of the twentieth century until Crissey and Bernstein described a delayed carotid injury following blunt trauma to the neck [13] in 1974 and laid out four postulated mechanisms of blunt injury to the vessels of the neck: direct blow to the neck; hyperextension with contralateral rotation of the head; laceration of an artery by immediately adjacent fractured bone (sphenoid or petrous bones); and intraoral trauma [13, 14]. Thought to be an extremely rare complication of blunt force trauma, the subject was widely under-described and under-reported in the medical literature until an increased awareness of the true burden of this injury pattern began to come to light in the late 1980s and early 1990s. Early work on this subject in the 1980s was primarily small case series [15–17] and generally described this injury pattern as rare or “distinctly unusual” [16].

Despite the relatively small numbers of patients reported in these series, there is evidence in this early period that some of the salient features of BCVI were beginning to be identified. First, Pozzati and colleagues described a latent period following injury and prior to stroke in 1989; they reported on an asymptomatic period of 2 weeks to 6 months in five patients with blunt carotid artery injuries [18]. Second, the role of diagnostic angiography was established by the Memphis group in a report of 56 patients with CAI; they further suggested a management strategy based on anatomic defect [4]. Finally, the recognition that patterns of injury predispose patients to BCVI was reported during this early period [3, 19, 20].

Throughout the 1990s, however, the overall rate of BCVI was described as low or rare; Davis and colleagues identified a rate of injury in 0.1% of blunt trauma patients in their retrospective series [3], while Martin et al. reported on eight patients with BCVI over a 10-year period [19]. As knowledge of this perceived rare clinical entity increased, the high mortality and morbidity associated with these injuries also began to be recognized. In 1995, Ramadan et al. reported a 17% mortality and 28% stroke rate in a cohort of 82 BCVI patients over a 6-year period [21], while Fabian and colleagues reported a 31% mortality among the 67 patients (87 vessels injured) with an identified BCVI [22]. It is also worthwhile to note that the Memphis group's 1996 paper is one of the first to comment on the importance of anticoagulation in preventing morbidity and improving mortality BCVI patients [22]. They also called for a more liberal screening paradigm to help identify at-risk patients [22].

Building on this growing understanding of the true frequency of BCVI in blunt trauma patients, the other critical early finding in this area of research was the recognition that not all BCVI patients present with stroke; there is a clinically silent period, or asymptomatic period, during which intervention can help prevent stroke [2, 16, 23]. In order to diagnose BCVI in these asymptomatic patients prior to neurologic insult, screening criteria based on radiologic and clinical findings were developed and implemented beginning in the mid-1990s. Biffl and colleagues described the institution of liberal screening criteria at Denver Health beginning in 1996 in an attempt to capture these asymptomatic patients [24], while the Memphis group reported on increasing screening for diagnosis of BCVI in 2001 based on recognition of injury patterns based on patients treated 1995—1999 [25]. These two groups of investigators would become the dominant voices for institution and refinement of screening criteria, with the Denver Guidelines being widely disseminated and instituted throughout the early 2000s [7•, 26, 27].

As the mechanism of injury and neurological sequelae of BCVI became better understood and more widely reported in the medical literature, there was a concomitant refinement in the available technology for diagnosis of BCVI. Formal cerebral angiography remained the sole diagnostic technique for much of the early period of work examining BCVI. Early reports of the possible utility of computed tomography angiography (CTA) in the early 2000s by Biffl et al. identified a sensitivity of 68% based on a subset analysis of patients who underwent both angiography and CTA of the neck [28]. These early CT scanners were 8 or 16-slice detectors, yet there were encouraging early reports of the diagnostic sensitivity of a non-invasive imaging option [29]. Additional investigations in this area questioned the true sensitivity of CTA; the Memphis group reported a 47% sensitivity for CTA to identify CAI as compared with cerebral angiography among these early-generation CT scanners [30]. As CTA technology continued to improve, so too did reports of the increased sensitivity of CTA and its expanding role as a screening examination of patients at risk for BCVI [31•, 32–36]. Consequently, more and more centers adopted a BCVI screening protocol that incorporated CTA imaging in an attempt to identify all at-risk patients [7•, 8•, 29, 31•, 37, 38•, 39–41].

These foundational decades of research led to the publication of practice management guidelines from the Western Trauma Association (WTA) and the Eastern Association of Trauma (EAST) in 2009 and 2010, respectively [42•, 43•]. As we enter into the next phase of research in BCVI, multiple centers are investigating how to improve diagnostic algorithms, and to identify optimal treatments for BCVI patients hence minimizing the attendant morbidity and mortality of this injury [1•, 6•, 10–12, 44–47].

Screening Algorithms in Evolution

Recognition of the clinically silent period of BCVI following injury led to efforts to identify patients at risk for BCVI [25]. The Denver group instituted a liberal screening protocol in 1996 of asymptomatic patients that included "an injury mechanism compatible with severe hyperextension or flexion and rotation of the neck; significant soft-tissue injury of the anterior neck; cervical spine fracture; displaced midface fracture or mandibular fracture associated with a major injury mechanism; and basilar skull fracture involving the sphenoid, mastoid, petrous, or foramen lacerum" [24]. This description marks one of the earliest guidelines for screening patients deemed at risk for BCVI based on radiographic and clinical findings. The Memphis group described a similar screening strategy that included "all patients with cervical spine fractures, LeFort II or II facial fractures, Horner's syndrome, skull base fractures involving the foramen lacerum, neck soft tissue injury, or neurological abnormalities unexplained by intracranial injuries" [30]. These two centers became the dominant voices in the medical literature with respect to screening guidelines. Based upon these early descriptions, and with the growing knowledge of this injury complex, additional centers developed their own institution-specific screening criteria in an attempt to identify patients at risk for BCVI: Eastman described a modification of the Denver criteria as published in 1999 [48] adopted by the Parkland group that included "Lateralizing neurologic deficit not explained by CT head, infarct on CT head, cervical hematoma (non-expanding), massive epistaxis, anisocoria/Horner's syndrome, GCS score <8 without significant CT findings, cervical spine fracture, basilar skull fracture, severe facial fracture (LeForte II or III only), seatbelt sign above the clavicle, or cervical bruit or thrill" [7•], while the Baltimore group described a screening algorithm "using an expanded version of the current EAST trauma guidelines… BCVI screening parameters: skull base fracture, cervical spine injury (both fracture and ligamentous injury), displaced facial fractures, mandible fractures, GCS score of 8 or less, significant flexion or 'clothesline' mechanism, hard signs of neck vascular injury, or focal neurologic deficits" [31•]. Each of these authors describe slight adjustments to the originally published guidelines based on institutional practice patterns and the creation of guidelines as developed in a multi-disciplinary fashion [7•, 31•], a recommendation made as a part of the Western Trauma Association 2009 guidelines [42•].

As BCVI became increasingly identified via screening protocols, there was an awareness that specific screening criteria alone did not capture all patients at risk for BCVI. Stein and colleagues from Baltimore identified a cohort of 147 patients with BCVI, of whom 22% would not have been identified by classic radiologic or clinical findings [49]. Additional research from the Baltimore group identified a more contemporary cohort of 16,026 screened patients between July 2009 and January 2012, of whom 256 patients were diagnosed with BCVI based upon whole-body CT scanning (the default scanning protocol for blunt polytrauma patients at the R Adams Crowley Shock Trauma Center); 56 of these patients (30% of all patients with BCVI) did not have any clinical or radiographic risk factors for BCVI identified based upon expanded EAST guidelines [31•]. Emmet and colleagues from Memphis also reported on the potential for missed injuries by relying on clinical or radiographic criteria alone; in their series of 748 screened patients, 117 patients were found to have BCVI, of whom 19 (16%) had no conventional criteria for BCVI screening [50]. Prompted by these reports, the Denver group undertook efforts to expand screening criteria in an attempt to capture the approximately 20% of patients not identified by the classic screening criteria [1•]. They identified complex skull fractures, upper rib fractures, mandible fractures, scalp degloving injuries, and great vessel injuries as risk factors that should be included in screening criteria; this effort led to the most recent iteration of BCVI screening guidelines used at Denver Health Medical Center [1•] (Fig. 1). Recent work from University of California at Irvine supports the expanded Denver criteria; these authors report an examination of the National Trauma Databank that identified a statistically significantly higher rate of BCVI detection among blunt trauma admissions (0.19% versus 0.22%, $P < 0.001$) when comparing the "classic" Denver Criteria to the expanded criteria [38•]. Likewise, the use of the expanded Denver criteria has been supported by additional authors' reports on institutional experience with BCVI screening from a variety of centers [44, 47].

The ideal screening criteria would identify all patients at risk for a specific disease, allowing clinicians to identify and treat patients to prevent attendant morbidity or mortality. While this remains the goal of BCVI screening, there remain clinicians who doubt the clinical utility of formulated screening criteria. In addition to early reports from Baltimore about the significant proportion of patients in whom no clinical or radiologic risk factors exist to prompt screening as well as the questionable utility of treatment [31•, 49], other authors have advocated for routine CTA of the neck in any trauma patient undergoing CT of the head or neck alone [41]. Jacobson and colleagues performed a pre- and post-protocol analysis of the use of routine CTA of the neck in any blunt trauma patient undergoing either a CT of the cervical spine or a CTA of the chest. They found that in addition to a marked increase in the number of patients undergoing CTA of the neck (1.5% versus 19% of all blunt trauma patients), they also found a significantly increased number of BCVI following implementation of this protocol (0.2% incidence versus 1.1%) [41]. Perhaps even more compelling, and adding to the experience of investigators in Baltimore, Jacobson and his coauthors identified 37% of patients in their cohort with BCVI who met no screening criteria guidelines, echoing the results published by Stein and Bruns [31•, 41, 49].

Although thorough and evidence-based screening guidelines currently exist for screening for BCVI, it is important for all clinicians to realize that a mere list of injuries cannot substitute for clinical judgment. While it is important to note and understand the evolution of screening criteria based on radiologic and clinical criteria, it is likewise of paramount importance to understand that the mechanism of injury is equally as important for the clinician to entertain the possibility that the patient could have a BCVI. There are numerous reports of patients identified to have a BCVI without radiologic or clinical criteria that would prompt screening by either the Denver or Memphis criteria [31•, 41, 51], but missing in these reports is the notion that clinician judgment can add to the existing screening criteria. To take one example, Ritter and Kraus describe a case report of a 26-year-old woman involved in a motorcycle collision as an un-helmeted passenger who was thrown from the motorcycle and was noted to lose consciousness immediately following the accident and to be concussed at the time of arrival of paramedics [51]. Though these authors make clear that thorough radiographic investigations demonstrated only a dislocated shoulder, this patient clearly has a high energy mechanism of injury with concomitant chest and head trauma (though she did not have an intracranial lesion, she lost consciousness following the accident), both of which are risk factors for BCVI as identified in the

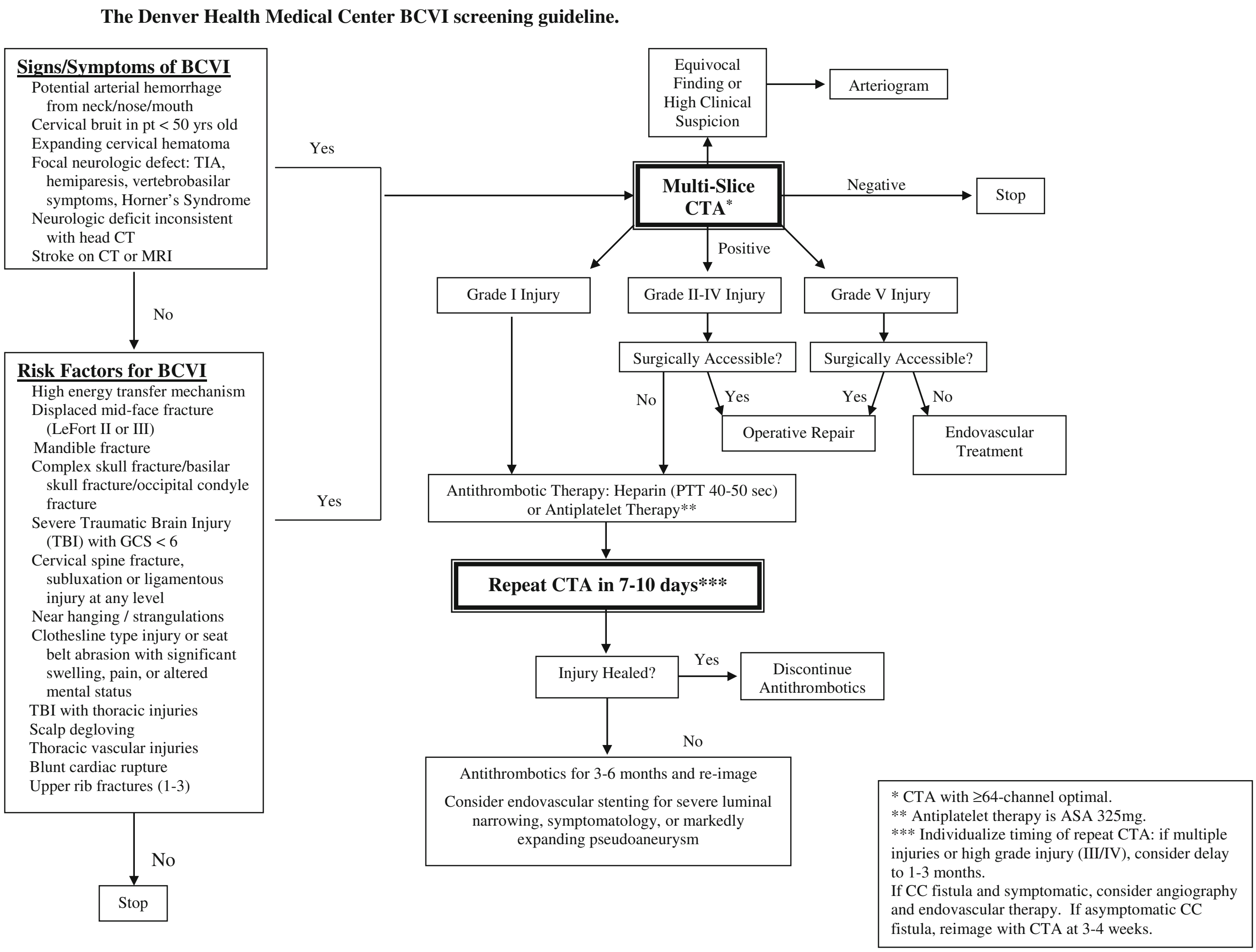

Fig. 1 The Denver Health Medical Center BCVI screening guideline

current iteration of Denver Health BCVI screening guidelines (Fig. 1).

The timing of BCVI screening is likely an under-investigated area of research. While there are numerous centers that have written extensively on the criteria for inclusion in screening, far fewer have commented on the timing of this screening. Buch and colleagues at Boston University, in addition to refining the Denver criteria, have devised a screening protocol that triages patients based on injury mechanism into those who should undergo immediate CTA screening versus those who can undergo such screening within 24–48 h following presentation [52]. Injuries that prompt an immediate CTA include skull-base fractures, cervical spine fractures, cervical spine injury, soft tissue injury to anterior neck, significant neurological deficit (e.g., lateralizing sign, Horner's syndrome, TIA), or evidence of brain infarct on CT. Injuries that would prompt a CTA examination within 24–48 h following presentation include diffuse axonal injury, complex facial fractures, combined significant head and chest trauma, near-hanging, seatbelt abrasions on the neck, or other unexplained neurologic deficits [52]. These investigators examined a 4-year period (2007–2010) of all blunt trauma admissions, of whom 432 were screened for BCVI and 46 (10.6%) were found to have BCVI. Analysis of these patients identified a strong association with skull base fracture or cervical spine fracture and BCVI as identified by CTA (31 of 46, 67.4%, $P < 0.001$), though failed to identify an association with isolated mid-face fracture and BCVI [52]. What is unclear from these authors' work is the reason for delay in BCVI screening among the second cohort of patients. Current evidence supports early screening for BCVI with appropriate institution of antithrombotic treatment to prevent stroke [10, 42•, 43•].

Diagnostic Imaging

While many centers have adopted BCVI screening criteria that rely on the use of CTA for confirmation of diagnosis, the early body of literature published following increased awareness of BCVI in the mid-1990s initially relied solely on formal digital subtraction cerebral angiography for diagnosis [22–25, 30]. As CTA technology has improved, there has been an increasing number of reports of the feasibility of CTA-based algorithms for BCVI screening [6•, 7•, 12, 29, 31•, 37, 38•, 39, 41, 49, 53–56]. During this technical evolution, however, there were controversies surrounding the exact role that CTA should play. The Memphis group, long advocates of assessment of patients at risk for BCVI with formal angiography, published multiple reports comparing CTA and angiography. An early report from 2002 demonstrated that compared with angiography, CTA had a 47% sensitivity in detecting CAI and a 53% sensitivity in detecting VAI, calling into question the appropriateness of relying on CTA technology alone for BCVI screening [30]. Subsequent reports from other centers demonstrated vastly superior sensitivities to the early experience in Memphis; the Parkland group, using a 16-channel CT scanner, demonstrated a 100% sensitivity in detecting BCVI among a cohort of 146 patients who underwent both CTA and angiography [57]. These and other reports of the relatively high sensitivity and high negative predictive value of 16-slice and greater CTA [34, 58] helped prompt CTA-based screening recommendations to be included in both the EAST practice guidelines [43•] and the Western Trauma guidelines [42•]. In part, it is likely that the combination of steadily improving CT technology, increased experience in radiologic interpretation of these studies, and the desire to spare patients the small but real risks of invasive angiography (catheter site hematoma, retroperitoneal bleeding, injury to femoral artery, contrast nephropathy, iatrogenic stroke) [59, 60] helped spur investigators to continue to examine the role of CTA-based imaging guidelines. The Memphis group has recently published an updated longitudinal experience at their center in the diagnosis of BCVI and, of note, now relies on a CTA-first guideline with confirmatory angiography reserved for positive findings on CTA [45].

Alternative non-invasive imaging technologies have been examined for what role, if any, they can play in the detection of BCVI. Early experimental models of comparing ultrasound with arteriography were initially promising, boasting an 86% sensitivity in the detection of these injuries [61], but in general, this technology has fallen out of favor as the majority of lesions are in anatomically inaccessible places (base of the skull) to permit ultrasound examination. The appeal of magnetic resonance imaging (MRI) technology—sparing patients iodinated contrast, greater sensitivity in detecting cerebral ischemia—prompted early investigators to examine a possible role for this technology in the diagnosis of BCVI. Biffl and colleagues not only reported on a small subset of patients who underwent both magnetic resonance angiography (MRA) and angiography and noted a sensitivity of 75%, but also report that multiple injuries were misclassified and that MRA had a positive predictive value of only 43% [28]. A contemporaneous analysis of MRA versus angiography by Miller et al. demonstrated sensitivities of 50% for CAI and 47% for VAI [30]. A more recent systematic review of MRA in the diagnosis of BCVI reported ranges of sensitivities of 25–85% and specificities of 65–99% using MRI technology, but noted that there were only a small number of studies from which to extrapolate this data [62]. Furthermore, MRI technology may be difficult to obtain after hours, and blunt polytrauma patients may have incompatible hardware or other clinical factors that preclude it from use [14].

Conclusions

It is important for the clinician to have a high index of suspicion for BCVI in blunt trauma patients. The benefits of early recognition and diagnosis have been well-established, and prompt initiation of treatment can radically reduce stroke risk and attendant morbidity and mortality among this patient population. Future areas of research include optimizing screening protocols, treatment regimens, and long-term follow-up.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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