Blunt cerebrovascular injuries in the craniofacial fracture population - Are we screening the right patients?

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2021-04

Puolakkainen , T , Vahasilta , L , Bensch , F , Narjus-Sterba , M , Wilson , M L , Thoren , H & Snall , J 2021 , ' Blunt cerebrovascular injuries in the craniofacial fracture population - Are we screening the right patients? ' , International Journal of Oral and Maxillofacial Surgery , vol. 50 , no. 4 , pp. 463-470 . https://doi.org/10.1016/j.ijom.2020.09.004

http://hdl.handle.net/10138/341581
https://doi.org/10.1016/j.ijom.2020.09.004

Title Page

Title: **Blunt cerebrovascular injuries in the craniofacial fracture population – are we screening the right patients?**

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Keywords: Craniomaxillofacial fracture, Vascular trauma, Blunt cerebrovascular injury, Screening protocol

Short title: BCVI and craniofacial fractures

Funding: The authors received no specific funding for this work

Abstract

Current knowledge of blunt cerebrovascular injuries (BCVI) in craniomaxillofacial fracture (CMF) patients is limited. The purpose of this study was to determine the occurrence of BCVI in patients with all types of CMF. The retrospective study included CMF patients in a level 1 trauma center during a 3-year period. Patients who were not imaged with computer-tomographic angiography and patients with other than blunt injury mechanisms were excluded. The primary outcome variable was BCVI. A total of 753 patients were included in the analysis. BCVI was detected in 4.4% of the screened patients. Among the screened patients, BCVI occurred in 8.7% of cranial fracture patients, in 7.1% of combined craniofacial fracture patients and in 3.1% of facial fracture patients. Risk of BCVI was significantly increased in patients with isolated cranial fractures (OR 2.55, CI 1.18, 5.50; $p=0.017$), motor vehicle accidents (OR 3.42, CI 1.63, 7.17; $p=0.001$) and high-energy injuries (OR 3.17, CI 1.57, 6.40; $p=0.001$). BCVI in CMF patients are relatively common in high-energy injuries. However, these injuries also occur in minor traumas. Imaging thresholds should be kept low in this patient population when BCVI are suspected.

Introduction

Blunt cerebrovascular injuries (BCVIs) are relatively uncommon, but when misdiagnosed and left untreated, can result in permanent disability or death. In particular, lower grades of BCVI are often asymptomatic upon initial investigation and can therefore easily be missed[1]. Several screening protocols for BCVI have been suggested when specific signs, symptoms and risk factors are presented[2]. The classification most commonly used in contemporary practice is the enhanced Denver guidelines, initially proposed by Biffl and colleagues in 1991[3] and later updated in 2011[1]. An alternative screening protocol defined by the Eastern Association for the Surgery of Trauma (EAST) has also consolidated its position in clinical settings[4]. However, differences in local regulations and disparities in incidence rates reported by academic institutions have hindered progress towards a unified screening protocol[5].

An increasing body of evidence suggests that 1-2% of patients who experience trauma are at risk of BCVI[6-10]; this can be as high as 9% in patients with certain risk factors such as severe head injuries[2, 11]. Current treatment options for BCVI are based on prompt initiation of antithrombotic agents[12]. In severe cases endovascular stenting or surgical therapy may be indicated. As BCVI often are clinically asymptomatic, aggressive screening methods have played a pivotal role in reducing the time to diagnosis[8, 10] and have also decreased the incidence of cerebrovascular ischemia-related complications[13, 14]. However, there is a lack of consensus regarding screening criteria as up to 20% of BCVI can be missed even when strictly following certain screening guidelines[15]. This indicates a need to reassess the current state of screening protocols for BCVIs.

A correlation between craniofacial fractures and BCVI has been documented, yet not completely understood[16-18]. Although it is recognized that cranial fractures can indicate BCVIs, recent studies have suggested that facial fractures can also be independent risk factors[2]. For example, the current Denver guidelines suggest Le Fort II and III fractures, as well as isolated mandibular fractures, to be independent risk factors for BCVI[8]. Moreover, a recent publication highlighted a correlation between BCVI and craniofacial fractures[19]. However, the true significance of each specific fracture type on BCVI remains unclear.

Craniofacial fracture patients are a special group when estimating BCVI risk, as they are prone to sudden head rotation and hyperextension of the neck. The purpose of this study is to report BCVI incidence rates for all types of craniofacial fractures, and to describe the substantial explanatory and predictor variables for these injuries. Additionally, we analyze the distribution of BCVIs by affected vessel and vertebral level. Lastly, we report the extent to which our BCVI patient population fulfilled the screening indications of the expanded Denver criteria. We hypothesized that different predisposing factors for BCVI can be found in craniofacial fracture patients.

Methods

Study design:

This retrospective study was based on all patients admitted to a level 1 trauma center (Töölö Trauma Center, Helsinki University Hospital, Helsinki, Finland) with all types of craniofacial fractures during 2016-2018. Upon initial admission, patients were first examined according to a local screening protocol based on the expanded Denver criteria. They were then subjected to computed tomographic angiography (CTA) of the cervical arteries if BCVI was suspected by positive extended Denver criteria or surgeon's discretion. Craniofacial fractures were diagnosed based on clinical examination and appropriate radiological imaging.

All CTA studies in this cohort were reviewed by a board-certified radiologist (F.B.) and CT images of skull base fractures were reviewed by a maxillofacial surgeon (J.S.). Both reviewers have special expertise in head and neck traumatology. Their reviews were compared to the initial report and any inconsistencies were agreed upon by consensus.

Inclusion and exclusion criteria:

All patients with any craniofacial fracture were reviewed. Patients who were screened for BCVI with CTA were included in further analyses. Patients who were not CTA-screened or sustained gunshot and stabbing injuries were excluded from the analysis.

Study Variables:

The main study outcome variable was BCVI.

The primary predictor variable was the type of craniofacial fracture, which was grouped as cranial fracture, combined craniofacial fracture, and facial fracture.

The secondary predictor variables were cervical injury, intracranial hemorrhage, Glasgow coma scale value of less than 6 (GCS<6), thoracic injury and high-energy trauma. High-energy traumas were those associated road and traffic related injuries, falls from over 3 meters, and in industrial injuries[20].

Additional predictor variables were the specific craniofacial fracture subtype, which were classified in distinct groups. Isolated zygomaticomaxillary and/or orbital fractures were grouped as zygomatic-maxillary-orbital (ZMO) fractures. Le Fort fractures and other different combinations of midfacial fractures were categorized as combined midfacial fractures. Skull fractures extending to the carotid canal and foramen magnum were analyzed separately.

Explanatory variables were gender, age, mechanism of injury (categorized as ground-level fall, assault, motor vehicle accident, bicycle accident, fall from height, fall from stairs and other/unknown) and alcohol accession to injury. Alcohol influence was verified from blood samples, by the use of a breathalyzer or the history given by the patient or paramedics. If alcohol influence could not be confirmed, these patients were classified as “No alcohol”.

In addition, patients with a BCVI were retrospectively evaluated according to the expanded Denver guidelines. Based on patient files, patients with high-energy transfer mechanism, Le Fort II or III fracture, mandibular fracture, combined skull fracture or basilar skull fracture, severe traumatic brain injury with GCS<6, seat belt sign, scalp degloving, cervical spine injury, blunt cardiac rupture or upper rib fractures were identified in order to assess whether screening indications would have been fulfilled.

Statistical Analysis:

An initial examination of the cohort was carried out using descriptive statistics. Categorical variables are reported as percentages, and continuous variables are reported as means with corresponding standard deviations or medians with corresponding interquartile ranges. Age was analyzed as a continuous variable. Pearson chi-square or Fisher's exact tests were conducted to estimate the relationship between the independent variables and BCVI.

Logistic regression analysis was conducted to estimate the association between BCVI and the described risk factors. First, univariate logistic regression was done to identify the risk factors for BCVI between the predictor and independent variables. Subgroup analyses were also done for the patients with isolated cranial fractures and isolated facial fractures, respectively. Covariates that were statistically significant in the unadjusted models, as well as clinical predictor variables were included in the adjusted model. Statistically significant covariates or those with $p<0.2$ were retained in the following final model with the predictor variables. Odds ratios (OR) were reported with their corresponding 95% confidence intervals and statistical significance at $p<0.05$. The Hosmer-Lemeshow model was used to test the fit of the models. The Hosmer-Lemeshow statistic was 4.5 with a p-value of 0.809 while the link test, which detects a specification error in the model, had a p-value of 0.252, suggesting a good fit. Multicollinearity was tested using the variance inflation factor (VIF) for the adjusted models. The VIF value for each covariate was less than 5 in each of the final models. The data analysis was conducted using Stata version 11 (StataCorp, TX, USA) and the R statistical environment 3.5.0.

Ethical considerations:

The study was approved by the Internal Review Board of the Head and Neck Center, Helsinki University Hospital, Helsinki, Finland (HUS/356/2017 and HUS/54/2019).

Results

In total, 1912 craniofacial fracture patients were reviewed. Altogether 1159 patients were excluded from the study, as 1155 patients were not scanned with CTA and four patients sustained firearm and stabbing injuries. Hence, 753 CTA-imaged patients were included in the final analyses.

Of the included patients, 33 (4.4%) sustained BCVI for a total number of 39 BCVIs. Multiple injuries were detected in six of the screened patients (18.2%). The median age for all patients was 45.7 years and 34.7 years for patients with BCVI. The most common mechanism for a craniofacial fracture was ground-level fall (27.6% of all patients) followed by assaults (22.0%) and MVAs (15.3%). Alcohol usage was involved in 37.3% of all fracture cases. BCVI occurred in 8.7% of cranial fractures, in 7.1% of combined craniofacial fractures and in 3.1% of facial fractures.

Table 1 summarizes the descriptive data of patients included in the study, and the association between the occurrence of BCVI and explanatory variables. Patients with isolated cranial fractures were more prone to have BCVIs than patients with other craniofacial fracture types (Tables 1, 2 and 3). Accordingly, BCVI risk was significantly higher in these patients (OR 2.55, Cl 1.18, 5.50; $p=0.017$), while those with facial fractures were less prone to have BCVI (OR 0.36, Cl 0.18, 0.74; $p=0.005$). Fractures extending to the carotid canal and foramen magnum were significantly correlated with BCVI occurrence ($p<0.001$).

BCVI was significantly correlated with high-energy trauma and MVAs in CTA-imaged craniofacial fracture patients. In the univariate analysis (Table 3), patients involved in MVAs and high-energy impact events were significantly more likely to be at increased risk for BCVI injuries (OR 3.42, CI 1.63, 7.17; p=0.001) and (OR 3.17, CI 1.57, 6.40; p=0.001), respectively. The number of concomitant injuries was significantly associated with BCVI occurrence. Each of the additional injuries had a significant and higher risk of BCVIs, with thoracic injury being the highest risk (OR 4.36, Cl 2.04, 9.36; $p<0.001$) (Table 1). The odds of BCVI were more than two-fold compared to those without injuries associated with cervical injury (OR 2.74, CI 1.01, 7.45; p=0.048), intracranial hemorrhage (OR 2.43, CI 1.21, 4.90; p=0.013) and $GCS<6$ (OR 2.33, CI 1.31, 8.49; p=0.012). Multivariate analyses showed an increased risk of BCVI only with thoracic injuries (OR 2.63, CI 1.14, 6.05; p=0.023) (Table 4).

In CTA-screened, isolated facial fracture patients (n=553) the highest risk factors for BCVI were fractures localized to different combinations of facial thirds (OR 4.14, CI 1.40, 12.24; p=0.010) and other (i.e not separately specified) types of facial fractures (OR 11.10, CI 1.09, 112.67; p=0.042), In addition, cervical injuries (OR 3.61, CI 0.98, 13.26; p=0.053) and MVA injuries (OR 3.37, CI 1.15, 9.90; p=0.027) increased the risk for BCVI.

When isolated cranial fractures (n=115) were considered, only thoracic injuries showed significant increased risk for BCVI in the univariate analysis (OR 11.28, CI 2.66, 47.82; $p<0.001$).

Figure 1 and Table 5 summarize the details of the diagnosed BCVIs in CTA-scanned patients. According to the retrospective data, 30 of the CTA-screened patients (90.9%) fulfilled the expanded Denver screening criteria. The remaining three patients who did not meet these screening criteria had midface and upper face fractures: one had an isolated ZMO-fracture, one had a combined ZMO and frontal bone fracture, and one had an isolated frontal bone fracture. Twenty-seven (69.2%) injuries were located in the internal carotid arteries or common carotid artery and 12 (30.8%) in the vertebral arteries. Two thirds of all BCVIs (29 of 39 74.4%) were located between the cervical levels of C0 and C2. The remaining injuries were distributed evenly between the C3-C5 and C6-T1 planes. Over 50% of the diagnosed BCVIs were ranked as grade 2 injuries.

Of the 33 patients with BCVI, 6 deceased during the hospital stay due to other injuries than BCVI or stroke. The remaining 27 patients were anticoagulated according to the local protocol, except one, for whom no medication was initiated due to contraindications. In one patient, the injury extended to the intracranial portion of the internal carotid artery. The patient received long-term anticoagulative medication. The extradural, intracavernotic pseudoaneurysm diminished during the follow-up. None of the BCVI patients sustained from stroke as a complication from BCVI during the hospital stay.

Discussion

The purpose of this study was to increase recognition of BCVI incidence rates in CTA-imaged patients with all types of craniofacial fractures. Detailed analyses were performed based on explanatory and predictor variables. Special emphasis was placed on the distribution and location of BCVIs in regard to the affected vessel and corresponding vertebral level. In addition, we retrospectively assessed how our BCVI patient population would have fulfilled the screening indications for the expanded Denver criteria. We hypothesized that different predisposing factors for BCVIs can be found in CTA-scanned craniofacial fracture patients.

Our results showed a high occurrence of BCVIs in the CTA-screened craniofacial fracture population (4.4%). When considering the fracture subtypes, the occurrence of BCVI was significantly higher in isolated skull fractures (8.7%). BCVI rate was also notably high in isolated facial fracture patients (3.1%). Our results reinforce previous findings that demonstrate the increased risk of BCVI among patients with cranial fractures[21, 22]. Interestingly, a recent international multicenter study suggested that the role of facial fractures as risk factors of BCVIs is more significant than previously thought[2].

The authors concluded that the BCVI risk is increased in any craniofacial fracture, including fractures other than Le Fort II/III or basilar skull fractures. However, the authors did not present detailed data on the facial fracture patterns, hence leaving a gap in this knowledge.

The risk of BCVI is significant in CTA-imaged, craniofacial fracture patients with injuries associated with MVAs and high-energy accidents. In a previous study concerning BCVIs among a polytrauma patient population, craniofacial fractures were strongly represented. BCVIs occurred in nearly one fifth of craniofacial fracture patients when all craniofacial fracture types were considered[19]. However, in the present study BCVIs were also detected in patients with low-energy mechanisms.

Interestingly, CTA-screened patients with isolated ZMO-fractures were significantly less prone to BCVIs. This result is in agreement with other publications, but remains somewhat conflicting. All three patients with BCVIs who did not meet the screening criteria were diagnosed with unilateral ZMO-fractures and/or frontal bone fractures. Moreover, one of these patients had a grade III injury. Sudden head rotation and neck hyperextension are common even in low-energy facial fracture injuries, and can result from minor injuries[23]. In the present study, half of the BCVIs (17/33, 51.5%) were associated with injuries other than high-energy injuries; BCVI occurred in 3.0% of CTA-screened patients who had been involved in minor injuries. Hence, the risk of BCVIs in low-energy craniofacial injuries should not be overlooked.

An important finding was that BCVI was identified in patients who did not meet the extended Denver criteria. This raises the question of how often BCVI was undiagnosed in the 1155 craniofacial fracture patients who were not CTA-screened during the same period as only 39.4% of the patients were CTA-screened. This would indicate a need for more liberal screening protocols in order to correctly diagnose BCVI.

Our results revealed a high rate of BCVI among isolated skull fracture patients who were imaged with CTA (8.7%). Previous studies have emphasized BCVI risk in combined skull fractures and skull base fractures[24, 25], but our results did not show any differences in BCVI risk among the different skull fracture types. Considering the fractures extending to carotid and vertebral vessel foramina, the association was significant when assessing the risk of BCVI in all types of craniofacial fractures ($p<0.001$). 17.4% of patients with fractures extending to these specific foramina had BCVIs, thus confirming the significant association between fracture line and skull base foramina[24, 26, 27]. The risk was the highest when the fracture line extended through both the carotid canal and the foramen magnum, reflecting a high-energy trauma mechanism.

Mundinger and colleagues reported the significance of subcondylar and combined midfacial fractures as independent risk factors for blunt internal carotid artery injuries (BCAIs). Additionally, the authors reported an incidence of 1.2% for diagnosed BCAIs in facial fracture patients[17]. Based on current knowledge, the inclusion of vertebral arteries in this study would have been beneficial. Previous reports have demonstrated that up to 50% of BCVIs occur in the vertebral arteries[28, 29], thereby emphasizing the need to assess the vertebral arteries accordingly when screening for BCVIs. Our study showed that in the CTA-screened craniofacial fracture population, more than two thirds of BCVIs were located in the carotid arteries.

The anatomic proximity between facial fractures and vascular structures has previously been highlighted[30-32]. However, studies regarding the anatomical location and cervical planes of BCVIs are limited. According to earlier results, injuries around the extracranial portions of the transverse foramina appear to be most common[33]. In the present study, almost 75% of the BCVIs were diagnosed in the upper cervical level (between the cervical planes of C0 and C2), which is higher than the mean for BCVI patients in general[34]. This could be explained by the severe vascular stretching that occurs in the occipito-cervical junction and the upper cervical spine when the head and cervical spine sways or rotates in varying directions in craniofacial injuries. Thus, vascular injuries in this patient population are mostly localized to the upper cervical planes and carotid arteries.

The gold standard for BCVI imaging is digital subtraction angiography (DSA), as it provides superior resolution and direct evaluation of collaterals[35, 36]. The application of DSA is nevertheless limited by its inherent invasiveness and high cost. With increasingly refined imaging protocols and technical advancement, multidetector CTA has become the routine imaging modality for BCVI screening due to its noninvasiveness, cost-effectiveness, and high sensitivity and specificity. Hence, 16-slice compound tomographic angiography is a reliable noninvasive screening test for clinically significant blunt cerebrovascular injuries[35-38].

Our study is not without limitations, the most important being its retrospective nature. Issues regarding bias and confounding factors are inherent and persistent, and discussion over whether clinical conclusions can be made from these studies remains prevalent. A prospective study setup would also allow us to examine the relationship between craniofacial fractures and BCVIs as well as delayed effects in non-screened patients, even though it cannot exclude confounding factors resulting from polytrauma. Nevertheless, our study was based on descriptive patient files, which are more detailed compared to the data most registry studies are based on. Additionally, the present study included a relatively large cohort size, involving all craniofacial fracture types.

The BCVI incidence rate was 4.4% among CTA-screened craniofacial fracture patients. Of the screened patients, BCVI occurred in 8.7% who sustained an isolated skull fracture. The rate of BCVI was notably high in isolated facial fracture patients (3.1%). As previously shown, high-energy trauma, MVAs and combined injuries increase the risk of BCVI. The present study demonstrated that a similar increase in BCVI is also present in the craniofacial fracture patient population. Importantly, BCVIs were detected in minor injury mechanisms and in patients who did not meet the extended Denver screening criteria. The current BCVI imaging criteria of craniofacial fracture patients is focused on patients with specific skull fracture types, Le Fort II/III fractures and mandibular fractures. Based on our results, we suggest that imaging criteria should be expanded to other fracture types as well and to include patients sustaining from combined craniofacial fractures, any combination of fractures affecting different facial thirds as well as all types of severe midfacial fractures.. In addition, the risk of BCVI in low-energy craniofacial injuries should not be overlooked.

Declarations

The authors declare that they have no conflicts of interest. The authors received no specific funding for this work. The study was approved by the internal review board of the Head and Neck Center, Helsinki University Hospital, Helsinki, Finland (HUS/357/2017). Patient consent was not required for this study. All authors consent to the submission of this manuscript to the International Journal of Oral and Maxillofacial Surgery.

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Tables

Table 1. Descriptive statistics for blunt cerebrovascular injuries and associated variables.

	Patients without blunt cerebrovascular injury, n (%)	% of n	Patients with blunt cerebrovascular injury, n (%)	% of n	P-value
All	720	95.6	33	4.4	
Sex					0.437
Male	523 (72.6)	95.3	26 (78.8)	4.7	
Female	197 (27.4)	96.6	7 (21.2)	3.4	
Age (years)	45.7		34.7		0.216
Median (Interquartile range)	30.9, 63.6		25.4, 58.6		
Mechanism					
Ground-level fall	201 (27.9)	96.6	7 (21.2)	3.4	0.550
Assault	162 (22.5)	97.6	4 (12.1)	2.4	0.200
Motor vehicle accident	103 (14.3)	89.6	12 (36.4)	10.4	0.001
Bicycle accident	85 (11.8)	96.6	3 (9.1)	3.4	0.787
Fall from height	62 (8.6)	93.9	4 (12.1)	6.1	0.522
Fall from stairs	42 (5.8)	97.7	1 (3.0)	2.3	1.000
Other/Unknown	65 (9.0)	97.0	2 (6.1)	3.0	0.760
Alcohol involved					
Yes	273 (37.9)	97.2	8 (24.2)	2.9	0.112
No	447 (62.1)	94.7	25 (75.8)	5.3	
High-energy					
Yes	165 (22.9)	91.2	16 (48.5)	8.8	0.001
No	555 (77.1)	97.0	17 (51.5)	3.0	
Associated injuries					<0.001
No associated injury	438 (60.8)	97.3	12 (36.4)	2.7	
One associated injury	200 (27.8)	95.7	9 (27.3)	4.3	
Two associated injuries	66 (9.2)	90.4	7 (21.2)	9.6	
Three associated injuries	14 (1.9)	77.8	4 (12.1)	22.2	
Four associated injuries	2 (0.3)	66.7	1 (3.0)	33.3	
Type of associated injury					
Cervical injury	44 (6.1)	89.8	5 (15.2)	10.2	0.056
Intracranial hemorrhage	219 (30.4)	92.8	17 (51.2)	7.2	0.011
Glasgow coma scale < 6	45 (6.3)	88.2	6 (18.2)	11.8	0.019
Thoracic injury	74 (10.3)	87.1	11 (33.3)	12.9	<0.001
Craniofacial fracture type					0.010
Isolated cranial fracture	105 (14.6)	91.3	10 (30.3)	8.7	0.014
Combined craniofacial	79 (11.0)	92.9	6 (18.2)	7.1	0.252
Isolated facial fracture	536 (74.4)	96.9	17 (51.5)	3.1	0.004

Table 2. Descriptive statistic for blunt cerebrobascular injuries and subtypes of craniofacial fractures in 753 patients.

	Patients without blunt cerebrovascular injuries, n (%)	% of n	Patients with blunt cerebrovascular injuries, n (%)	% of n	P-value
Cranial fracture					0.014
No	615 (85.4)	96.4	23 (69.7)	3.6	
Yes	105 (14.6)	91.3	10 (30.3)	8.7	
Base of the skull	45 (42.9)	90.9	7 (70.0)	9.1	0.181
Other part of the skull	42 (40.0)	93.9	2 (20.0)	6.2	0.313
Combined skull fracture	18 (17.1)	91.7	1 (10.0)	8.3	1.000
Fracture extending to skull foramina					0.003
No	691 (96.0)	96.2	27 (81.8)	3.8	
Yes	29 (4.0)	82.6	6 (18.2)	17.4	
Carotid canal	19 (15.5)	82.6	4 (33.3)	17.4	0.123
Foramen magnum	8 (6.5)	100.0	0 (0.0)	0.00	1.000
Carotid canal with foramen magnum	2 (1.6)	50.0	2 (16.7)	50.0	0.040
Combined craniofacial fracture					0.252
No	641 (89.0)	96.0	27 (81.8)	4.0	
Yes	79 (11.0)	92.9	6 (18.2)	7.1	
Facial fracture					0.004
No	184 (25.6)	92.0	16 (48.5)	8.0	
Yes	536 (74.4)	96.9	17 (51.5)	3.1	
Zygomatic-maxillary-orbital	265 (43.1)	98.2	5 (21.7)	1.9	0.052
Mandible	111 (18.1)	96.5	4 (17.4)	3.5	1.000
Combined midfacial	95 (15.5)	96.9	3 (13.0)	3.1	1.000
Combination of facial thirds	81 (13.2)	91.0	8 (34.8)	9.0	0.003
Nasal	40 (6.5)	97.6	1 (4.4)	2.4	1.000
Upper third	18 (2.9)	94.7	1 (4.4)	5.3	0.507
Other	5 (0.8)	83.3	1 (4.4)	16.7	0.198

Table 3. Univariate logistic regression analysis for blunt cerebrovascular injuries in 753 craniofacial fracture patients.

	Odds Ratio	95% confidence intervals	P-value
Gender (Female)	0.71	0.31, 1.67	0.439
Age	0.98	0.96, 1.00	0.063
Injury mechanism			
Ground level	0.70	0.30, 1.63	0.402
Assault	0.48	0.16, 1.37	0.169
Motor vehicle accident	3.42	1.63, 7.17	0.001
Bicycle accident	0.75	0.22, 2.50	0.636
Fall from height	1.46	0.50, 4.30	0.488
Fall from stairs	0.50	0.07, 3.78	0.506
Other/unknown	0.65	0.15, 2.78	0.561
Alcohol involved	0.52	0.23, 1.18	0.118
Craniofacial fracture type			
Cranial fracture	2.55	1.18, 5.50	0.017
Combined craniofacial	1.80	0.72, 4.50	0.207
Facial fracture	0.36	0.18, 0.74	0.005
High-energy	3.17	1.57, 6.40	0.001
Associated injuries			
Cervical injury	2.74	1.01, 7.45	0.048
Intracranial hemorrhage	2.43	1.21, 4.90	0.013
Glasgow coma scale <6	2.33	1.31, 8.49	0.012
Thoracic injury	4.36	2.04, 9.36	<0.001
Number of associated injuries			
None (reference)	1.00		
One	1.64	0.68, 3.96	0.269
Two	3.87	1.47, 10.19	0.006
Three	10.43	2.99, 36.42	<0.001
Four	18.25	1.55, 215.33	0.021

Table 4. Multivariable logistic regression analysis for blunt cerebrovascular injuries in 753 craniofacial fracture patients.

	Adjusted Odds Ratio	95% confidence intervals	P-value
Craniofacial fractures			
Facial fracture (reference)	1.00		
Combined craniofacial	1.78	0.66, 4.83	0.258
Cranial fracture	2.29	0.99, 5.33	0.054
Age	0.99	0.97, 1.01	0.183
Motor vehicle accident	2.10	0.94, 4.70	0.071
Cervical injury	1.91	0.65, 5.62	0.240
Thoracic injury	2.63	1.14, 6.05	0.023

Table 5. Descriptive data of 39 blunt cerebrovascular injuries in 33 craniofacial fracture patients.

	n (%)
Artery involved	
Internal carotid artery / Common carotid artery	27 (69.2)
Vertebral artery	12 (30.8)
Multiple blunt cerebrovascular injuries	
No	27 (81.8)
Yes	6 (18.2)
Cervical plane	
C0-C2	29 (74.4)
C3-C5	5 (12.8)
C6-T1	5 (12.8)
Gradus	
1	9 (23.1)
2	21 (53.9)
3	5 (12.8)
4	4 (10.6)
5	0 (0.00)

Captions to illustrations

Figure 1: **Representative imaging showing the anatomical location of each blunt cerebrovascular injury**

Figure text: Each star represents one blunt cerebrovascular injury in the corresponding vessel and cervical plane

Supplemental digital content 1 caption:

Supplemental digital content 1: Flowchart of patients

Supplemental digital content text: Flowchart of patients with blunt cerebrovascular injuries (BCVI).