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Risk factors for blunt cerebrovascular injury in the pediatric patient: A systematic review

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ABSTRACT

Background: While blunt cerebrovascular injury (BCVI) is a rare complication of blunt trauma, it is associated with significant morbidity and mortality. In the pediatric population, unique anatomy and development require screening criteria that accurately diagnose these injuries while limiting unwarranted radiation.
Methods: We searched Medline OVID, EMBASE, and Cochrane Library databases for studies that investigated the risk factors of BCVI in individuals younger than 18 years of age. We adhered to the Preferred Reporting Items in Systematic Reviews and Meta-Analyses (PRISMA) guidelines and assessed the quality of each study using the Newcastle-Ottawa Scale. We compared key characteristics of the papers, including incidence of BCVI, incidence of risk factors, and statistical significance of risk factors.
Results: Of 1304 studies, 16 met the inclusion criteria. Of these, 15 were retrospective cohort studies and one was a retrospective case control study. Most of the studies included all pediatric blunt trauma admissions, but four only included those which underwent imaging, one only included those with cervical seatbelt sign, and one excluded those who did not survive 24-h post-admission. The ages included as pediatric varied between papers. Papers examined different risk factors and reported differing statistical significances. Though no single risk factor was found to be statistically significant in every study, cervical spine and skull fractures were found to be significant by most. Maxillofacial fractures, depressed GCS score, and stroke were found to be statistically significant by multiple studies. Twelve studies examined cervical soft tissue injury, and none found it to be statistically significant.
Conclusions: The risk factors most found to be statistically significant for BCVI were cervical spine fracture (10/16 studies), skull fracture (9/16), maxillofacial fractures (7/16), depressed GCS score (5/16), and stroke (5/16). There is a need for prospective studies on this topic.
Level of evidence: Level III, Systematic Review.

1. Background

Though the true incidence of blunt cerebrovascular injury (BCVI) in pediatric trauma patients is debated; the severe consequences of this injury have been a stimulus for research in the past decade. One area that has been investigated is risk factors of BCVI. This is of particular importance because the most widely used-diagnostic test for BCVI, CT angiography, involves radiation exposure [1]. Children are significantly more vulnerable to complications of radiation on account of their small body size and increased chance of lifetime exposure [2]. While avoiding unnecessary CTA in children is an important goal, diagnosing BCVI is critical due to the potential complication of strokes and other serious neurological sequelae [3]. Many of these adverse neurologic events can be silent, occurring hours to days after an injury [3]. Timely diagnosis allows for early therapy that may reduce the incidence of stroke, making effective screening for children at risk for BCVI paramount [4,5].

Currently, there are several screening criteria for BCVI that include different risk factors. Earlier screening tools, including the Denver criteria, Memphis criteria, and EAST criteria, were not derived in pediatric populations, but have been applied to children [4]. More recently, screening criteria such as the Utah and McGovern scores were created

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specifically for screening for BCVI in children. Screening criteria is heterogeneous, often dependent on the institution at which it was derived.

We hypothesize that examination of the literature will reveal common risk factors for pediatric BCVI that can be used to optimize screening for this type of injury.

2. Methods

2.1. Design

We conducted a systematic review according to Preferred Reporting Items in Systematic Reviews and Meta-Analyses (PRISMA) guidelines [6]. Using a pre-determined protocol, we performed a systematic search of the OVID Medline, EMBASE, and Cochrane Library databases. All databases were last searched in January 2023. The search protocol for this systematic review was registered with the University of York Center for Reviews and Dissemination of the National Institute for Health Research PROSPERO database (registration no. CRD42022308691).

2.2. Selection of studies

The search strategy is summarized in Appendix A. We structured our search around the population, intervention, comparison, outcome (PICO) framework to address the question, "What are the risk factors for blunt cerebrovascular injury in pediatric patients?" [7] We identified studies evaluating the association of several different screening criteria with incidence of BCVI. We did not include studies which did not examine risk factors in relation to incidence of BCVI. Eligible studies included randomized control trials, non-randomized control trials, and retrospective or prospective cohort studies. We limited the search to those including children ≤18 years. We excluded case reports, opinion pieces, review articles, and studies involving non-human subjects. We did not

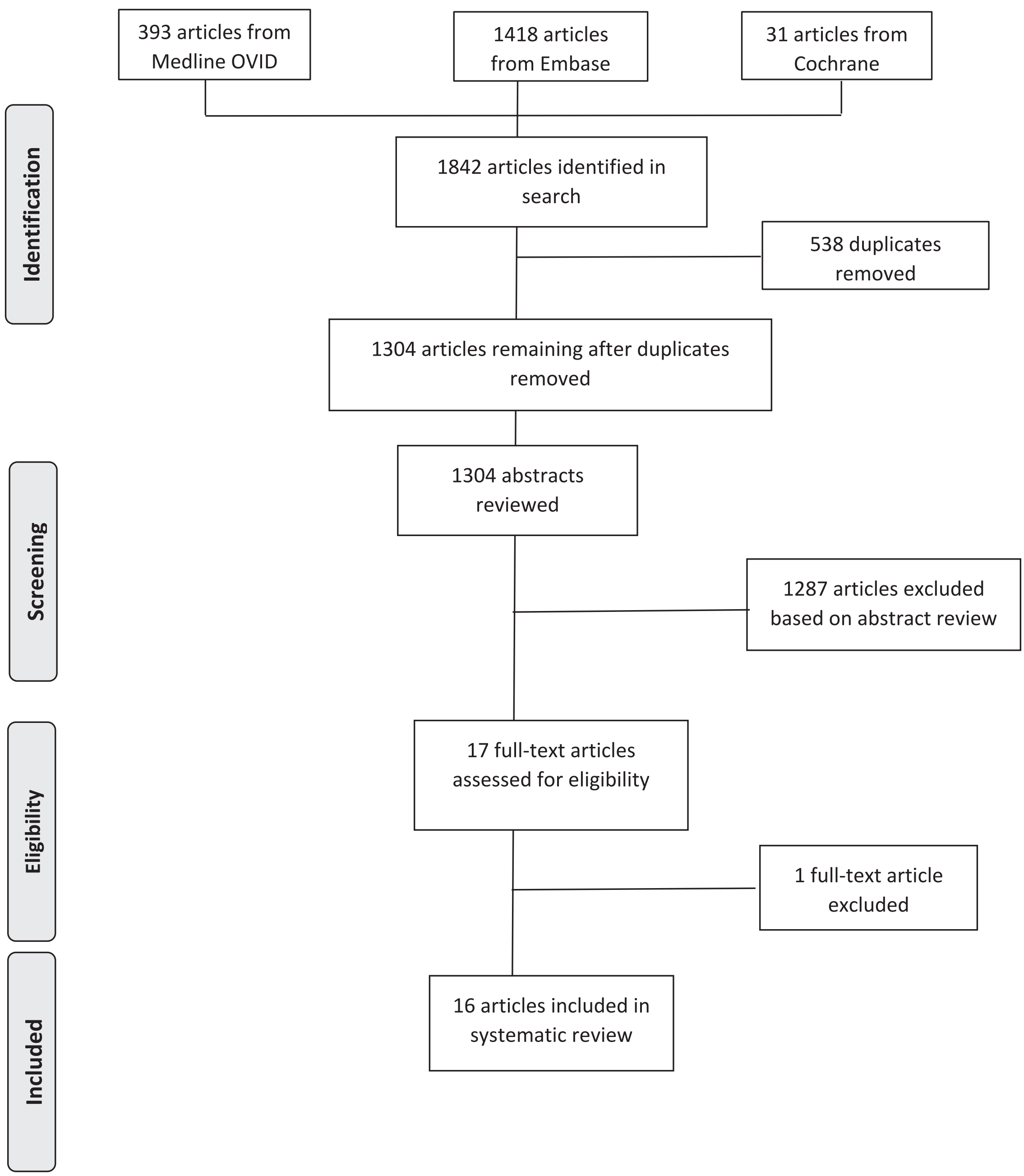

Fig. 1. PRISMA flow diagram.

Table 1
Source summaries.

Source	Design	Population	Outcome/Control			Newcastle-Ottawa scale appraisal			
			BCVI	Sample size (number of patients)	Prevalence	Selection	Comparability	Outcome	Total
Azarakhsh	Retrospective cohort	blunt trauma patients <15 years old admitted to six level 1 trauma centers between October 2009 and June 2011	27 BCVI in 23 patients	5829	0.4%	4	0	3	7
Cook	Retrospective cohort	blunt trauma patients ≤18 years treated at level 1 trauma center from 2005 to 2015	128 BCVI in 96 patients	7440	1.3%	4	0	3	7
Desai	Retrospective cohort	blunt trauma patients <18 years old at two pediatric trauma centers between March 2002 and November 2012 who underwent CTA of the neck	9 BCVI in 8 patients	137	5.8%	4	0	3	7
Dewan	Retrospective cohort	patients <18 years old who underwent CTA evaluation of the head or neck for suspected traumatic BCVI at 4 pediatric trauma centers from 2003 to 2013	57 BCVI in 52 patients	645	8.1%	4	0	3	7
Farzaneh	Retrospective cohort	blunt trauma patients ≤ 18 years from National Trauma Data Bank from 2007 to 2015	1998 patients	885,100	0.2%	4	0	3	7
Grigorian	Retrospective cohort	blunt trauma patients <16 years old registered in the Pediatric Trauma Quality Improvement Program from 2014 to 2016	109 patients	69,149	<0.2%	4	1	3	8
Herbert	Retrospective cohort	blunt trauma patients ≤15 years treated at level I trauma center between 2005 and 2015	21 patients	12,614	0.17%	4	0	3	7
Kopelman	Retrospective cohort	blunt trauma patients <15 years presenting over a 5-year period at level 1 trauma center	14 BCVI in 11 patients	1209 patients	0.9%	4	0	3	7
Leraas	Retrospective cohort	Blunt trauma patients ≤18 years registered in the national trauma data bank from 2008 to 2014	809 patients	422,181 patients	19.2 per 10,000 cases	4	2	3	9
Mallicote	Retrospective cohort	blunt trauma patients ≤18 years presenting at level 1 trauma center from 2005 to 2013; blunt trauma patients ≤18 years in National Trauma Data Bank from 2007 to 2014	1 patient;2136 patients	2795 patients; 776,355 patients	0.03%; 0.27%	4	2	3	9
Ravindra (2015)	Retrospective cohort	patients <18 years who underwent CTA during examination for BCVI at Primary Children's Hospital from 2003 to 2013	37 BCVIs in 36 patients	234 patients	15.4%	4	0	3	7
Rossidis	Retrospective case control	blunt trauma patients ≤18 years evaluated at The Children's Hospital of Philadelphia from January 2005 to January 2015.	11 patients	11,596 patients	0.095%	4	2	3	9
Savoie	Retrospective cohort	blunt trauma patients <18 years old registered in National Trauma Data Bank from 2007 to 2014	1682 patients	732,702 patients	0.2%	4	0	3	7
Tolhurst	Retrospective cohort	patients 4–18 years evaluated for blunt cervical spine trauma from 1998 to 2008	7 patients	61 patients	11.5%	4	0	3	7
Ugalde	Retrospective cohort	Blunt trauma patients <18 years at level 1 trauma center from November 2002–December 2014	53 patients	11,446 patients	0.4%	4	1	3	8
Weber	Retrospective cohort??	Blunt trauma patients <18 years with ISS > 9 from 2002 to 20,015	42 patients	8128 patients	0.5%	4	0	3	7

include abstracts. We did not exclude studies based on date of publication, language, or country of origin.

2.3. Appraisal of studies

Two reviewers identified relevant studies through a review of titles and abstracts against the exclusion criteria. A third reviewer resolved discrepancies. The same two appraisers completed a full-text review of all identified studies to confirm study inclusion. The reviewers appraised the quality of each selected study using the Newcastle-Ottawa Scale for non-randomized cohort studies and case control studies as appropriate. The Newcastle-Ottawa Scale awards points for methodological quality. A third reviewer resolved discrepancies.

The reviewers aligned the interpretation of the Newcastle-Ottawa Scale score among the chosen studies to ensure consistency [8]. For representativeness, if a study included blunt trauma patients cared for in hospital, we considered the study to be "truly representative of the average pediatric blunt trauma patient with potential BCVI in the community." For ascertainment of exposure, we considered trauma registries and electronic medical records as "secure records." For "demonstration that outcome of interest was not present at the start of the study, we assigned all studies as "yes." For comparability, we assigned 1 point if a study controlled for one factor, two points if the study controlled for >1 factor, and 0 points if the study did not adjust for any factors. For assessment of outcome, we accepted registries and medical records as "independent blind assessment." We assumed that all studies had adequate follow-up for our primary outcome of BCVI to be identified.

2.4. Data extraction

Two reviewers extracted data from each of the identified papers. Data extracted included study design, population, and sample size, and overall incidence of BCVI. For each of the papers, we determined which potential risk factors for BCVI were examined and what the association with each of these risk factors were with incidence of BCVI. Discrepancies were discussed and resolved by the reviewers.

2.5. Data analysis

Our a priori plan was to perform a meta-analysis of associations between screening criteria and incidence of BCVI if the systematic review indicated a range of studies with suitable structure and quality. Outcomes were displayed in Tables C—D as 1. incidence of each risk factor among known BCVI cases and 2. incidence of BCVI among those with each risk factor.

3. Results

Of the 1304 citations identified in the search, 16 studies (reporting on 1,374,676 patients) met the eligibility criteria of the systematic review (Fig. 1 A; Table 1, Table 2). All studies were available in English. The types of study designs included retrospective cohorts ($n = 15$) and a retrospective case control study (n = 1). All studies were conducted at institutions in the United States. All studies measuring gender involved mostly male patients (range = 54.7% - 90.9%), and all patients were under the age of 18 years.

There was variation in the patient inclusion criteria between the studies. While the majority of studies included all patients admitted for blunt trauma evaluation, four of the studies included only those who had imaging such as CTA or MRI done [5,9-11]. One study excluded patients who did not survive 24 h post admission [4]. While all studies included pediatric patients, the specific ages varied between studies. Five studies included patients ≤ to 18 years [4,12-15], six studies included patients <18 [5,9,10,16-18], one study included patients <16 [19], one study included patients ≤15 [20], two included those <15 [21,22], and one study included only those 4–18 years old [23].

All studies examined the incidence of BCVI as an outcome in their patient population, but there was significant variation in the potential risk factors for BCVI examined by each of the studies. Risk factors examined included injuries to the head and neck: cervical spinal injury, seatbelt sign, basilar skull fracture, Le Fort II/III fracture, maxillofacial fracture, mandible fracture, facial injury, intracranial injury, fracture through carotid canal, petrous temporal bone fracture, cervical cord injury w/o fracture, diffuse axonal injury, scalp degloving, epistaxis, jugular venous injury, clothesline injury. Some risk factors included specific neurologic signs, such as focal neurologic deficit, GCS ≤8 or < 8, Rotterdam score > 3, stroke on imaging, aniscoria, and cranial nerve injury. Other risk factors included systemic signs such as ISS >15, hypotension on admission, and significant blood loss. Others included injuries to other parts of the body, such as extremity fracture, upper or lower extremity injury, scapula fracture, abdominal injury, pelvic injury, thoracic fracture, thoracic/chest injury, spinal injury, lumbar fracture, blunt cardiac injury, clavicle fracture, and rib fracture. The mechanism of motor

Table 2
Summary of statistical significance of risk factors.

Source	Risk Factor Summary
Azarakhsh	No statistical analysis available.
Cook	No statistical analysis available.
Desai	No single risk factor for BCVI met statistical significance except for GCS score. Mean GCS score significantly lower ($P = 0.02$) in the BCVI group vs the non-BCVI group
Dewan	No statistical analysis available.
Farzaneh	Skull fracture, extremity fractures, and vertebral injuries were associated with an increased risk for BCVI.
Grigorian	Factors independently associated with BCVI include skull base fracture, cervical spine fracture, intracranial hemorrhage, GCS ≤8, and mandible fracture. MVC not an independent predictor.
Herbert	Factors statistically significantly associated with BCVI include focal neurological deficit, carotid canal fracture, petrous temporal bone fracture, cerebral infarction, and automobile-pedestrian accident.
Kopelman	Basilar skull fracture, cervical spine fracture, and GCS score </= 8 was all found to be statistically significant risk factors for the presence of a BCVI. The highest risk of having a BCVI was the presence of a concerning neurologic examination.
Leraas	Pediatric patients did not experience correlation between BCVI and cervical soft tissue injury. All other examined risk factors were statistically significant.
Mallicote	Basilar skull fracture, cervical spine fracture, cervical fracture, cervical cord injury, cervical subluxation/dislocation, jugular venous injury, thoracic vascular injury, and cranial nerve injury are all associated with BCVI.
Ravindra	(2015 finding) - GCS <8, focal neurologic deficit, carotid canal fracture, petrous temporal bone fracture and stroke on imaging are independent risk factors for BCVI.
Rossidis	The independent risk factors significantly associated with BCVI were cervical spine fracture, male gender, Le Fort II or III facial fracture, and ISS.
Savoie	Cervical spine fracture, skull base fracture, diffuse axonal injury, Le Fort II/III fracture, mandible fracture associated with BCVI.
Tolhurst	Cervical spine fracture extension to transverse foramina, fracture/dislocations or severe subluxations, or C1-C3 injury associated with increased rates of BCVI.
Ugalde	Independent predictors associated with BCVI were ISS ≥16, infarct on head imaging, hanging mechanism, cervical spine fracture, and basilar skull fracture.
Weber	Independent predictors associated with an increased risk of BCVI include cervical spine injury, facial injury, basilar skull fracture, and ISS.

Table 3
Number of patients with BCVI who had each risk factor.

Source	Risk Factor								Outcomes
	Cervical spinal injury (16)	Basilar skull fracture (13)	GCS (12)	Soft tissue injury of the neck (ie. seatbelt sign) (12)	Stroke on imaging* (12)	Motor Vehicle Collision/Accident (12)	Le Fort II/III fracture (midfacial fracture) (10)	Neurologic Deficit (7 or 8)	Stroke (12)
Azarakhsh	1/23 (4.3%)	7/23 (30.4%)	–	4/23 (17.4%)	6/23 (26.1%)	–	0/23 (0%)	0/23 (0%)	6/23 (26.1%)
Cook	38/96 (40%) (cervical spine fracture)	21/96 (22%) (basilar fracture w/ carotid canal involvement)	64/96 (67%) GCS </= 8; median GCS 3	–	17/96 (18%)	60% (58/96)	25/96 (26%)	63/96 (66%)	17/96 (18%)
Desai	2/8 (25%), PPV 0.09, NPV 0.95, Sn 0.25, Sp 0.84, $p = 0.62$ (cervical spine fracture.)	4/8 (50%), PPV 0.14, NPV 0.96, Sn 0.50, Sp 0.81, $p = 0.05$	mean GCS, 8.67 =/− 6.22, $p = 0.2$	⅛ (12.5%)	1/8 (12.5%)	3/8 (37.5%)	–	–	1/8 (12.5%)
Dewan	4/52 (7.7%)	–	26/52 (50%) (GCS</=7)	3/52 (5.8%)	16/52 (31%)	18/62 (35%)	–	18/52 (35%)	16/52 (31%)
Farzaneh	31/1998 (2%) (cervical fracture)	129/1998 (6.5%) $p < 0.01$; OR 1.004, CI 1.003–1.004, $p < 0.01$ (Any skull fracture)	1149/1998 (57.5%) GCS < 6, OR 0.99993, CI 0.9993–0.9995, $p < 0.001$; mean GCS, 6.3 $p < 0.01$	28/1998 (1.4%) $p < 0.01$	–	710/1998 (35.5%) $p < 0.01$	–	–	–
Grigorian	31/109 (28.4%), $p < 0.001$, OR 3.15, CI 1.91–5.18, $p < 0.001$ (cervical fracture); 5/109 (4.6%), $p < 0.001$ (cervical spine injury)	58/109 (53.2%), $p < 0.001$, OR 3.84, CI 2.40–6.14, $p < 0.001$	49/109 (45.0%) GCS </= 8, OR 2.11, CI 1.33–3.54, $p = 0.003$; median GCS 9, $p < 0.001$	24/109 (22.0%), $p < 0.001$; OR 1.42, CI 0.88–2.29, $p = 0.15$	3/109 (2.3%)	58/109 (53.2%), OR 1.65, CI 0.97–2.81, $p = 0.07$	10/109 (9.2%), $p < 0.001$, OR 1.20, CI 0.62–2.29, $p = 0.59$	–	3/109 (2.3%)
Herbert	3/21 (14.3%)	–	10/21 (47.6%) GCS </= 8	0/21 (0%)	6/21 (28.6%)	11/21 (52.4%)	0/21 (0%)	4/21 (19%)	6/21 (28.6%)
Kopelman	3/11 (27%), RR 30.7 [9.8–96.4]; $p < 0.001$ (cervical fracture)	7/11 (64%), RR 19.9 [11.5–34.4], $p < 0.0001$	5/11 (45%) GCS </= 8, RR 42.6 [18.1–100.4], $p < 0.001$	1/11 (9%)	4/11 (36%)	6/11 (55%)	0/11 (0%)	2/11 (18%)	4/11 (36%)
Leraas	48/809 (5.9%) fracture; 27/809 (3.3%) subluxation; cervical fracture or subluxation OR = 1.0058, CI 1.0052–1.0066 $p < 0.001$	289/809 (35.7%), OR 1.0072, CI 1.0066–1.0078, $p < 0.001$	457/809 (40.4%) GCS </= 8, OR 1.0113, CI 1.0108–1.0118, $p < 0.001$	140/809 (17.3%) OR 1.0002, CI 0.9998–1.0006, $p = 0.212$	53/809 (6.6%), OR 1.0879, CI 1.0838–1.0919, $p < 0.001$	–	264/809 (32.6%), OR 1.0040, CI 1.0035–1.0045, $p < 0.001$	–	53/809 (6.6%), OR 1.0879, CI 1.0838–1.0919], $p < 0.001$
Mallicote	fracture, subluxation, dislocation OR 3.0, CI 2.3–3.8; Cervical Spine Fracture OR 3.6, CI 3.1–4.1; Cervical Spine Fracture w/ Cord Injury OR 12.4, CI 10.2–15.2	OR 3.0, CI 2.6–3.5	GCS </= 8 not an independent risk factor	Not independent risk factor	–	–	Not independent risk factor	–	–
Ravindra (2015)	2/36 (5.6%), $p = 0.60$ ("associated spine fractures")	6/36 (16.7%), $p = 0.80$	26/36 (72.2%) GCS </= 8, $p < 0.001$; OR 2.9 CI 1.2–6.9, $p = 0.020$	–	6/36 (16.7%), $p = 0.01$; OR 5.8, CI 1.5–21.8, $p = 0.01$	11/36 (30.6%)	–	10/36 (27.8%), $p < 0.001$; OR 4.6, CI 1.6–13.0, $p = 0.004$	6/36 (16.7%), $p = 0.01$; OR 5.8, CI 1.5–21.8, $p = 0.01$
Rossidis	6/11 (54.5%), $p < 0.0001$ cervical fracture; OR 36.88, CI 8.36–169.95, $p < 0.0001$	5/11 (45.5%), $p < 0.0001$	5/11 (45.5%) GCS </= 8, OR 16.42, CI 2.16–102.33, $p = 0.0090$; mean 8.2+/− 5.4, $p = 0.0015$	2/11 (18.2%), $p < 0.0001$	–	–	1/11 (9.1%), $p < 0.0001$; OR 63.71, CI 2.16–1124.68, 0.0216	–	–

(continued on next page)

Table 3 (*continued*)

Source	Risk Factor								Outcomes
	Cervical spinal injury (16)	Basilar skull fracture (13)	GCS (12)	Soft tissue injury of the neck (ie. seatbelt sign) (12)	Stroke on imaging* (12)	Motor Vehicle Collision/Accident (12)	Le Fort II/III fracture (midfacial fracture) (10)	Neurologic Deficit (7 or 8)	Stroke (12)
Savoie	307/1682 (18.3%)	713/1689 (42.4%)	–	48/1682 (2.85%)	53/1682 (3.15%)	694/1682 (motorcyclists and car occupants); 9/1982 (unspecified MVT)	237/1682 (14.1%)	–	53/1682 (3.15%)
Tolhurst	7/7 (100%)	–	–	–	–	4/7 (57.1%)		6/7 (85.7%)	
Ugalde	23/53 (43.4%) p</=0.001; OR 3.63, CI 1.86–7.08, $p = 0.000$	26/53 (49.1%) $p = 0.01$; OR 2.1, CI 1.08–4.1, $p = 0.03$	27/53 (50.9%) GCS </= 8, $p = 0.004$	11/53 (20.8%), $p = 0.68$	10/53 (18.9%), OR 3.95, CI 1.57–9.95, $p = 0.003$	31/53 (58.5%), $p = 0.58$	–	–	10/53 (18.9%), OR 3.95, CI 1.57–9.95, $p = 0.003$
Weber	13/42 (31.0%) p</=0.001; OR 8.2, CI 3.3–20.3, $p < 0.001$	13/42 (31.0%) $p = 0.020$; OR 2.4, CI 1.04–5.45, $p = 0.039$	–	–	2/42 (8.3%)	(MVC) 35/42 (85.4%) $p = 0.039$	"Facial injury" 18/42 (42.9%); OR 4.4, CI 2.13–9.20, $p < 0.001$	–	2/42 (8.3%)

vehicle collision was also examined. Four studies examined the likelihood of BCVI when ≥ 2 risk factors were present [13,15,21,22].

The results are summarized in Tables 1-5. In table C—D, risk factors are organized left to right from most to least frequently studied, with risk factors that were included by less than four of the studies being excluded from the tables. Ten studies found cervical spine fracture to be a significant risk factor for BCVI [11-19,22]. Ten studies found skull fracture to be a significant risk factor. Farzaneh found any skull fracture significant, Grigorian, Kopelman, Leraas, Mallicote, Savoie, Ugalde, and Weber found skull base/basilar skull fracture to be significant, and Herbert and Ravindra found specific basilar skull fractures, carotid canal and petrous temporal bone fractures, significant [10,12-14,16-20,22]. Five studies found depressed GCS score to be a significant risk factor. Desai found mean GCS score to be significantly lower in those with BCVI. Grigorian, Leraas and Kopelman found a GCS </=8 significant and Ravindra found GCS <8 significant [9,10,13,19,22]. Similarly, two studies identified focal neurological deficit to be associated with BCVI [10,20]. Three studies found that mandible fractures were significantly associated with BCVI [13,16,19], and three studies found Le Fort II/III facial fractures to be significant [13,15,16]. Weber describes "facial injury" as statistically significant [18]. Five studies found stroke to be a significant risk factor. Ravindra and Leraas simply identify stroke, while Grigorian mentions intracranial hemorrhage specifically and Herbert and Ugalde mention cerebral infarction specifically [10,13,17,19,20]. A high ISS is named by Weber, Ugalde, and Rossidis as a significant risk factor [15,17,18]. Ugalde and Leraas both find hanging mechanism significant, Farzaneh finds extremity fractures significant, and Leraas finds significant blood loss to be a significant association [12,13,17].

Notably, no studies examining the significance of soft tissue injury of the neck/seatbelt sign as an independent risk factor for BCVI found it to be significant [9,12-17,19,20,22].

Based on the Newcastle Ottawa Scale, all studies were rated as "good". However, based upon the varying study populations, designs, and risk factors examined, we opted not to combine the results using meta-analysis.

4. Discussion

Our systematic review of 16 studies of BCVI in pediatric patients revealed large variations in study population and screening criteria used/risk factors examined. The definition of a pediatric patient differed between studies, with some including all patients 18 years and younger and others including only those under 16 or 15 years. One study chose not to include patients under 4, which excludes an important demographic group of patients experiencing blunt trauma. Other notable differences in the inclusion criteria were including using all admitted patients with blunt trauma,only those surviving 24 h, or only those who received imaging for BCVI. Additionally, several of the studies used the National Trauma Data Bank, leading to the likelihood that some patients are represented in multiple studies when study periods overlap.

The risk factors or screening criteria examined in each study also varied greatly. The utilization of stroke differed between studies, with some including it as a risk factor and some as an outcome measure. If a stroke has been identified in the setting of pediatric trauma, it can be assumed that CTA imaging would be obtained. Future studies should include stroke only as an outcome measure to ensure clear imaging guidelines, as the goal of BCVI identification is to prevent secondary complications such as stroke. Due to the heterogeneity of risk factors examined, outcome measures utilized across studies, and population overlap between multiple studies, we concluded that a meta-analysis was not practical. There is a need for further rigorous studies with greater standardization of data and distinct patient populations to fill knowledge gaps regarding BCVI risk factors in children.

Current BCVI screening tools in the pediatric population include the Utah score and the McGovern score. The Utah score awards points for GCS ≤8, focal neurologic deficit, carotid canal fracture, petrous temporal bone fracture, and cerebral infarction on CT. The McGovern score utilizes the same screening criteria but adds an additional two points for mechanism of injury. In the study by Herbert, creators of the McGovern score found that the Utah score did not accurately predict BCVI in their cohort of patients and misclassified 47.6% as low risk [20]. Another multicenter validation study also found a misclassification rate of 40.9% for the Utah score [24]. While the McGovern score in comparison had a misclassification rate of only 19%, there is an opportunity to increase the sensitivity for optimal screening guidelines [20]. Neither of these scores include cervical spine injury, which was found to be significant in several of the studies we examined in this paper. As with the adult screening tools, systematic reviews can help to guide expansion or redefinition of screening criteria used in the pediatric population going forward. Although limited in children, there are multiple reviews of BCVI risk factors in adults. Since its development in the mid-90s, the Denver screening criteria has been examined by several systematic reviews that have helped refine its criteria over the years, including expansion of the criteria in 2011. Subsequent reviews, such as a 2018 review by Brommeland,

Table 4
Number of patients with BCVI who had each risk factor.

Source	Risk Factor								
	Intracranial injury* (8)	Thoracic injury (6)	ISS (6)	>/=2 risk factors/screening criteria* (5)	Mandible fracture (5)	Hanging mechanism (5)	Fracture through carotid canal (4)	Petrous temporal bone fracture (4)	Thoracic Fracture (4)
Azarakhsh	–	–	–	8/23 (34.8%)	–	–	–	–	–
Cook	–	0/96 (0%)	median ISS, 34	–	8/96 (8%)	2/96 (2%)	21/96 (40%)	31/96 (31%)	11/96 (11%)
Desai	5/8 (62.5%); PPV 0.16, NPV 0.95, Sn 0.63, Sp 0.67, $p = 0.13$	–	–	–	–	–	–	–	–
Dewan	35/52 (67%)	–	–	–	–	–	17/52 (33%)	7/52 (13.5%)	–
Farzaneh	399/1998 (20%)	94/1998 (4.7%) $p < 0.01$	1225/1998 (61.3%) ISS > 8 (646/1998 unknown ISS); mean ISS, 25.8, $p < 0.01$	–	–	–	–	–	4/1998 (0.3%)
Grigorian	73/109 (67%) $p < 0.001$; OR, 3.11; 95% CI, 1.89–5.14; $p < 0.001$	2/109 (1.8%) sternum fracture, OR 2.26, CI 0.51–10.05, $p = 0.29$; 1/109 (0.9%) thoracic aorta injury, OR 1.58, CI 0.17–14.30, $p = 0.69$; 37/109 (33.9%) pulmonary contusion, OR 1.15, CI 0.67–1.95, $p = 0.62$; 26/109 (23.9%) pneumothorax, OR 1.91, CI 1.10–3.29, $p = 0.02$ (all incidence $p < 0.001$); 1/109 (0.9%) hemothorax, $p = 0.07$, OR 0.55, CI 0.07–4.30, $p = 0.57$	median ISS 25, $p < 0.001$	–	13/109 (11.9%), $p < 0.001$); OR, 1.99; 95% CI, 1.05–3.84; $p = 0.04$	0/109 (0%), $p = 0.97$	–	–	12/109 (11.0%) $p < 0.001$); OR 1.13, CI 0.57–2.26, $p = 0.72$
Herbert	14/21 (66.7%)	–	–	–	–	–	8/21 (38.1%)	6/21 (28.6%)	–
Kopelman	–	7/11 (67%)	–	6/11 (55%)	–	–	–	–	–
Leraas	–	–	–	432/809 (53.4%)	91/809 (11.2%)	11/809 (1.4%), OR 1.0118, CI 1.0083–1.0153], $p < 0.001$	–	–	–
Mallicote		OR 3.0, CI 2.0–4.4	–	–	OR 1.4, CI 1.2–1.7	–	–	–	–
Ravindra	5/36 (13.9%), $p = 0.90$ epidural hematoma; 11/36 (30.6%), $p = 0.69$ subdural hematoma; 11/36 (30.6%) $p = 0.28$ traumatic SAH	–	–	–	–	0/36 (0%)	16/36 (44.4%), $p = 0.007$; OR 4.3, CI 1.7–10.8, $p = 0.002$	5/36 (13.9%), $p = 0.17$; OR 6.8, CI 1.9–24.6, $p = 0.004$	–
Rossidis	–	–	8/11 (72.7%) ISS>/=15, OR 1.10, CI 1.04–1.17, $p = 0.0276$; mean ISS 26.7 ±12.6, $p = 0.0002$	7/11 (63.6%); RR 7.8, $p < 0.0001$	–	–	–	–	–
Savoie	–	–	–	–	144/1682 (8.56%)	–	–	–	
Tolhurst	–	–	–	–	–	–	–	–	–
Ugalde	33/53 (62.3%) $p = 0.02$	–	13/53 (24.5%) ISS >15, $p = 0.01$; OR 2.17, CI 1.05–4.49, $p = 0.04$	–	–	3/53 (5.7%) $p = 0.09$, OR 8.71, CI 1.52–49.89, $p = 0.015$	–	–	10/53 (18.9%) $p = 0.20$
Weber	"Head injury" 31/42 (73.8%) $p = 0.028$; OR 1.5, CI 0.54–4.05, $p = 0.455$	33/42 (78.6%) $p \leq 0.001$	Mean = 39 $p \leq 0.001$; OR 1.05, CI 1.03–1.07, $p < 0.001$	40/42 (95.2%)	–	–	–	–	–

Table 5
Number of patients with each risk factor that were diagnosed with BCVI

Source	Risk Factor																	Outcome
	Cervical spinal injury (11)	Basilar skull fracture (10)	Motor Vehicle Collision/ Accident (7)	GCS (6)	Intracranial injury (head trauma) * (6)	Le Fort II/III fracture (midfacial fracture) (6)	Soft tissue injury of the neck (ie. seatbelt sign) (6)	Neurologic Deficit (5)	Stroke on imaging* (4)	Hanging mechanism (3)	Thoracic Fracture (3)	Thoracic injury (3)	>/=2 risk factors/screening criteria* (2)	Fracture through carotid canal (2)	ISS > 15 (2)	Mandible fracture (2)	Petrous temporal bone fracture (2)	Stroke (4)
Azarakhsh	1/40	7/283	–	–	–	0/40	4/93	0/18	–	–	–	–	8/63	–	–	–	–	–
Desai	2/23 (8.7%)	4/28 (14.3%)	–	–	5/32 (15.6%)	–	–	–	–	–	–	–	–	–	–	–	–	2/23 (8.7%)
Farzaneh	31/1699 (1.8%)	129/33,139 (0.39%) (any skull fracture)	710/184,887 (0.38%)	1149/324,349 (0.35%) GCS < 6	399/54,992 (0.73%)	–	28/2678 (1.0%)	–	–	–	4/1170 (0.34%)	94/19,002 (0.49%)	–	–	1225/296,293 (0.41%)	–	–	–
Grigorian	31/1964 (1.6%) (cervical frac); 5/142 (3.5%) (cervical spine injury)	58/4949 (1.2%)	58/11,384 (0.51%)	49/2693 (1.8%) GCS</=8	73/10,785 (0.68%)	10/4329 (0.23%)	–	–	–	0/3 (0%)	12/1286 (0.93%)	2/146 (1.4%) sternum fracture; 1/33 (3.0%) thoracic aorta injury; 37/3351 (1.1%) pulmonary contusion; 26/2184 (1.2%) pneumothorax; 1/125 (0.80%) hemothorax	–	–	–	13/999 (1.3%)	–	–
Herbert	–	–	11/220 (5.0%)	10/143 (7.0%) GCS</=8	–	–	–	4/25 (16%)	2/9 (22.2%)	–	–	–	–	8/28 (28.6%)	–	–	6/21 (28.6%)	2/9 (22.2%) of those who presented with stroke
Kopelman	3/13 (23%)	7/41 (17%)	–	5/16 (31%) GCS</=8	–	none of this injury in sample.	1/3 (33%)	2/2 (100%)	–	–	–	–	4/20 (20%)	–	–	–	–	–
Ravindra	2/18 (11.1%)	6/37 (16.2%)	11/60 (18.3%)	26/108 (24.1%) GCS</=8	5/31 (16.1%) epidural hematoma; 11/65 (16.9%) subdural hematoma; 11.54 (20.4%) traumatic SAH	–	–	10/24 (41.7%)	6/14 (42.9%) (ischemic)	0/18 (0%)	–	–	–	16/60 (26.7%)	–	–	5/18 (27.8%)	6/14 (42.9%)
Rossidis	6/151 (3.97%)	5/567 (0.88%)	–	–	–	1/3 (33.3%)	2/139 (1.4%)	–	–	–	–	–	–	–	–	–	–	–
Savoie	2.52% (307/12201)	713/52,976 (1.35%)	–	–	–	237/13,047 (1.82%)	48/26,402 (0.18%)	–	–	–	–	–	–	–	–	144/14,756 (0.98%)	–	–
Tolhurst	7/61 (11.5%)	–	4/31 (12.9%)	–	–	–	–	6/20 (30%)	–	–	–	–	–	–	–	–	–	–
Ugalde	23/86 (26.7%)	26/127 (20.5%)	31/212 (14.6%)	27/126 (21.4%) GCS</=8	33/178 (18.5%)	–	11/86 (12.8%)	–	10/25 (40.0%)	3/8 (37.5)	10/50 (20%)	–	–	–	13/173 (7.5%)	–	–	–
Weber	13/245 (5.3%)	13/1353 (0.96%)	35/5475 (0.64%)	–	"Head injury" 31/4573 (0.68%)	"Facial injury" 18/983 (1.83%)	–	–	2/45 (4.4%)	–	–	33/3438 (0.96%)	–	–	–	–	–	2/45 (4.4%)

helped to confirm the validity of this expanded criteria, and a 2019 review by Bensch has since suggested further augmentations [1,23]. Systematic reviews such as the review by Kim in 2020 continue to support the use of screening criteria for BCVI in adults [25].

These systematic reviews and meta-analyses have been applied to improve care for adult patients; however, their findings cannot be applied directly to the pediatric population. Differences in response to traumatic injury, developmental anatomy, and cerebrovascular reserve all contribute to different manifestations of BCVI than in adults. Anatomic differences such as disproportionately greater weight of the head, immature neck musculature, and higher ligamentous laxity increase forces placed on the head and neck during blunt trauma. Furthermore, children may have some anatomical protection from stroke as the presence of a complete Circle of Willis is greater in children, while an incomplete Circle of Willis increases significantly with age [26]. The latter may result in a decreased capacity for collateral blood flow in the presence of a large vessel occlusion. Not surprisingly, the risk of stroke in untreated BCVI in adults has been reported to be as high as 64% for carotid artery injury (CAI) and 50% for vertebral artery injury (VAI) while the risk of stroke in untreated BCVI in children has been reported to be between 26 and 38%. [21,27-29]

Moreover, the Denver criteria, as well as the Memphis criteria, another commonly used adult-derived screening tool, include soft-tissue neck injury in their scores. Our current review did not find the cervical soft tissue injury or "seatbelt sign" to be associated with BCVI in children. A recent multi-center prospective study comparing the Denver, Memphis, EAST, Utah, and McGovern criteria/scores in a pediatric population, found the Memphis score (which includes cervical spine fracture and basilar skull fracture) to be most sensitive, at 91.7%, but with the lowest specificity, at 71.1% [30]. While limited by the small number of BCVI in the cohort, further refining this rule by removing cervical soft tissue injury, for starters, may allow for increased specificity without significantly compromising sensitivity. An optimal decision rule in children would synthesize what we know from prior studies and use physiological characteristics specific to children to inform a rule. The left and right internal carotid artery arise from the common carotid artery between the 3rd and 4th vertebral level and is most susceptible to blunt trauma at the cervical and petrous segments. It follows that both cervical spine and basilar skull fractures would be considered both anatomically and based on what many prior authors have determined.

Our study has limitations. We may have failed to identify all appropriate studies to include in our review despite a comprehensive search strategy of multiple databases. The included papers were largely retrospective cohorts with no randomized controlled trials. Although the results of observational studies may be influenced by confounders, they are the best representation of available data and therefore included. Additionally, patient overlap and lack of data standardization prevented meta-analysis of the data.

In conclusion, the available research is limited and includes data on a wide range of screening measures. The current review determined that basilar skull fracture, cervical spine injury, and GCS <8 are most commonly found to be significantly associated with BCVI in children, while cervical soft tissue injury or "seatbelt sign" is not associated in any of the studies reviewed. A clear conclusion regarding what variables constitute significant risk factors to guide screening guidelines for BCVI in children is necessary and this systematic review, albeit without a meta-analysis, can be a starting point.

Author statement

The authors of "Risk Factors for Blunt Cerebrovascular Injury in the Pediatric Patient: A Systematic Review," Schulz, Weihing, Shah, Cox, and Ugalde, declare that they have no competing financial interests or personal relationships that affect this work.

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CRediT authorship contribution statement

Madison Schulz: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Veronica Weihing:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Manish N. Shah:** Writing – review & editing, Writing – original draft. **Charles S. Cox:** Writing – review & editing, Writing – original draft. **Irma Ugalde:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

The authors report no conflicts of interest.

Appendix A. Publication search strategy

1. Pediatrics/ or pediatric emergency medicine/
2. Adolescent/ or exp. child/ or exp. infant/
3. ("adolescen* or "child" or "infan*" or "teen*" or "youth*" or "pediatric*" or "paediatric*").ab,kf,kw,ti.
4. 1 or 2 or 3
5. Exp spinal fracture/ or exp. neck injuries/ or exp. cerebrovascular trauma/ or exp. carotid artery injuries/ or exp. vertebral artery dissection/ or exp. vascular system injuries/
6. ("cervical*vascular*injur*" or "cervical*injur*" or "vascular*injur*" or "cervical*vascular*trauma*" or "carotid*injur*" or "carotid*dissect*" or "carotid*trauma*" or "carotid*artery*injur*" or "carotid*artery*dissect*" or "carotid*artery*trauma*" or "vertebral*artery*injur*" or "vertebral*artery*dissect*" or "vertebral*artery*trauma*" or "cerebrovascular*trauma*" or "cerebrovascular*injur*").ab,kf,kw,ti.
7. Exp "intracranial embolism and thrombosis"/ or cerebral hemorrhage, traumatic/ or intracranial hemorrhage, traumatic/ or stroke/ or brain infarction/ or brain stem infarctions/ or infarction, anterior cerebral artery/ or infarction, middle cerebral artery/ or infarction, posterior cerebral artery/ or hemorrhagic stroke/ or exp. ischemic stroke/
8. stroke*.ab,kw,ti.
9. 5 or 6 or 7 or 8
10. Wounds, nonpenetrating/ or contusions/.
11. ("blunt*trauma*" or "blunt*injur*" or "non*penetrating*injur*" or "non*penetrating*trauma*").ab,kf,kw,ti.
12. 10 or 11.
13. Exp skull fractures/ or skull fracture, basilar/ or spinal fractures/ or exp. neck injuries/ or whiplash injuries/ or soft tissue injuries/.
14. Exp neurologic manifestations/ or exp. spinal cord injuries/.
15. ("neurologic*deficit*" or "seatbelt*sign*" or "neck*abrasion*" or "neck*soft*tissue*injur*" or "cervical*spin*injur*" or "cervical*spin*fracture*" or "basilar*skull*fracture*" or "hanging*" or "carotid*canal*fracture*" or "carotid*canal*injur*" or "petrous*temporal*bone*fracture*" or "petrous*bone*fracture*" or "temporal*bone*fracture*" or "neurologic*depression*" or "GCS" or "glasgow*coma*scale*" or "utah*score*" or "utah*screening*criteria*" or "ISS" or "mcgovern*screening*criteria*" or "injury*severity*score*").ab, kf,kw,ti.
16. 13 or 14 or 15.
17. 4 and 9 and 12 and 16.

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