Facial Fracture Patterns Associated with Traumatic Optic Neuropathy

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Abstract

Traumatic optic neuropathy (TON) is rare. The heterogeneity of injury patterns and patient condition on presentation makes diagnosis difficult. Fracture patterns associated with TON have never been evaluated. Retrospective review of 42 patients diagnosed with TON at the R. Adams Cowley Shock Trauma Center from May 1998 to August 2010 was performed. Thirty-three patients met criteria for study inclusion of fracture patterns. Additional variables measured included patient demographics and mechanism. Cluster analysis was used to form homogenous groups of patients based on different fracture patterns. Fracture frequency was analyzed by group and study population. Visual depiction of fracture patterns was created for each group. Cluster analysis of fracture patterns yielded five common "groups" or fracture patterns among the study population. Group 1 ($n = 3$, 9%) revealed contralateral lateral orbital wall (100%), zygoma (67%), and nasal bone (67%) fractures. Group 2 ($n = 7$, 21%) demonstrated fractures of the frontal bone (86%), nasal bones (71%), and ipsilateral orbital roof (57%). Group 3 ($n = 14$, 43%) involved fractures of the ipsilateral zygoma (100%), lateral orbital wall (29%), as well as frontal and nasal bones (21% each). Group 4 ($n = 5$, 15%) consisted of mid- and upper-face fractures; 100% fractured the ipsilateral orbital floor, medial and lateral walls, maxilla, and zygoma; 80% fractured the orbital roof and bilateral zygoma. Group 5 ($n = 4$, 12%) was characterized by fractures of the ipsilateral orbital floor, medial and lateral orbital walls (75% each), and orbital roof (50%). A notably high 15 of 33 patients (45%) sustained penetrating trauma. Our study demonstrates five fracture pattern groups associated with TON. Zygomatic, frontal, nasal, and orbital fractures were the most common. Fractures with a combination of frontal, nasal, and orbital fractures are particularly concerning and warrant close attention to the eye.

Keywords
- traumatic optic neuropathy
- blindness
- craniofacial trauma
- facial fractures
- fracture pattern

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Traumatic optic neuropathy (TON) is a rare sequela of blunt and penetrating craniofacial trauma, with an incidence of 2 to 5%.[1–3] It is defined as any damage to the optic nerve secondary to trauma that may occur primarily or secondarily to the initial insult. No treatment algorithm exists for the identification of this debilitating complication, and the heterogeneity of injury patterns makes diagnosis difficult. Furthermore, concomitant life-threatening injury with significant trauma may also contribute to a delay in diagnosis. Rapid recognition of this complication is essential in providing the greatest chance of restoring visual acuity. Steroids, surgical decompression of the optic nerve, a combination of the two, and observation are used as means of initial management, but no method is accepted as superior.[4–6] Regardless of the treatment plan implemented, prompt diagnosis of TON is essential to optimize outcomes.[7] Knowledge of facial fracture patterns can help predict and identify intracranial injury following facial trauma.[8–10] The association between fracture pattern and TON has never been quantified. The purpose of this study is to identify common fracture patterns associated with TON to help assist centers with high-volume facial trauma to more readily recognize this injury for prompt treatment.

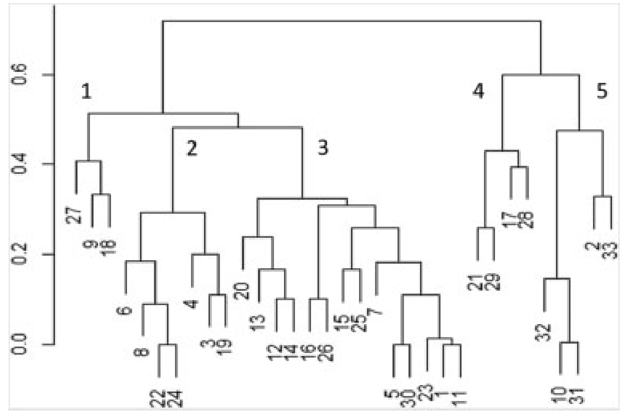

Fig. 1 Cluster dendrogram with associated patient number identifier from analysis of fracture patterns yielded five common groups or fracture patterns in the study population. Groups 1 through 5 are labeled at the "branch" of the cluster tree.

Methods

Institutional review board approval was obtained for retrospective review of patients diagnosed with TON at the R. Adams Cowley Shock Trauma Center/University of Maryland Medical Center from May 1998 to August 2010. Patients were identified by *International Classification of Disease, Ninth Edition* code. Facial fracture patterns were recorded. Additional variables included patient demographics, injury mechanism, and associated injury classifications. TON is the only outcome variable. Patients with a diagnosis of TON, sudden or progressive onset of visual loss following craniofacial trauma, were screened. Patients whose charts were missing demographic or radiographic data were excluded. All radiographic fracture patterns were confirmed by author review of computed tomographic (CT) imaging. In this study, the fracture patterns and the number of fracture patterns were evaluated in 42 patients with TON. Complete data are available for 33 patients. Nine were excluded due to incomplete medical records. The fractures considered include (1) angle, (2) body, (3) ramus, (4) symphyseal, (5) parasymphyseal, (6) coronoid, (7) condylar, (8) subcondylar, (9) maxillary sinus, (10) orbital floor, (11) medial orbital wall, (12) lateral orbital wall, (13) orbital roof, (14) zygoma, (15) frontal, (16) nasal combo, and (17) basilar. A total of 33 defined fractures (contralateral and ipsilateral for all fractures except for symphysis) as well as a total number of fractures were analyzed. Cluster analysis was used to form homogenous groups of patients based on the different fracture patterns.[11] Cluster analysis categorizes clusters of cases based on how similar they are to each other. The hierarchical cluster analysis procedure implemented using R-3.1.1 (package = " cluster") was used to identify the subgroups of patients with similar fracture patterns.[12] The daisy-algorithm was used for the analysis because of the mixed data where the number of fractures was a numeric variable and the other variables were binary, having a fracture or no fracture.

Results

Thirty-three out of 42 patients met inclusion criteria. Basic patient demographics and mechanism data are shown in ►**Table 1**. Analysis of fracture patterns yielded five common groups of fracture patterns among the study population (►**Figs. 1** and **2**). Fracture frequency within each group and for the study was analyzed (►**Table 2**). Not every patient within a group shares each fracture, but rather they are grouped by frequency of fracture combinations. Frequency of fracture

Table 1 Demographic, mechanistic, and clinical data for study population

	1	2	3	4	5	Study ($n = 33$)
Sex (% M)	100%	86%	57%	100%	80%	76%
Mean age	18	28	37	22	52	34
Side (% right)	33%	86%	57%	0%	80%	58%
Mechanism (% penetrating)	100%	14%	36%	100%	60%	45%
Mean number of fractures	4.7	2.6	2.4	12.6	4.25	4.7
Mean Glasgow Coma Scale	15	11	10	9	7	10

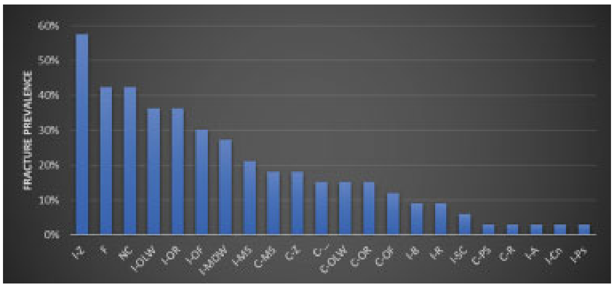

Fig. 2 Graphical representation of fracture prevalence among the study population. Abbreviations are deciphered in ►**Table 2**.

within the group population is demonstrated by color code in a visual depiction of the craniofacial skeleton (►**Fig. 3**).

The first fracture pattern, Group 1 ($n = 3$, 9%), consists primarily of the contralateral lateral orbital wall (100%), nasal bone (67%), and contralateral zygoma (67%; ►**Fig. 3**, image 1).

Group 2 ($n = 7$, 21%) demonstrates a fracture pattern composed of the frontal bone (86%), nasal bones (71%), and ipsilateral (57%) and contralateral orbital roofs (14%; ►**Fig. 3**, image 2). This group is composed largely of patients who suffered blunt trauma, either due to assault or motor vehicle accident (►**Table 1**).

Group 3 fracture pattern ($n = 14$, 43%) is composed of the ipsilateral zygoma (100%), ipsilateral lateral orbital wall (29%), frontal and nasal bones (21% each), ipsilateral maxillary sinus, orbital floor, and orbital roof (each 14%; ►**Fig. 3**, image 3).

Group 4 ($n = 5$, 15%) consists largely of mid- and upper-face fractures. One hundred percent of patients sustained fractures of the ipsilateral orbital floor, medial and lateral orbital walls, maxillary sinus, and zygoma. Eighty percent of patients sustained fractures of the ipsilateral zygoma and orbital roof and contralateral zygoma. Sixty percent of patients sustained fractures of the frontal bone, nasal bones, and contralateral lateral orbital floor. Forty percent sustained fractures of the contralateral lateral orbital wall, orbital roof, and ipsilateral mandibular subcondylar or ramus (►**Fig. 3**, image 4). All were young men, three of who sustained gunshot wounds to the face.

Group 5 ($n = 4$, 12%) was characterized by fractures of the ipsilateral orbital floor, medial and lateral orbital walls (75% each), and orbital roof (50%; ►**Fig. 3**, image 5).

The optic nerve was affected in the right and left eyes in 19 and 14 cases, respectively. Fifteen patients sustained penetrating trauma, and 18 patients sustained blunt trauma. Twenty-five injuries were intraorbital. The remaining eight injured the canalicular optic nerve. Four patients expired. Frontal bone and ipsilateral zygoma fractures were the most commonly fractured in 42% of all cases. Ipsilateral orbital roof and lateral wall were observed in 36% of cases, and fractures of the ipsilateral orbital floor and medial orbital wall in 30 and 27% of cases, respectively.

Discussion

Many articles have discussed the diagnosis and treatment of TON.[1,5–7,13,14] Fracture pattern analysis has been used to predict intracranial injury following craniofacial trauma, but this is the first study performed to identify facial fracture patterns associated with TON.[10] Given the low incidence of TON and high prevalence of concomitant, life-threatening injuries in patients who sustain craniofacial trauma, TON is likely to be overlooked. Knowledge of such common fracture patterns may help emergency department as well as trauma and craniofacial surgeons more easily identify this condition. Our analysis demonstrated five groups of facial fracture patterns associated with TON. Among the most prevalent in this study, in descending order, are fractures of the ipsilateral zygomatic bone; frontal and nasal bones; orbital walls, roof, and floor; and the ipsilateral maxilla. Fractures of these bones indicate transmission of high-velocity forces across the facial skeleton buttresses and are associated with a worse visual prognosis.[15–17] A systematic review from 2012 characterized ocular impairment and visual loss to be closely associated with orbital floor blowout and zygomaticomaxillary complex (ZMC) fractures.[18] A retrospective review by Ansari also found zygomatic and ZMC fractures to be most associated with vision loss.[19] Vaca et al found nasoorbitoethmoid (NOE) and nasal bone fractures to be more likely to result in blindness than other facial fractures in the context of an open globe injury.[20] Not surprisingly, other studies show decreased visual acuity following orbital and midface trauma.[15] Our study shows TON results from a particularly high incidence of zygomatic and nasal bone fractures (58 and 42%, respectively) as well as frontal bone fractures (42%) and orbital roof fractures (36). When force is applied to the superior orbital rim, it is transmitted to and concentrated on the optic canal and orbital roof.[21] One might infer that fractures of the frontal bone thereby transmit sheer and traction force on the optic nerve and its vasculature. Given the anatomical proximity of the frontal bone to the orbit and the force necessary to cause frontal bone fracture, the association of TON with such fractures in this study is unsurprising. Frontal bone fractures, particularly in combination with zygomatic, nasal bone, NOE, or orbital roof fractures, should alert the maxillofacial surgeon to direct special attention to this pathology at presentation or upon gaining consciousness.

TON can be either direct or indirect. Direct TON results from anatomical damage to the optic nerve by penetrating trauma or bony laceration. Indirect TON results from optic nerve damage secondary to compression or swelling from transmission of high velocity force from a distant site.[14,17] This transmission of force is highlighted by patients 9, 18, and 27 of Group 1, who demonstrate indirect TON as a result of sheer force transmitted to the optic nerve contralateral to the side of fracture(s). Fractures of the orbit, as seen in Groups 4 and 5, pose a risk for both direct and indirect TON as a consequence of these forces. This transmission of force is further highlighted by the patients in Group 2, where fractures of the frontal cranium transmit compressive and/or sheer forces to the optic nerve.

In this study, analysis of the dendrogram demonstrates orbital fractures as the linking mechanism for Groups 4 and 5. Given the proximity of the orbital bony framework to the optic nerve and findings in other studies, this is not

Table 2 Fracture pattern data for entire study cohort and individual group subdivision

Study ($n = 33$)		Total number of fractures	% with fracture	Bone	Number of fractures	% with fracture	Bone	Number of fractures	% with fracture
Ipsilateral zygoma	I-Z	19	58		Clade I			Clade IV	
Frontal	F	14	42	C-OLW	3	100	C-MOW	5	100
Nasal combo	NC	14	42	NC	2	67	I-MOW	5	100
Ipsilateral orbital lateral wall	I-OLW	12	36	C-Z	2	67	I-MS	5	100
Ipsilateral orbital roof	I-OR	12	36	F	1	33	I-OF	5	100
Ipsilateral orbital floor	I-OF	10	30	C-MS	1	33	I-OLW	5	100
Ipsilateral medial orbital wall	I-MOW	9	27	C-OR	1	33	I-Z	5	100
Ipsilateral maxillary sinus	I-MS	7	21	C-Ps	1	33	C-MS	4	80
Contralateral maxillary sinus	C-MS	6	18	C-R	1	33	C-Z	4	80
Contralateral zygoma	C-Z	6	18	I-B	1	33	I-OR	4	80
Contralateral medial orbital wall	C-MOW	5	15				F	3	60
Contralateral orbital lateral wall	C-OLW	5	15		Clade II		NC	3	60
Contralateral orbital roof	C-OR	5	15	F	6	86	C-OF	3	60
Contralateral orbital floor	C-OF	4	12	NC	5	71	C-OLW	2	40
Ipsilateral body	I-B	3	9	I-OR	4	57	C-OR	2	40
Ipsilateral ramus	I-R	3	9	C-OR	1	14	I-R	2	40
Ipsilateral subcondyle	I-SC	2	6				I-Sc	2	40
Contralateral parasymphysis	C-PS	1	3		Clade III		I-A	1	20
Contralateral ramus	C-R	1	3	I-Z	14	100	I-B	1	20
Ipsilateral angle	I-A	1	3	I-OLW	4	29	I-Cn	1	20
Ipsilateral condyle	I-Cn	1	3	F	3	21	I-Ps	1	20
Ipsilateral parasymphysis	I-Ps	1	3	NC	3	21			
Symphysis	S	0	0	I-MS	2	14		Clade V	
Basilar	B	0	0	I-OF	2	14	I-MOW	3	75
Contralateral angle	C-A	0	0	I-OR	2	14	I-OF	3	75
Contralateral body	C-B	0	0	I-MOW	1	7	I-OLW	3	75
Contralateral coronoid	C-C	0	0	I-R	1	7	I-OR	2	50
Contralateral condyle	C-Cn	0	0				F	1	25
Contralateral subcondyle	C-Sc	0	0				NC	1	25
Ipsilateral coronoid	I-C	0	0				C-MS	1	25
							C-OF	1	25
							C-OR	1	25
							I-B	1	25

surprising. The majority of cases in these two groups resulted from penetrating trauma near the orbit. Penetrating trauma to the orbit does not preclude injury to only the ipsilateral eye; Group 1 demonstrates how sheer force secondary to penetrating trauma can damage the contralateral eye. Groups 2 and 3 further emphasize the ability of sheer force to damage the craniofacial skeleton and optic nerve following blunt trauma. In these closely linked groups, we see that blunt trauma to the upper and middle thirds of the face can have an equally debilitating result.

The findings of this study are not intended to change study protocols, but the findings bring greater awareness and anatomic understanding of the fracture patterns that cause this pathology. Craniomaxillofacial and trauma surgeons who evaluate polytrauma patients might take a few generalizations away from this study. First, fractures involving a combination of the zygoma, frontal and nasal bones, and orbital walls (notably the roof) should cause the surgeon to consider TON among immediate diagnoses when evaluating a patient with any visual deficit. Such fracture combinations imply greater

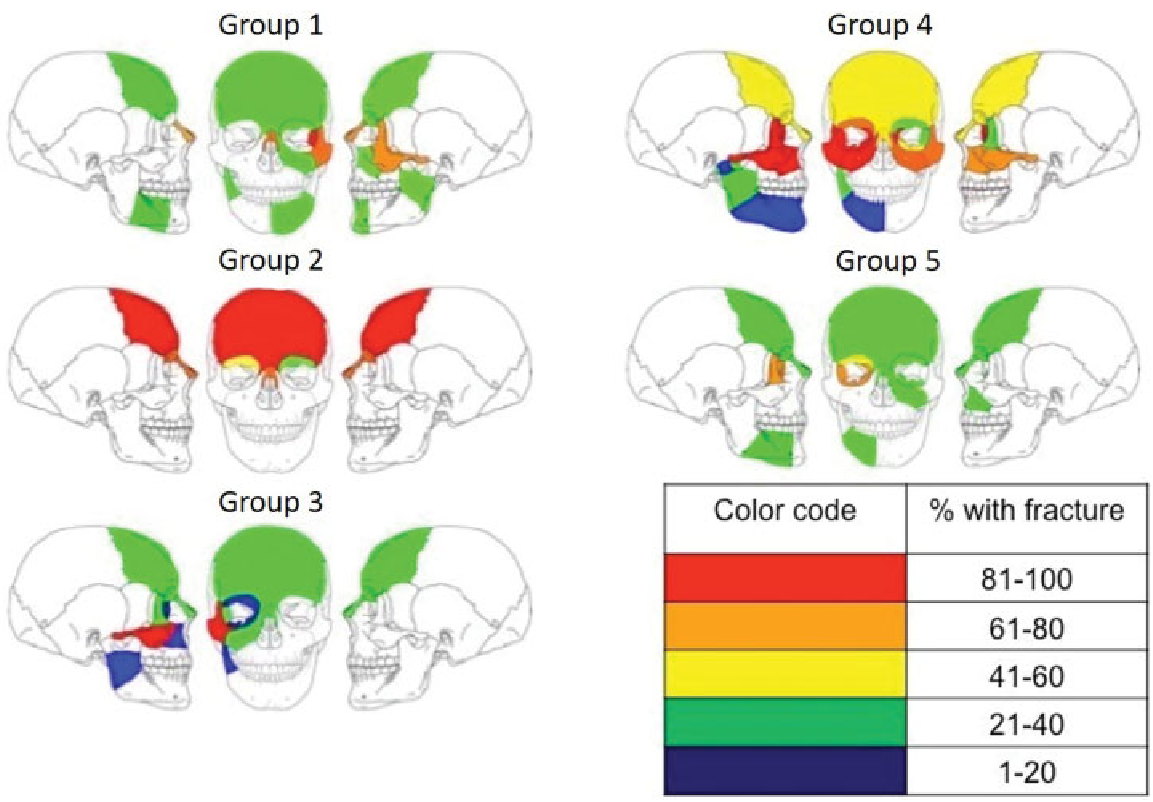

Fig. 3 Facial skeleton fracture patterns within groups.

forces transmitted through the craniofacial skeleton, thereby increasing risk of optic nerve damage. Common fractures such as nasal bone and ZMC fractures are common, and we must bear this in mind; high impact trauma that affects the front bone and orbital roof should grab the surgeon's attention. Sheer forces can affect distant structures resulting in contralateral, indirect TON. Lack of anatomic proximity to fractures does not allow exclusion of a diagnosis of TON. The surgeon must be vigilant in this evaluation, particularly because many patients will be comatose upon presentation secondary to the inflicted trauma. Prompt diagnosis and documentation of injury not only allows the surgeon to cater to and anticipate individual patient needs but is also increasingly important in the current complicated medicolegal environment.

Although this is the largest series to date evaluating facial fracture patterns associated with this phenomenon, this analysis has limitations. This is a retrospective study with sample size limited by the rarity of TON. Only 42 cases are identified over a 12-year period, and merely 33 patients meet inclusion criteria; this limits further refinement of fracture patterns analysis. Identification of additional cases of TON with meticulous documentation of radiographic findings would further elucidate fracture patterns. The large trauma volume at the Shock Trauma Center makes manual review tedious, and reliance on diagnosis codes for patient identification may result in missed cases and additional refinement of fracture patterns; however, the registry at this institution is very thorough. TON may not be detected until 2 to 3 weeks after the insulting trauma, which may have resulted in missed cases. A high proportion of patients sustained penetrating trauma (45%). Penetrating trauma may have alerted more urgent ophthalmology consultation, increasing TON diagnosis in this population. Human error in review of CT imaging or documentation may result in flaws to the data, but the CT scans were all doubly reviewed by the authors, all of who were overseen by the senior author (E.D.R.). The high incidence of patients admitted comatose or who expired during or prior to admission for high impact blunt or penetrating craniofacial trauma likely resulted in missed cases of TON whose fractures could not be evaluated for the purposes of this study. This is secondary to nondiagnosis or potentially incorrectly coded diagnoses. Recovery of visual acuity was not recorded for this study. Many trauma patients with TON often do not return for follow-up due to expiration or choices beyond our control, making outcomes difficult to document.[14] If an appropriately powered patient population could be followed up, a future prospective study might correlate fracture pattern with posttraumatic visual acuity to identify which fracture patterns portend a more favorable prognosis and would contribute strongly to the literature, perhaps changing practice patterns.

Conclusion

TON is a rare but devastating sequela of craniofacial trauma. ZMC, frontal, nasal, and orbital bone fractures are most frequently associated with TON. The transmission of high-velocity forces through the craniofacial skeleton can result in either direct or indirect optic nerve damage. Our study of fracture patterns demonstrates five groups of fracture patterns associated with TON. Zygomatic, frontal, nasal, and orbital fractures were the most common in this patient population. The fracture patterns identified in this study may help craniofacial surgeons identify and treat TON to maximize patient outcomes.

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Note

This work has not yet been presented at any meetings.

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