Remember the Vessels! Craniofacial Fracture Predicts Risk for Blunt Cerebrovascular Injury

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Purpose: The risk factors for blunt cerebrovascular injuries (BCVIs) are currently under intensive research, yet it is still controversial who should be screened. This study aimed to determine whether craniofacial fractures are associated with BCVI.

Patients and Methods: This retrospective cohort study focused on patients with suspected polytrauma after whole-body computed tomographic angiography of the cervical arteries. Patients were reviewed for BCVI and craniofacial fractures. Exclusion criteria were hanging injury, gunshot injury or other penetrating injury to the neck, and a cervical fracture on any level. The outcome variable was BCVI, and the main predictor variable was a craniofacial fracture. A secondary predictor variable was a type of craniofacial fracture classified as a facial fracture, skull fracture, or a combination of facial and skull fracture. Other predictor variables were gender, age, and mechanism of injury. In addition, specific craniofacial fractures were analyzed in more detail. The relevance of associations between BCVI and the predictors underwent χ^2 testing. Significance was set at .01.

Results: Four hundred twenty-eight patients 13 to 90 years old during a 12-month period were included in the analysis. Craniofacial fractures occurred in 75 (17.5%). BCVI occurred significantly more frequently in those with than in those without a craniofacial fracture (18.6 vs 7.4%; $P = .002$). Patients with craniofacial fracture had a 4-fold increased risk for BCVI, whereas those 31 to 50 years old had 3.4-fold increased risk. Type of craniofacial fracture, gender, and mechanism of injury were not associated with BCVI.

Conclusion: Craniofacial fractures are a serious risk factor for BCVI. This research suggests that in patients with any craniofacial fracture and suspected polytrauma, rigorous imaging of cervical arteries in search of BCVI is essential.

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Blunt cerebrovascular injury (BCVI) can lead to devastating neurologic sequelae. BCVI occurs in 1 to 2% of all patients with blunt trauma, and in severely injured patients, the incidence can be at least twice as high.[1-5] Early recognition and prompt initiation of treatment of these injuries have resulted in a marked decrease in

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cerebrovascular ischemic insults from 20 to 31% to 0.5 to 9.6%.[3,6-9] If left untreated, mortality associated with these injuries increases to 9 to 13%.[3,4,6]

BCVI diagnosis has been facilitated by the widespread adoption of standardized screening protocols and advances in imaging technology, such as multidetector cervical computed tomographic angiography (CTA). Various screening guidelines are available to identify patients with risk factors suggestive of a possible BCVI, such as the evidence-based guidelines established by the Eastern Association for the Surgery of Trauma (EAST)[10] and the Denver Group guide for practicing physicians in screening, diagnosing, and treating BCVI.[3,6,8,11]

The most common etiology for BCVI is assumed to be hyperextension of the neck, causing stretching of the carotid arteries over the lateral processes of C1 to C3.[11,12] Basic screening guidelines, such as the Denver criteria, include fractures of the upper cervical spine as an indication for BCVI screening. Further studies have suggested expanding screening protocols to include any cervical fracture.[13,14]

The role of facial fractures in BCVIs is not completely understood, and BCVIs can be missed when applying insufficient screening protocols. Mundinger et al[15] investigated 4,398 patients with facial fractures and found BCVI in 1.2%. They also reported that 20% of BCVIs would have been missed by the EAST BCVI screening criteria. Burlew et al[11] similarly reported that one fifth of patients with confirmed BCVI did not meet the Denver screening criteria, and up to one third of them had a mandibular fracture. Geddes et al[16] implemented expanded screening criteria (mandibular fractures, complex skull fractures, traumatic brain injury with thoracic injuries, scalp degloving, thoracic vascular injuries, and upper rib fractures) to include the "missing" 20% of patients with BCVI. They found that 28% of patients with asymptomatic BCVI were identified solely by the new screening indications provided as the expanded criteria. Most current BCVI screening criteria include only Le Fort pattern fractures as an indication for imaging, although a systematic review identified mandibular fractures as the most Q2 common BCVI-associated craniomaxillofacial pattern.[17]

A correlation between skull base fractures and BCVI has been repeatedly reported in previous studies.[1,14,15,18,19] These studies were consistent in indicating skull base fractures as a risk factor for BCVI, although fracture types varied. Previously, the focus was on petrous bone fractures and carotid canal involvement,[18-20] whereas more recent investigations have taken into account other parts of the skull base[13-15] and fronto-orbital area.[11] York et al[21] reported BCVI rates for all types of skull fractures.

In bony craniofacial trauma, fracture lines often continue across facial and cranial bones, so the craniofacial region can be considered a single unit. Therefore, in contrast to previous studies, the present analyses included any type of facial and skull fracture, with the aim of analyzing possible correlations between BCVI and craniofacial fractures and evaluating BCVI incidence in different types of craniofacial fractures. The hypothesis was that there would be an association between craniofacial fractures and BCVI. Specific aims for the study were to analyze whether some facial fracture subtypes correlate with an increased risk for BCVI.

Patients and Methods

STUDY DESIGN

For this retrospective study, the cohort consisted of patients with suspected blunt high-energy polytrauma who were admitted to a level 1 trauma center (Töölö Trauma Center, Helsinki University Hospital, Helsinki, Finland) in accord with a trauma alarm protocol from May 2015 through May 2016. These included patients with a mechanism of injury serious enough to require computed tomography (CT) of the whole body. All patients were subjected to split-bolus whole-body 64-slice CT (Discovery CT 750 HD, GE Healthcare, Milwaukee, WI) including angiography (aWBCT), which includes a continuous scan from the skull base to the ischium in simultaneous arterial and portal venous phases. Table 1 presents the imaging protocol. Data for patients imaged by aWBCT, in addition to their demographic data, clinical findings, and initial reports, were retrospectively retrieved from the Picture Archiving and Communications System (Impax 6, Agfa HealthCare NV, Mortsel, Belgium) and electronic patient files.

Exclusion criteria were hanging injury, gunshot injury or other penetrating injury to the neck region, and cervical fracture at any level.

All CT studies were reviewed by 2 board-certified radiologists with 12 and 6 years of experience in trauma radiology, respectively, who were blinded to the initial reports. Any discrepancies were resolved by consensus.

STUDY VARIABLES

The main outcome variable was BCVI. The main predictor variable was a craniofacial fracture. A secondary predictor variable was type of craniofacial fracture classified as a facial fracture, skull fracture, or a combination of facial and skull fractures. Other predictor variables were gender, age, mechanism of injury, and craniofacial fracture subgroups.

Patients with craniofacial fractures were identified and their fractures were divided into 4 facial fracture subgroups and 3 skull fracture subgroups. Facial fractures consisted of *1)* combined facial fractures

Table 1. IMAGING PROTOCOL OF BODY COMPUTED TOMOGRAPHIC ANGIOGRAPHY OF CERVICAL ARTERIES

Split-bolus imaging protocol
Scan area
Circle of Willis and ischium (lower extremities on request)
Contrast enhancement
Cervical spine in arterial phase
Body in simultaneous arterial and venous phases
80 mL+ 50-mL contrast medium bolus (Omnipaque* 350 mg/mL + iohexol) at 22-second interval
Contrast delay
Cervical spine, SmartPrep* with 130-HU threshold
Body, 45-second fixed delay
Image acquisition parameters
Slice thickness, 0.625 mm
Range, 120-700 mA
Pitch, 39.37 mm/rotation
Table feed: neck, 98.4 mm/second; body, 137.5 mm/second
Neck: kV 100, NI 40
Body: kV 120, NI 50
Reformatted series
Axial, coronal, sagittal planes; vascular and bone windows
Reformatted slice thickness
Cervical spine: axial, 1.25 mm; coronal and sagittal, 1.5 mm
Cervical vessels, 2 mm coronal and sagittal
Body, 3 mm coronal and sagittal

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(mandibular and midfacial fractures, midfacial and upper third fractures, and panfacial fractures extending to all facial thirds); *2)* upper third fractures (fractures of the frontal sinus, orbital roof, or anterior skull base); *3)* midfacial fractures (multiple midfacial fractures, Le Fort I to III, naso-orbito-ethmoidal, zygomatic, and orbital fractures other than the roof or nasal fractures); or *4)* lower facial fractures (exclusively mandibular fractures). Skull fractures consisted of *1)* basilar skull fractures (fractures of the sphenoid, petrous temporal bone, or basilar portion of the occipital bone); *2)* other skull fractures; or *3)* complex skull fractures (combination of basilar skull fractures and other skull fractures). Specific facial fractures and fractures involving the carotid canal and foramen magnum were documented separately.

STATISTICAL ANALYSIS

For statistical analysis, SPSS 24.0 (IBM Corp, Armonk, NY) was used. The relevance of associations between BCVI and craniofacial fractures, facial and skull fracture subtypes, gender, age, and mechanism of trauma was tested with the χ^2 test. Significance level was set at .01. Multivariate logistic regression analysis was performed to test the relation between BCVI and the explanatory variables gender, age, mechanism of injury, and any craniofacial fracture.

ETHICAL APPROVAL

The internal review board of the Division of Musculoskeletal Surgery at the Helsinki University Hospital approved the study. Patient-informed consent was waived, because the study was retrospective. The study followed the principles of the Declaration of Helsinki.

Results

Of the 465 patients, 7 were excluded for poor image quality or lack of intravenous contrast media and 30 were excluded for cervical spine fractures. None of the patients had sustained a hanging, gunshot, or other penetrating injury to the neck region. Thus, 428 patients were accepted for the final analyses.

Table 2 presents descriptive statistics for the 428 patients. Most patients (71%) were male, and mean

Table 2. DESCRIPTIVE STATISTICS FOR 428 PATIENTS WITH TRAUMA

	n	%
Gender		
Male	304	71.0
Female	124	29.0
Age (yr)		
Mean	41.9	
Range	13-90	
Age groups (yr)		
13-30	133	31.1
31-50	156	36.4
51-70	111	25.9
71-90	28	6.5
Mechanism of trauma		
Motor vehicle accident	199	46.5
Fall from height	86	20.1
Bicycle accident	35	8.2
Pedestrian traffic injuries	24	5.6
Fall on stairs	19	4.4
Assault	14	3.3
Other	51	11.9
Craniofacial fracture	75	17.5
Facial fracture	42	9.8
Skull fracture	19	4.4
Facial + skull fracture	14	3.4
BCVI	40	9.3

Abbreviation: BCVI, blunt cerebrovascular injury.

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age was 41.9 years. The most common mechanism of injury was motor vehicle accident (46.5%), followed by fall from a height (20.1%) and bicycle accident (8.2%). Other injury mechanisms were pedestrian traffic injuries (5.6%), a fall on the stairs (4.4%), and assault (3.3%). The remaining 11.9% fell under other injury mechanisms, in which the mechanism was unknown or the trauma was considered of relatively low energy. Such mechanisms include falls from low heights or on even on the ground, sports injuries, and being struck by or crushed between blunt objects. Craniofacial fractures had occurred in 75 patients (17.5%), of whom 42 (58.3%) had a facial fracture, 19 (25.3%) had a skull fracture, and 14 (18.7%) had facial and skull fractures, and 40 (9.3%) had BCVI.

Table 3 presents the association between BCVI and its predictors. BCVI was evident in 18.6% of patients with craniofacial fracture, reaching significance (P = .002). BCVI occurred most frequently with skull fractures (21.1%), followed by facial fractures (19.0%) and combinations of facial and skull fractures (14.3%), although the differences among these 3 patient groups were nonsignificant (P = .882). No meaningful associations emerged between BCVI and gender or mechanism of trauma. Table 4 presents a logistic regression analysis between BCVI and gender, age group, mechanism of injury, and craniofacial fractures. Analysis showed a 4-fold higher risk of BCVI in patients with craniofacial fracture than in those with other trauma (odds ratio [OR] = 4.096; 95% confidence interval [CI], 1.866-8.993; P < .001). Patients 31 to 50 years old had a 3.4-fold higher risk than their reference group (13 to 30 yr; OR = 3.426; 95% CI, 1.356-8.656; P = .009).

Table 5 presents associations between craniofacial fracture subgroups and BCVI. In the 56 patients with facial fractures, BCVI most commonly occurred in combined facial (20.0%) and midfacial (20.0%) fractures. None with exclusively upper or lower facial fractures showed BCVI. No statistically relevant differences appeared between BCVI and facial fracture subgroups. Of the 33 patients with skull fractures, BCVI occurred most frequently in those with complex skull fractures (37.5%), followed by basilar skull fractures (14.3%), but in no other types of skull fracture. The correlation between BCVI and complex skull fractures was almost significant (P = .033).

Table 6 presents specific facial fractures and fractures extending into the carotid canal and foramen magnum. Further analysis showed that all BCVIs in facial fractures occurred in isolated zygomatico-orbital fractures (35.7%), combined facial fractures

Table 3. ASSOCIATION BETWEEN BCVI AND PREDICTORS IN 428 PATIENTS WITH TRAUMA

Q5

	n	BCVI Present	%	BCVI in 40 Patients, %	*P* Value
Gender					.110
Male	304	24	7.9	60.0	
Female	124	16	12.9	40.0	
Age groups (yr)					.110
13-30	133	7	5.3	17.5	
31-50	156	21	13.5	52.5	
51-70	111	9	8.1	22.5	
71-90	28	3	10.7	7.5	
Mechanism of trauma					.500
Motor vehicle accident	199	23	11.6	57.5	
Fall from height	86	9	10.5	22.5	
Bicycle accident	35	1	2.9	2.5	
Pedestrian traffic injuries	24	1	4.2	2.5	
Fall on stairs	19	2	10.5	5	
Assault	14	0	0	0	
Other	51	4	7.8	10	
Craniofacial fracture					
Yes	75	14	18.6	35.0	.002
No	353	26	7.4	65.0	
Facial fracture	42	8	19.0	20	.882
Skull fracture	19	4	21.1	10	
Facial + skull fracture	14	2	14.3	5	

Note: Significance level was set at .01.

Abbreviation: BCVI, blunt cerebrovascular injury.

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Table 4. MULTIVARIATE REGRESSION ANALYSIS FOR BLUNT CEREBROVASCULAR INJURIES IN 428 PATIENTS WITH TRAUMA

		95% CI for OR		
	OR	Lower	Upper	*P* Value
Gender (ref, female)	0.460	0.223	0.946	.035
Age groups (ref, 13-30 yr)				
31-50 yr	3.426	1.356	8.656	.009
51-70 yr	2.179	0.746	6.370	.155
71-90 yr	2.432	0.531	11.145	.253
Mechanism of injury (ref, MVA)				
Fall from height	0.701	0.293	1.675	.424
Bicycle accident	0.110	0.013	0.908	.040
Pedestrian traffic injuries	0.170	0.020	1.449	.105
Fall on stairs	0.491	0.092	2.622	.405
Assault	0.000	0.000		.998
Other	0.452	0.143	1.433	.178
Craniofacial fracture (ref, yes)	4.096	1.866	8.993	<.001

Note: Significance level was set at .01.

Abbreviations: CI, confidence interval; MVA, motor vehicle accident; OR, odds ratio; ref, reference.

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(20.0%), and isolated orbital fractures (12.5%). The number of specific facial fractures was insufficient for statistical analysis. Only 1 patient with a skull base fracture extending to the foramen magnum (12.5%) had BCVI, and none of the 5 patients with a fracture extending to the carotid canal had BCVI.

Discussion

The purpose of this study was to analyze possible correlations between BCVI and craniofacial fractures and to evaluate the incidence of BCVI in different types of craniofacial fractures, with the hypothesis of there being an association between craniofacial fractures and BCVI. Furthermore, the authors investigated a possible correlation of facial fracture subtypes to BCVI.

The present study of craniofacial fractures and BCVI showed a strong correlation, with BCVI occurring 2.5 times more frequently in patients with craniofacial fracture than in those with all other types of severe trauma. Nearly 1 in 5 patients with craniofacial fracture (18.6%) was diagnosed with BCVI. There was no difference between facial fractures and skull fractures with regard to BCVI. Logistic regression showed a 4-fold higher risk of BCVI for craniofacial fractures compared with all other trauma.

Thus, the present results are in line with those of Buch et al[14] who stated that BCVI can occur in up to 11% of patients with blunt trauma injuries. However, overall BCVI incidence was considerably higher (9.3%) in the present study than in previous studies.[1-5] One possible explanation for the higher incidence of BCVI could be the authors' institution serving as a level 1 trauma center and a tertiary hospital and therefore having a higher incidence of severe trauma. Furthermore, the authors' guidelines

Table 5. ASSOCIATION BETWEEN BCVI AND SUBGROUPS OF CRANIOFACIAL FRACTURES IN 75 PATIENTS WITH CRANIOFACIAL FRACTURE

	n	BCVI Present	%	BCVI in 14 Patients, %	*P* Value
Facial fracture					
Any (n = 56)	56	10	17.9	71.4	.757
Combined facial	20	4	20.0	28.6	.090
Upper	1	0			
Midfacial	30	6	20.0	42.9	
Lower	5	0			
Skull fracture					
Any (n = 33)	33	6	18.2	42.9	.924
Basilar skull fracture*	21	3	14.3	21.4	.033
Other	4	0			
Complex skull fracture†	8	3	37.5	21.4	

Note: Significance level was set at .01.

Abbreviation: BCVI, blunt cerebrovascular injury.

* Fracture of the sphenoid, petrous, temporal, clivus, or occipital condyle.

† Basilar skull fracture plus other skull fracture.

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Table 6. SPECIFIC FACIAL FRACTURES AND FRACTURES EXTENDING TO THE CAROTID CANAL AND FORAMEN MAGNUM AND BCVI IN 75 PATIENTS

	n	BCVI Present	%	*P* Value
Facial fractures (n = 56)				NA
Combined facial	20	4	20.0	
Upper third	1	0		
Multiple midfacial	4	0		
Exclusively orbital	8	1	12.5	
Exclusively zygomatico-orbital	14	5	35.7	
Exclusively maxillary	1	0		
Exclusively nasal	3	0		
Exclusively condylar	2	0		
Exclusively non-condylar	3	0		
Skull fractures (n = 33)				.084
Carotid canal	5	0		
Foramen magnum	8	1	12.5	
Fracture not involving foramen	20	5	25.0	

Note: Significance level was set at .01.

Abbreviations: BCVI, blunt cerebrovascular injury; NA, Q6 ■■■.

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for BCVI screening in patients with high-energy trauma seem liberal; in addition to the Denver criteria, the authors included thoracic and lower cervical spine trauma. In the authors' unit, even if the trauma alarm protocol has not been triggered, the attending trauma surgeon can order an aWBCT when clinical signs or mechanism of trauma indicate possible severe trauma. Thus, the liberal screening protocol could have increased the number of imaged patients and diagnosed BCVIs, especially among facial fracture cases.

Buch et al[14] reported that 87% of their patients with BCVI also had cervical or skull base fractures or a combination of the 2, but concluded that isolated midface fractures in the absence of cervical spine or skull base fractures were not associated with underlying BCVI. However, the only facial injuries observed in their study were complex facial fractures with midface instability. The authors excluded cervical fractures to focus on the effect of craniofacial fractures alone. Occurrence was almost evenly divided among isolated facial fractures, isolated cranial fractures, and combinations of the 2 groups. Further analysis showed a high occurrence of BCVI in combined facial fractures and midfacial fractures, especially in zygomatico-orbital fractures (Figs 1, 2). Based on these results, facial fractures should be considered an independent risk factor for BCVI. For more accurate conclusions about different types of craniofacial fractures, a larger number of patients with specific fracture types is required.

Recent studies have emphasized the relevance of facial fractures in BCVIs, such as mandibular and especially extracapsular condylar fractures[15,22] and maxillary fractures involving pterygoid plates.[15] Kang et al[23] described the injury mechanism of the internal carotid artery (ICA) in conjunction with Le Fort I osteotomy. Owing to the anatomic proximity of the ICA to the foramen lacerum and the pterygoid plate, the artery can be directly damaged if a sharp bony edge causes shearing near the skull base. This is in line with the findings of Mundinger et al[15] who concluded that in patients with facial fracture, risk for BCVI without applying screening criteria was higher in patients with Le Fort I fractures. The same study reported corresponding findings in patients with mandibular subcondylar fractures. Vranis et al[22] studied condyle fractures in more detail and found that direct injury caused by bony fragments, especially displaced extracapsular condyle fractures, increased the risk for BCVI. According to these studies, Le Fort I fractures and extracapsular mandibular condylar fractures, in particular, can lead to localized ICA damage.

The authors found no associations between BCVI and these fracture subtypes. The present study showed a high occurrence of BCVI, especially in zygomatico-orbital fractures, indicating that a facial fracture is a marker of substantial trauma energy, which in turn increases the likelihood of BCVI, even when the fracture does not cause direct mechanical damage to a vessel.

Others have reported an association between skull base fractures and BCVI.[1,14,15,18,19] In the present study, the authors analyzed all types of cranial fractures. BCVI occurred most frequently in complex skull fractures (combination of basilar skull fractures and other skull fractures; 37.5%) and basilar skull fractures (14.2%), but none of the patients with exclusively other skull fracture types showed BCVI. This differs from the findings of York et al[21] who reported a high BCVI rate in fractures in other parts of the skull, with 29% of patients with non-basilar skull fractures having ICA injury. Carotid canal fractures also have been implicated as a risk factor for BCVI. Petrous bone fractures and carotid canal involvement can lacerate a blood vessel, especially in the intraosteal segment.[20] York et al[21] also evaluated the incidence of ICA injury and skull fractures, establishing that in skull fractures with carotid canal involvement (35%), injury to the ICA was twice as frequent as without canal involvement (15%). Interestingly, in the present study, none of the 5 patients with carotid canal involvement and only 1 of 8 patients with a fracture extending to the foramen magnum had BCVI. The number of these patients was small, and further investigation with a

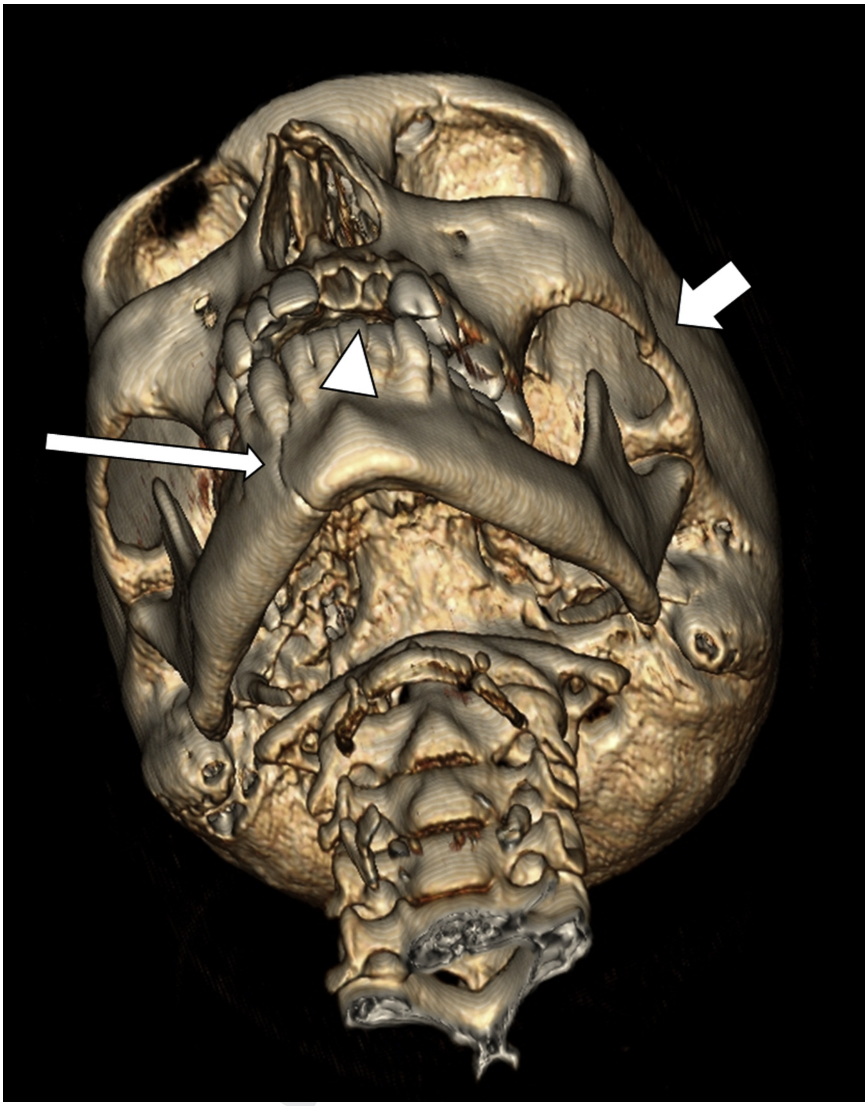

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FIGURE 1. A 25-year-old unconscious woman was admitted with an unclear injury mechanism. Radiologic imaging depicted a left zygomatic arch fracture (*broad arrow*), right mandibular parasymphyseal fracture (*thin arrow*), and dental injuries to the upper incisors (*arrowhead*).
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larger cohort of patients might clarify any associations between skull fracture subtypes and BCVI.

The question arises as to whether BCVI correlates with a certain type of injury or requires a certain amount of trauma energy. Even minor craniofacial trauma has coincided with serious carotid injury. One case study described a healthy young man with a non-dislocated mandibular double fracture as a result of a single punch, who was diagnosed with carotid dissection and acute secondary embolic infarcts.[24] Considering that report and the variation in craniofacial fractures with BCVI in the present and previous studies, the energy required to cause any craniofacial fracture seems sufficient to cause an associated BCVI. Interestingly, a previous study found that a long styloid process of the temporal bone can contribute to the pathogenesis of cervical carotid dissection.[25] Thus, taking into consideration that hyperextension, rotation, and lateral flexion of the neck predispose to BCVI, more detailed evaluation of a local anatomic association is required. Further investigation of the level of BCVI and possible vectors for trauma energy would probably shed some light on these associations.

Controversy still exists concerning which patients with trauma are at risk for BCVI and for whom screening is thus indicated. Current BCVI screening guidelines allow for BCVI being missed and risk for stroke. Thus, more liberalized screening for BCVI during initial CT in patients with trauma and signs of typical mechanisms or high-energy trauma is warranted.[2] The overall incidence of BCVI has increased during the past decade, in part because of the increased availability and accuracy of cervical CTA in

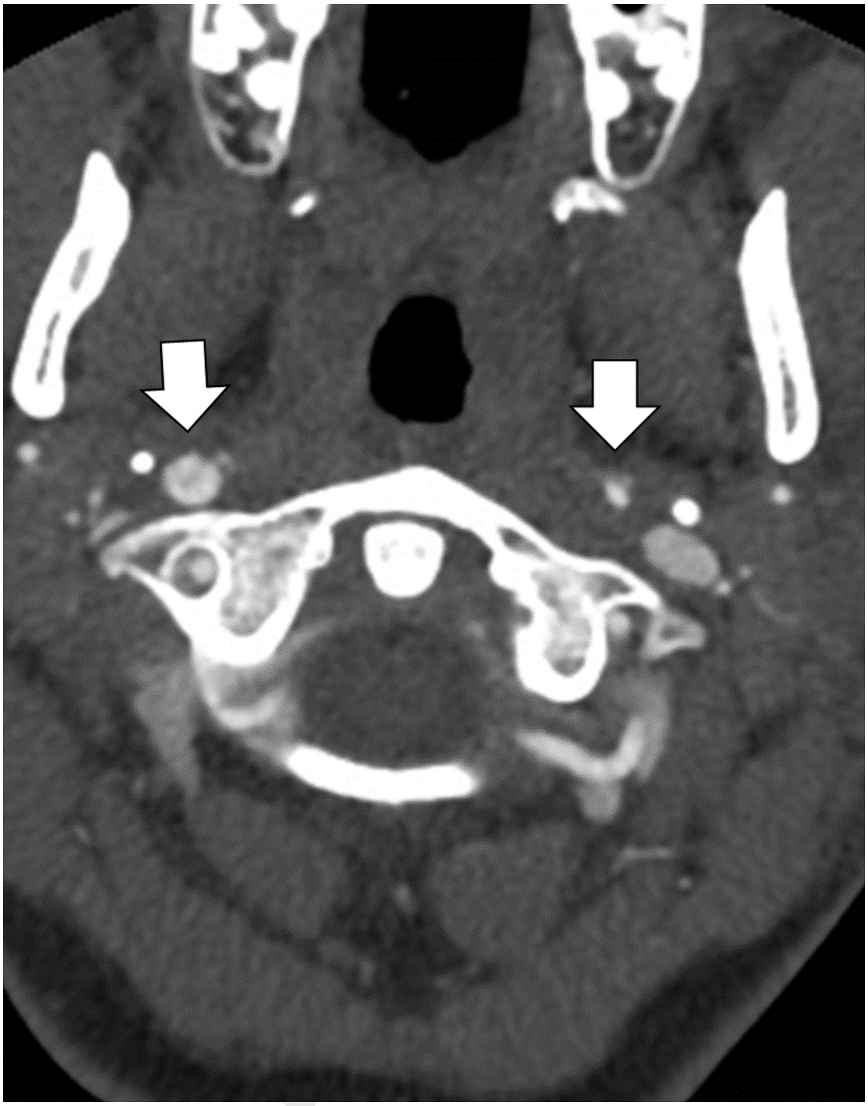

FIGURE 2. Cervical computed tomographic angiography displayed blunt cerebrovascular injury (Biffl grade 2) in the 2 internal carotid arteries (*arrows*).

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combination with an increasing index of suspicion and increased experience among trauma surgeons treating these injuries.[1,26]

Despite greater academic interest in this topic, unambiguous evidence of associations between craniofacial injuries and BCVIs is lacking. The present study found that craniofacial fractures are a notable risk factor for BCVI, without relevant differences in risk between fracture subtypes. Therefore, in all patients with polytrauma and craniofacial fractures, Q3 BCVI should be excluded.

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