Is the pure and impure distinction of orbital fractures clinically relevant with respect to ocular and periocular injuries? A retrospective study of 473 patients

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ABSTRACT

Objective: To determine the association of "pure" orbital fractures (POF) and "impure" orbital fractures (IOF) with ocular and periocular injuries.
Materials and methods: A retrospective study of patients with orbital fractures was designed. The predictor variable was the orbital's fracture configuration (pure versus impure). The primary outcome variables were ocular and periocular injuries classified as mild, moderate, and severe. The secondary outcome was the need for surgical repair. Standard statistics for patient characteristics, the Fisher exact test for categorical variables, and the Mann—Whitney U test for continuous variables were computed to compare fractures.
Results: The sample was composed of 473 patients (220 POF and 253 IOF). No significant association between the two groups with regard to ocular and periocular injuries was found. Combined medial wall and floor fractures and naso-orbito-ethmoidal (NOE) fractures had the highest incidence of severe injury (34.5%, p = 0.02). Le Fort fractures were associated with moderate ocular and periocular injuries (36.4%, p = 0.01). Impure orbital fractures were more frequently associated with the need for surgical treatment (p = 0.04) than were POF.
Conclusion: The present study has demonstrated that the pure and impure distinction of orbital fractures was not clinically relevant with respect to ocular and periocular injuries. However, our findings seem to suggest that other parameters such as the direction of the impact and/or its magnitude, rather than merely the pure or impure configuration, could be involved in determining the risk of developing concomitant ocular and periocular injuries.

1. Introduction

Cranio-maxillo-facial fractures involving the orbits are frequent, with a prevalence of up to 50% (Shere et al., 2004; Alhamdani et al., 2015; Bartoli et al., 2015; Ross et al., 2017; Scolozzi et al., 2017). Since the 1960s, orbital fractures (OFs) have been categorized into two groups—"pure" and "impure"—with respect to preservation of the orbital rim (Cramer et al., 1965; Converse et al., 1967). Pure orbital fractures (POF) are limited to the orbital walls, whereas impure orbital fractures (IOF) involve the adjacent facial bones such

as in orbitozygomatic, naso-orbito-ethmoidal (NOE), Le Fort II or III, or panfacial fractures (Cramer et al., 1965; Converse et al., 1967).

Regardless of whether they are pure or impure, OFs that are not rapidly and adequately managed can lead to severe functional and aesthetic complications such as visual impairment, persistent annoying diplopia, infraorbital sensory nerve function, enophthalmos, and hypoglobus (Shere et al., 2004; Alhamdani et al., 2015; Bartoli et al., 2015; Ross et al., 2017; Scolozzi et al., 2017).

Originally, this classification was designed by some authors mainly to determine the number of surgical approaches for the orbital repair such as a single in POF versus multiple in IOF. Others have considered POF and IOF as two separate physiopathological entities with respect to different mechanisms of injury (Cramer et al., 1965; Converse et al., 1967).

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According to this theory, and considering that the involved mechanisms of these two entities are so different, one should also expect two distinct clinical expressions with respect to concomitant ocular and periocular injuries. Some authors have highlighted the crucial role of the orbital rim framework, which has been described as a "well-designed and protective structure" with a relatively high force tolerance that shields the globe of the eye from injury by acting as an energy absorber.

However, it has also been demonstrated that the severity of the injury and the force transmission depend not only on the bone strength and the resultant force tolerance to the peak load but also on other important parameters such as the magnitude of the causative force, the time duration of the impact, the angle of impact, and the surface area on which the impact strikes (Lee et al., 1987; Green et al., 1990; Bullock et al., 1997; Waterhouse et al., 1999; Warwar et al., 2000; Ahmad et al., 2003; Schaller et al., 2013; Patel et al., 2017).

To the best of our knowledge, only one study has reported on the possible association between the "purity" status of OFs and concomitant ocular injuries, demonstrating that POFs were at higher risk for ocular injuries compared to IOFs (Brown et al., 1999). Moreover, very few studies have reported associations between the type and severity of OFs and the risk of ocular and periocular injuries.

The purpose of our study was to assess the relationship between the pure and impure configuration of OFs and the occurrence of concomitant ocular and periocular injuries. The investigators hypothesized that POF could be associated with a higher rate of ocular and periocular injuries compared to IOF, because: (1) in POF, the impact forces are typically delivered directly to the eyeball, which, while absorbing the trauma's energy, is displaced posteriorly and downward. Thus, the orbital contents are more likely to be severely injured; and (2) in IOF, much of the impact force is absorbed and dissipated by the orbital rim before fracturing, thus leading to a substantial decrease in the residual energy transmitted to the orbital contents.

The specific aims of the study were to measure, compare, or estimate a set of likely variables to identify the possible risk factors for ocular and periocular injuries by prospectively analyzing the clinico-radiological charts of 473 patients.

2. Materials and methods

2.1. Study design

This retrospective study was composed of patients admitted for facial trauma at the University Hospital of Geneva, Switzerland, from 2009 to 2015. The study was conducted in accordance with the Declaration of Helsinki and was approved by our local Ethical Board (Study number 12-255).

2.2. Study sample

Only patients with orbital trauma and an available head computed tomography (CT) scan, as well as a comprehensive ophthalmological assessment (visual acuity, eyelid, conjunctival, corneal and pupil examination, ophthalmoscopy, slit-lamp examination, and tonometry, extraocular muscles and visual field testing), were included. Patients with insufficient clinical data, history of craniofacial trauma, and craniofacial malformation were excluded. All patients with orbital fracture were evaluated by a maxillofacial surgeon and an ophthalmologist on the day of the trauma.

The following symptoms were used as indication to explore the orbital floor surgically: (1) immediate ocular motility restriction in at least one field of gaze or annoying diplopia at the 10-day follow-up examination; and/or (2) enophthalmos immediately obvious to the naked eye or ≥ 2 mm difference between the globe projection of the two eyes as measured by Hertel exophthalmometry at the 10-day follow-up examination.

2.3. CT scan diagnosis

The diagnosis of orbital fracture was obtained using one of two 64-slice CT scanning systems (Siemens Sensation 64 or the GE Healthcare's CT750 HD scanning system). All CT scanned images were simultaneously reviewed in axial, coronal, and sagittal planes with OsiriX Imaging Software (version 3.0.2, 64-bit, Pixmeo, Geneva, Switzerland; www.osirix-viewer.com) running on MacOSX 10.8.5 (Apple Inc, Cupertino, CA). The fracture type was categorized into one of the two following groups: (1) pure orbital fractures (floor, medial wall, combined floor and medial wall fractures, and others such as lateral wall and/or roof fractures and/or a combination of wall fracture other than floor and medial wall); or (2) impure orbital fractures (orbito-zygomatic, naso-orbito-ethmoidal (NOE) and Le Fort II or III fractures (the number of patients presenting with Le Fort II and Le Fort III fractures was too limited to reach a statistical power allowing significant results if analyzed independently; thus, we decided to combine these two groups for the analysis), and others such as panfacial fractures, etc.).

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2.4. Study variables

The predictor variable was the orbital's fracture configuration (pure versus impure). The primary outcome variable was ocular and periocular injuries. The secondary outcome was the need for surgical exploration and/or repair of the orbital fracture. Other study variables included age, sex, ethnic group, mechanism of injury, fracture location and severity, cause of injury, and type of treatment (surgical versus conservative).

Based on Al Qurainy's classification (al-Qurainy et al., 1991), the ocular and periocular injuries were classified as follows: (1) mild (periorbital ecchymosis, periorbital subcutaneous emphysema, subconjunctival hemorrhage, corneal abrasion); (2) moderate eyelid laceration, relative afferent pupillary defect (RAPD), commotio retinae, Berlin's edema (Berlin's edema is also known as commotio retinae and represents the damage to the outer retinal layers following blunt trauma; it is associated with a transient decrease of visual acuity that usually resolves in 3–4 weeks without any acute treatment, traumatic anterior uveitis, or vitreous floaters); or (3) severe (hyphema, visual acuity impairment, laceration of ocular globe, retinal detachment with vitreous hemorrhage, traumatic ocular neuropathy and retrobulbar hemorrhage).

Diplopia and hypoesthesia of the infraorbital nerve were voluntarily added to the group of mild injuries, as they are common clinical signs encountered in orbital trauma and are easily detectable.

Retrobulbar hemorrhage, although not a clinical sign, was added to the severe injuries, as it can compromise visual function.

2.5. Statistical analysis

Patient characteristics were described using standard statistics (mean, standard deviation, frequency, and percentages). Characteristics were compared across groups using the Fisher exact test

for categorical variables and Mann—Whitney U test for continuous variables. The significance level was set at 0.05. All analyses were performed using R v3.4.3 statistical software (R Development Core Team, Vienna, Austria).

3. Results

Of the 473 patients, 220 (46.5%) had a POF and 253 (54.5%) had an IOF (Table 1). Orbital floor fractures (110; 50.0%) were the main type encountered in the POF category, followed by medial wall fractures (49; 22.3%). Orbito-zygomatic fractures were the most encountered among the IOF (177; 70.0%). The mean age at the time of trauma was significantly different with, respectively, 42.5 in the POF and 49.0 in the IOF category (p < 0.01), with an equivalent male predominance in both groups (69.1 in POF and 70.4% in IOF, respectively). Looking at age categories, OF were more frequent between the ages of 16 and 40 years. There was no IOF in patients under 8 years. Falls were the main cause of orbital trauma, both in POF and IOF, followed by assault and traffic accidents. A total of 46 (20.9%) and 74 (29.5%) patients required surgical exploration and repair of the orbital wall fracture in POF and IOF, respectively, and the difference was statistically significant (p = 0.04). The characteristics of the patients in POF and IOF groups who underwent operation are summarized in Table 2.

Among the POF and the IOF groups, almost every patient (99.1% and 98.4%, respectively) had ocular and periocular injuries of various severities, whereas severe ophthalmological injuries were encountered in 19.5% and 17.0% of POF and IOF, respectively (Table 3). All of these patients had at least a mild injury. Overall, there was no clinically significant difference between the two categories with respect to the type of ocular and periocular injuries, except for traumatic anterior uveitis, which was three times more frequent among patients with POF than among those with IOF (p = 0.013).

By contrast, significant associations were found between ocular and periocular injuries and the type of POF (Table 4). Compared to patients with other types of POF, patients with combined medial

wall and floor fractures had the highest incidence of severe ocular and periocular injuries (34.5%, p = 0.02), including visual acuity impairment (34.5%, p = 0.01) and retinal detachment with vitreous hemorrhage (10.3%, p = 0.01). Moreover, these patients were the only ones in which globe rupture occurred (6.9%, p < 0.01). This type of fracture was also associated with the highest incidence of corneal abrasion (13.8%, p = 0.04) among POF. Retrobulbar hemorrhage was found to occur significantly more in the group "other" (18.8%, p < 0.01).

As for POF, within the IOF category, significant statistical associations were found between ocular injuries and type of fracture (Table 5). The NOE fractures were associated with a high risk of developing two types of severe ocular and periocular injuries, such as hyphemia and retinal detachment with vitreous hemorrhage,

Table 1
Baseline sample characteristics in POF and IOF groups.

	POF (N = 220)	IOF (N = 253)	p
Age in years, median [IQR]	42.5 [27.0, 64.2]	49.0 [29.0, 75.0]	<0.01
Gender, Male (%)	152 (69.1)	178 (70.4)	0.84
Ethnic group, N (%)			0.23
African	33 (15.0)	28 (11.1)	
Asian	3 (1.4)	1 (0.4)	
Caucasian	183 (83.2)	224 (88.5)	
Hispanic	1 (0.5)	0 (0.0)	
Mechanism of injury, N (%)			0.01
Fall	81 (36.8)	107 (42.3)	
Assault	78 (35.5)	59 (23.3)	
Traffic accident	30 (13.6)	57 (22.5)	
Sport accident	12 (5.5)	13 (5.1)	
Other	19 (8.6)	17 (6.7)	
POF, N (%)			<0.01
Orbital floor	110 (50.0)	—	
Medial orbital wall	49 (22.3)	—	
Combined (medial wall and floor)	29 (13.2)	—	
Other	32 (14.5)	—	
IOF, N (%)			<0.01
Orbito-zygomatic	—	177 (70.0)	
Le Fort	—	44 (17.4)	
NOE	—	10 (4.0)	
Other	—	22 (8.7)	
Surgery N (%)	46 (20.9)	74 (29.5)	0.04

IQR, interquartile range; POF, pure orbital fractures; IOF, impure orbital fractures; NOE, naso-orbito-ethmoidal fractures.

Table 2
Baseline sample characteristics of the operated patients in POF and IOF groups.

	POF (N = 46)	IOF (N = 74)	p
Age, median [IQR]	36.5 [27.0, 53.2]	38.5 [26.0, 53.0]	0.76
Gender, Male (%)	31 (67.4)	60 (81.1)	0.14
Ethnic group, N (%)			0.18
African	10 (21.7)	10 (13.5)	
Asian	1 (2.2)	0 (0.0)	
Caucasian	34 (73.9)	64 (86.5)	
Hispanic	1 (2.2)	0 (0.0)	
Mechanism of injury, N (%)			0.01
Fall	12 (26.1)	18 (24.3)	
Assault	22 (47.8)	17 (23.0)	
Traffic accident	5 (10.9)	27 (36.5)	
Sport accident	4 (8.7)	6 (8.1)	
Others	3 (6.5)	6 (8.1)	
POF, N (%)			<0.01
Orbital floor	28 (60.9)	—	
Medial orbital wall	5 (10.9)	—	
Combined (medial wall and floor)	10 (21.7)	—	
Others	3 (6.5)	—	
IOF, N (%)			<0.01
Orbito-zygomatic	—	43 (58.1)	
Le Fort	—	22 (29.7)	
NOE	—	4 (5.4)	
Others	—	5 (6.8)	

IQR, interquartile range; NOE, naso-orbito-ethmoidal fractures.

Table 3
Association between OF and ocular and periocular injuries.

	POF (N = 220)	IOF (N = 253)	p
Ocular and periocular injuries	218 (99.1)	249 (98.4)	0.811
Mild N (%)	218 (99.1)	249 (98.4)	0.811
ION hypoesthesia	66 (30.3)	70 (28.8)	0.808
Periorbital ecchymosis, N (%)	214 (97.3)	244 (96.8)	0.989
Periorbital emphysema, N (%)	44 (20.2)	62 (25.6)	0.204
Diplopia, N (%)	64 (29.4)	52 (21.2)	0.056
subconjunctival hemorrhage, N (%)	147 (66.8)	177 (70.0)	0.526
Corneal abrasion, N (%)	9 (4.1)	8 (3.2)	0.769
Moderate N (%)	48 (21.8)	52 (20.6)	0.823
Eyelid laceration, N (%)	15 (6.8)	17 (6.7)	1
RAPD, N (%)	8 (3.6)	17 (6.7)	0.197
Anterior uveitis, N (%)	21 (9.5)	9 (3.6)	0.013
Berlin's edema, N (%)	16 (7.3)	19 (7.5)	1
Commotio retinae, N (%)	5 (2.3)	9 (3.6)	0.582
Severe N (%)	43 (19.5)	43 (17.0)	0.55
Impairment of visual acuity, N (%)	32 (14.5)	39 (15.4)	0.893
Hyphemia, N (%)	5 (2.3)	10 (4.0)	0.437
Laceration of ocular globe, N (%)	2 (0.9)	4 (1.6)	0.811
Retinal detachment, N (%)	5 (2.3)	12 (4.7)	0.233
Traumatic ocular neuropathy, N (%)	5 (2.3)	2 (0.8)	0.342
Oculomotor paralysis, N (%)	9 (4.1)	11 (4.3)	1
Retrobulbar hemorrhage, N (%)	12 (5.5)	7 (2.8)	0.211

ION, infra orbital nerve; RAPD, relative afferent pupillary defect.

Table 4
Association between type of POF and ocular and periocular injuries.

	Other (N = 32)	Medial wall (N = 49)	Orbital Floor (N = 110)	Medial wall and orbital floor (N = 28)	p
Ocular and periocular injuries	32 (100.0)	48 (98.0)	110 (100.0)	28 (96.6)	0.25
Mild N (%)	32 (100.0)	48 (98.0)	110 (100.0)	28 (96.6)	0.25
ION hypoesthesia	6 (18.8)	11 (22.9)	35 (32.1)	14 (48.3)	0.051
Periorbital ecchymosis, N (%)	31 (96.9)	47 (95.9)	108 (98.2)	28 (96.6)	0.86
Periorbital emphysema, N (%)	4 (12.5)	10 (20.8)	22 (20.2)	8 (27.6)	0.54
Diplopia, N (%)	10 (31.2)	10 (20.4)	30 (27.8)	14 (48.3)	0.07
subconjunctival hemorrhage, N (%)	18 (56.2)	31 (63.3)	75 (68.2)	23 (79.3)	0.26
Corneal abrasion, N (%)	1 (3.1)	2 (4.1)	2 (1.8)	4 (13.8)	0.04
Moderate N (%)	5 (15.6)	12 (24.5)	24 (21.8)	7 (24.1)	0.80
Eyelid laceration, N (%)	4 (12.5)	5 (10.2)	4 (3.6)	2 (6.9)	0.23
RAPD, N (%)	1 (3.1)	2 (4.1)	4 (3.6)	1 (3.4)	1.00
Anterior uveitis, N (%)	1 (3.1)	3 (6.1)	12 (10.9)	5 (17.2)	0.22
Berlin's edema, N (%)	0 (0.0)	4 (8.2)	10 (9.1)	2 (6.9)	0.37
Commotio retinae, N (%)	0 (0.0)	2 (4.1)	3 (2.7)	0 (0.0)	0.52
Severe N (%)	10 (31.2)	7 (14.3)	16 (14.5)	10 (34.5)	0.02
Impairment of visual acuity, N (%)	3 (9.4)	5 (10.2)	14 (12.7)	10 (34.5)	0.01
Hyphemia, N (%)	0 (0.0)	2 (4.1)	1 (0.9)	2 (6.9)	0.16
Laceration of ocular globe, N (%)	0 (0.0)	0 (0.0)	0 (0.0)	2 (6.9)	<0.01
Retinal detachment, N (%)	0 (0.0)	0 (0.0)	2 (1.8)	3 (10.3)	0.01
Traumatic ocular neuropathy, N (%)	1 (3.1)	1 (2.0)	2 (1.8)	1 (3.4)	0.94
Oculomotor paralysis, N (%)	3 (9.4)	1 (2.0)	4 (3.6)	1 (3.4)	0.41
Retrobulbar hemorrhage, N (%)	6 (18.8)	1 (2.0)	3 (2.7)	2 (6.9)	<0.01
Surgery N (%)	3 (9.4)	5 (10.2)	28 (25.5)	10 (34.5)	0.01

which was statistically significant (20%; p = 0.03 and 20%; p = 0.02, respectively). Le Fort fractures had the highest incidence of moderate ocular and periocular injuries (36.4%, p = 0.03), including eyelid laceration (18.2%, p = 0.01) and retinal commotion (11.4%, p < 0.01). These fractures were also associated with the highest incidence of corneal abrasion (11.4%, p < 0.01) among IOF. Of note, 25% of patients with Le Fort fractures had visual acuity impairment, with no statistical significance whatsoever.

Interestingly, surgical exploration and repair were performed more frequently in combined medial and floor fractures, NOE fractures, and Le Fort fractures (34.5%, 40% and 51.2%, respectively) (Table 5). Tables 6 and 7 provide an overview of the association between type of POF and IOF in patients who underwent operation and ocular and periocular injuries. No significant associations were found between ocular and periocular injuries and the type of surgically treated POF. On the other hand, significant associations were found between ocular and periocular injuries and the type of surgically treated IOF. The NOE fractures in patients who underwent operation were associated with a high risk of developing three types of severe ocular and periocular injuries, such as laceration of ocular globe, retinal detachment with vitreous hemorrhage, and traumatic ocular neuropathy, which were statistically significant (25%; p = 0.05; 25%; p = 0.04; 25%; p = 0.03, respectively). Of note, the orbital floor was explored in all surgically treated IOF cases. However, in none of these patients were severe ocular and periocular injuries such as retrobulbar hemorrhage a reason for surgical exploration of the orbital floor.

4. Discussion

The present study aimed to evaluate the relationship between the pure and impure configuration of OFs and the concomitant

Table 5
Association between type of IOF and clinical signs.

	NOE (N = 10)	Le Fort (N = 44)	Orbito-zygomatic (N = 177)	Other (N = 22)	p
Ocular and periocular injuries	10 (100.0)	44 (100.0)	174 (98.3)	21 (95.5)	0.55
Mild N (%)	10 (100.0)	44 (100.0)	174 (98.3)	21 (95.5)	0.55
ION hypoesthesia	3 (30.0)	8 (21.1)	53 (30.5)	6 (28.6)	0.72
Periorbital ecchymosis, N (%)	10 (100.0)	44 (100.0)	170 (96.6)	20 (90.9)	0.23
Periorbital emphysema, N (%)	3 (30.0)	18 (47.4)	37 (21.4)	4 (19.0)	0.01
Diplopia, N (%)	1 (10.0)	10 (25.6)	36 (20.6)	5 (23.8)	0.72
subconjunctival hemorrhage, N (%)	6 (60.0)	27 (61.4)	129 (72.9)	15 (68.2)	0.43
Corneal abrasion, N (%)	0 (0.0)	5 (11.4)	3 (1.7)	0 (0.0)	0.01
Moderate N (%)	1 (10.0)	16 (36.4)	30 (16.9)	5 (22.7)	0.03
Eyelid laceration, N (%)	0 (0.0)	8 (18.2)	9 (5.1)	0 (0.0)	0.01
RAPD, N (%)	0 (0.0)	7 (15.9)	9 (5.1)	1 (4.5)	0.06
Anterior uveitis, N (%)	0 (0.0)	2 (4.5)	6 (3.4)	1 (4.5)	0.9
Berlin's edema, N (%)	1 (10.0)	4 (9.1)	11 (6.2)	3 (13.6)	0.6
Commotio retinae, N (%)	0 (0.0)	5 (11.4)	2 (1.1)	2 (9.1)	<0.01
Severe N (%)	2 (20.0)	12 (27.3)	24 (13.6)	5 (22.7)	0.15
Impairment of visual acuity, N (%)	2 (20.0)	11 (25.0)	22 (12.4)	4 (18.2)	0.2
Hyphemia, N (%)	2 (20.0)	3 (6.8)	4 (2.3)	1 (4.5)	0.03
Laceration of ocular globe, N (%)	1 (10.0)	1 (2.3)	2 (1.1)	0 (0.0)	0.15
Retinal detachment, N (%)	2 (20.0)	4 (9.1)	4 (2.3)	2 (9.1)	0.02
Traumatic ocular neuropathy, N (%)	0 (0.0)	1 (2.3)	0 (0.0)	1 (4.5)	0.08
Oculomotor paralysis, N (%)	0 (0.0)	4 (9.1)	5 (2.8)	2 (9.1)	0.17
Retrobulbar hemorrhage, N (%)	0 (0.0)	1 (2.3)	4 (2.3)	2 (9.1)	0.29
Surgery N (%)	4 (40.0)	22 (51.2)	43 (24.4)	5 (22.7)	<0.01

Table 6
Association between type of POF and ocular and periocular injuries in operated patients.

	Others (N = 3)	Medial wall (N = 5)	Orbital Floor (N = 28)	Medial wall and orbital floor (N = 10)	p
Ocular and periocular injuries	3 (100.0)	5 (100.0)	28 (100.0)	10 (100.0)	—
Mild N (%)	3 (100.0)	5 (100.0)	28 (100.0)	10 (100.0)	—
ION hypoesthesia	1 (33.3)	3 (60.0)	15 (53.6)	6 (60.0)	0.87
Periorbital ecchymosis, N (%)	3 (100.0)	5 (100.0)	28 (100.0)	10 (100.0)	—
Periorbital emphysema, N (%)	1 (33.3)	3 (60.0)	5 (17.9)	3 (30.0)	0.25
Diplopia, N (%)	2 (66.7)	3 (60.0)	16 (59.3)	7 (70.0)	0.94
subconjunctival haemorrhage, N (%)	2 (66.7)	5 (100.0)	23 (85.2)	9 (90.0)	0.58
Corneal abrasion, N (%)	0 (0.0)	0 (0.0)	0 (0.0)	1 (11.1)	0.30
Moderate N (%)	1 (33.3)	1 (20.0)	8 (28.6)	3 (30.0)	0.97
Eyelid laceration, N (%)	0 (0.0)	1 (20.0)	2 (7.7)	0 (0.0)	0.53
Relative afferent pupillary defect, N (%)	1 (33.3)	1 (20.0)	1 (3.8)	1 (10.0)	0.29
Anterior uveitis, N (%)	0 (0.0)	1 (20.0)	5 (19.2)	4 (44.4)	0.38
Berlin's oedema, N (%)	0 (0.0)	0 (0.0)	6 (24.0)	2 (22.2)	0.51
Commotio retinae, N (%)	0 (0.0)	1 (20.0)	1 (4.0)	0 (0.0)	0.36
Severe N (%)	2 (66.7)	2 (40.0)	8 (28.6)	6 (60.0)	0.25
Impairment of visual acuity, N (%)	2 (66.7)	1 (20.0)	7 (28.0)	5 (55.6)	0.26
Hyphaema, N (%)	0 (0.0)	0 (0.0)	0 (0.0)	1 (11.1)	0.29
Laceration of ocular globe, N (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	—
Retinal detachment, N (%)	0 (0.0)	0 (0.0)	1 (4.2)	2 (25.0)	0.22
Traumatic ocular neuropathy, N (%)	0 (0.0)	1 (20.0)	1 (4.0)	0 (0.0)	0.4
Oculomotor paralysis, N (%)	0 (0.0)	0 (0.0)	1 (4.0)	1 (12.5)	0.71
Retrobulbar hemorrhage, N (%)	0 (0.0)	1 (20.0)	1 (4.2)	1 (12.5)	0.59

association with ocular and periocular injuries. We hypothesized that POF could be associated with a higher rate of ocular and periocular injuries compared to IOF. In fact, in IOF, the trauma energy is first absorbed and then dissipated by the orbital rim, causing its fracture, thus reducing the energy transmitted to the orbital contents and the risk of subsequent damage (Lee et al., 1987; Green et al., 1990; Bullock et al., 1997; Waterhouse et al., 1999; Warwar et al., 2000; Ahmad et al., 2003; Schaller et al., 2013; Patel et al., 2017).

Moreover, in IOF, the orbital walls classically are indirectly injured by an eccentric blow (on the zygomatic prominence in orbito-zygomatic fractures, on the nose in NOE fractures, and on the nasion region in Le Fort II and III fractures). Theoretically, these factors should contribute to a limited impact of such fractures on the orbital contents. Conversely, in POF, the orbital walls are injured following a direct impact on the eyeball. The extremely deformable semifluid orbital contents can stand very high loading without

rupturing, thus transmitting much of the impact force to the thin orbital walls, whose threshold for fracture is very low. Thus, this mechanism should lead to the expectation of more primary damage of the ophthalmic apparatus. This hypothesis seems to be supported by some experimental studies (Green et al., 1990; Waterhouse et al., 1999; Warwar et al., 2000; Ahmad et al., 2003; Schaller et al., 2013; Patel et al., 2017). Warwar et al. (2000), in an experimental study on human cadavers, demonstrated that the mean energy required to fracture the orbital floor following a direct load on the globe was 78 mJ. These values were significantly less than the energy needed to rupture the globe in the human eye and ranged from 1 to 2.2 J. From this corollary, we aimed to measure, compare, or estimate a set of likely variables to identify the possible risk factors of ocular and periocular injuries by prospectively analyzing the clinico-radiological charts of 473 patients.

The results of our study did not support our hypothesis, revealing that the rate of ocular and periocular injuries was similar

Table 7
Association between type of IOF and ocular and periocular injuries in patients who underwent operation.

	NOE (N = 4)	Le Fort (N = 22)	Orbito-zygomatic (N = 43)	Others (N = 5)	P
Ocular and periocular injuries	4 (100.0)	22 (100.0)	43 (100.0)	5 (100.0)	—
Mild N (%)	4 (100.0)	22 (100.0)	43 (100.0)	5 (100.0)	—
ION hypoesthesia	4 (100.0)	22 (100.0)	43 (100.0)	5 (100.0)	—
Periorbital ecchymosis, N (%)	3 (75.0)	7 (36.8)	28 (65.1)	3 (60.0)	0.18
Periorbital emphysema, N (%)	4 (100.0)	22 (100.0)	40 (95.2)	5 (100.0)	0.68
Diplopia, N (%)	1 (25.0)	15 (78.9)	11 (25.6)	3 (60.0)	<0.01
subconjunctival haemorrhage, N (%)	1 (25.0)	9 (47.4)	19 (44.2)	2 (40.0)	0.87
Corneal abrasion, N (%)	2 (100.0)	17 (81.0)	34 (79.1)	4 (80.0)	0.91
Moderate N (%)	0 (0.0)	4 (19.0)	2 (5.1)	0 (0.0)	0.23
Eyelid laceration, N (%)	0 (0.0)	10 (45.5)	12 (27.9)	2 (40.0)	0.25
Relative afferent pupillary defect, N (%)	0 (0.0)	5 (23.8)	5 (12.5)	0 (0.0)	0.37
Anterior uveitis, N (%)	0 (0.0)	5 (25.0)	2 (4.9)	1 (20.0)	0.1
Berlin's oedema, N (%)	0 (0.0)	2 (10.0)	2 (5.1)	0 (0.0)	0.75
Commotio retinae, N (%)	0 (0.0)	2 (10.0)	7 (17.5)	1 (20.0)	0.7
Severe N (%)	0 (0.0)	4 (20.0)	0 (0.0)	2 (40.0)	<0.01
Impairment of visual acuity, N (%)	1 (25.0)	10 (45.5)	8 (18.6)	2 (40.0)	0.14
Hyphaema, N (%)	1 (25.0)	8 (42.1)	6 (15.0)	2 (40.0)	0.13
Laceration of ocular globe, N (%)	1 (25.0)	3 (15.0)	0 (0.0)	1 (20.0)	0.05
Retinal detachment, N (%)	1 (25.0)	1 (5.0)	0 (0.0)	0 (0.0)	0.04
Traumatic ocular neuropathy, N (%)	1 (25.0)	4 (20.0)	0 (0.0)	1 (20.0)	0.03
Oculomotor paralysis, N (%)	0 (0.0)	1 (5.0)	0 (0.0)	1 (20.0)	0.09
Retrobulbar hemorrhage, N (%)	0 (0.0)	3 (15.0)	2 (5.3)	2 (40.0)	0.08

in the pure and impure categories. However, when assessing the different types of fractures within each category separately, we found significant association with the severity of ocular and periocular injuries. Hence, among the POF, combined medial wall and orbital floor fractures were associated with increased risk of developing specific severe ocular and periocular injuries. Amongst the IOF, Le Fort fractures were associated with increased risk of developing moderate ocular and periocular injuries. Moreover, combined medial wall and orbital floor fractures, NOE and Le Fort fractures were also significantly associated with the need for surgical exploration and repair, and this occurred regardless of the degree of severity of ophthalmic injuries.

Thus, these outcomes call into question the clinical relevance of using this classification based on the "purity" status of orbital fractures. Various studies have reported on ocular injuries associated with orbital fractures, with an incidence ranging from 2.7% to 90% (McCoy et al., 1962; Milauskas and Fueger, 1966; Miller and Tenzel, 1967; Fradkin, 1971; Gwyn et al., 1971; Jabaley et al., 1975; Luce EA et al., 1979; Holt JE et al., 1983; Ioannides et al., 1988; al-Qurainy et al., 1991; Brown et al., 1999; Amrith et al., 2000; Cook, 2002; Shere et al., 2004; Guly et al., 2006; Nagase et al., 2006; He et al., 2007; Barry et al., 2008; Gacto and Montero de Espinosa, 2009; Jamal et al., 2009; Mellema et al., 2009; Karabekir et al., 2012; Magarakis et al., 2012; Layton et al., 2014; Peacock et al., 2014; Riaz et al., 2014; Septa et al., 2014; Andrews et al., 2016; Ho et al., 2017; Malik et al., 2017; Ross et al., 2017). Such a wide range makes these results difficult to interpret because of several possible biases. Examples include the following: the type of study (retrospective or prospective); including ocular injuries as a main outcome versus including them with other complications; the degree of severity of ocular injuries; the inclusion of periocular injuries; the mechanism of trauma; the ophthalmological assessment performed by an ophthalmologist; and the time interval between injury and evaluation.

Thus, the lowest rates of incidence of ocular injuries (2.7%, 3.4%, and 6.7%) have been reported in three nonspecific studies that retrospectively assessed general complications associated with facial fractures (McCoy et al., 1962; Gwyn et al., 1971; Luce et al., 1979). Moreover, no information concerning the ophthalmological assessment and its timing in relation to the accident, the degree of severity of the injuries, and the possible periocular involvement were specified. Therefore, we can reasonably consider that these reported results underestimated the impact of ocular injuries following orbital fractures.

At the other extreme, the highest rate (90%) has been reported only by Al Qurainy et al. (1991), who prospectively and specifically analyzed ocular and periocular injuries as the main outcome in 363 patients with midfacial fractures involving the orbits. The injuries were classified as minor, moderate, or severe and were evaluated by an ophthalmologist 48 h following the trauma in severe cases and within 1 week for the other patients.

The incidence of ocular and periocular injuries found in our study is the highest reported in the literature. There are two likely explanations: (1) all of our patients were assessed by an ophthalmologist on the day of the trauma; and (2) we also included minor lesions such as periorbital ecchymosis and subconjunctival hemorrhages, which have not been considered previously in most studies on this topic.

Of the factors that play a role in determining the severity of the ocular injuries following orbital trauma, the most predominant are probably the fracture's pattern and the mechanism of the injury. Only a few studies have focused on the association between the fracture's pattern and the severity of ocular injuries. Al Qurainy et al. (1991) found severe ocular injuries in 33% of patients with comminuted malar fractures, among whom 41% had visual impairment, and in 16% of patients with blow-out fractures. Amrith et al. (2000) retrospectively analyzed the records of 104 patients and reported serious ocular injuries in 9%, among whom 78% had complex base of skull and roof fractures and 22% had either a blow-out or an unspecified zygoma fracture. Nagase et al. (2006), in a retrospective study including 266 patients, observed that the incidence of severe ocular injuries increased proportionally to the number of orbital walls affected (one wall: 0.68%; two walls: 2.2%; three walls: 13.5%; and four walls: 25%). Indeed, these results confirmed that two-wall orbital fractures such as orbito zygomatic fractures were associated with a low incidence of permanent visual impairment compared to three- and four-wall fractures. Moreover, the increased number of orbital walls affected also correlated with an increased incidence of permanent visual impairment. Barry et al. (2008) retrospectively reviewed data from 148 patients and found ocular injuries without specifying the degree of severity in 60% of the cases with pure blow-out fractures, in 28% of patients with complex, and in 9% with simple zygomatic fractures. Septa et al. (2014) prospectively reviewed 200 patients and found the following distribution of type of orbital fractures complicated by serious ocular injuries: zygomatic complex fractures: 61%; Le Fort II: 26.1%; unspecified multiples fractures: 11.9%; Le Fort III: 5.3%; NOE: 4.7% and Le Fort I: 1%. Peacock et al. (2014) retrospectively reviewed 28 patients and observed that the risk of ocular injuries was correlated with the number of facial fractures and that there was a 14.6-fold increase in patients with three or more fractures. Unfortunately, no information was given concerning either the type of fracture or the severity of ocular injury. Riaz et al. (2014), in a retrospective study of 296 patients, found exactly the same incidence rate of ocular injuries as reported by Barry et al. (2008). Finally, Andrews et al. (2016) retrospectively evaluated 279 patients and found a higher incidence of ocular injuries following penetrating trauma (39.1%) compared to blunt trauma (34.7%). Although they did not explicitly categorize the fractures as "pure" and "impure," they analyzed isolated single and multiwall fractures on one side and orbital fractures with involvement of other facial bones on the other side. Regarding the fracture pattern, their results were similar to the Nagase et al. finding that the incidence of ocular injuries was associated with the increased number of orbital walls affected. Curiously, isolated lateral orbital wall involvement was the fracture with the higher incidence of ocular injuries (50%), and was greater than the multiwall fractures (44%). The zygomatic complex (30.4%) and NOE (27.5%) fractures were the other two main patterns associated with an increased incidence of ocular injuries.

Thus far, Brown et al. (1999) remain the only authors to have investigated the association between "pure" and "impure" orbital fractures and the incidence of ocular injuries. They retrospectively evaluated 250 patients with 302 orbital fractures, all of whom had an ophthalmic examination. Their study reported a total of 107 POF (50%) and 96 IOF (45%). No specific details were given concerning the composition of both groups. These authors found ocular injuries occurring in 17.1% of patients, with a significant predominance in the POF group. Their incidence rate is not compatible with our findings, which revealed that almost all the patients had at least mild ocular and periocular injuries irrespective of the purity status of the fracture. This could be explained mainly by the fact that a different classification method was used to assess ocular injuries, which included only those that were severe.

In contrast to our findings, these authors found a higher incidence of ocular injury in the pure fracture group. However, these results should be interpreted with caution, given the ambiguous terminology used to define the pure and impure fracture groups. Indeed, the authors labeled "solitary orbital fractures" as POF, but they also included zygoma fractures in the same group, and they

labeled "fractures concomitant with the floor," which included both IOF and POF.

Regarding the mechanism of the injury, controversy still exists concerning the exact pathophysiology of orbital wall fractures. The orbits are often fractured indirectly as part of a midface fracture or by impact on the zygoma or also by a direct impact on the globe and/or the inferior orbital rim. Direction of the impact forces as well as their kinetic energies is of relevance in determining the bone distortion. Some authors have speculated that orbital walls are designed to be thin so that they fracture at relatively low forces, thus reducing the transmission of the kinetic energy to the globe (Green et al., 1990; Waterhouse et al., 1999; Warwar et al., 2000; Ahmad et al., 2003; Schaller et al., 2013; Patel et al., 2017). Green et al. (1990) analyzed the pure hydraulic mechanism by delivering different forces directly to the globe in an experimental animal model.

These authors showed that blow-out fractures appeared from 2.08J of delivered energy, and found 23% of globe ruptures. Based on a cadaver study, Rhee (2002) showed that higher forces are necessary to produce a fracture of both the medial wall and the orbital floor (>6.8 mJ) than the floor only (2.9 mJ). Patel et al. (2017), in a cadaver study, showed a higher maximum strain of the orbital floor for globe impact rather than for inferior orbital rim impact with the same delivered kinetic energy (3.9J). This suggests that direct trauma to the globe is more prone to produce orbital floor fractures than direct trauma to the inferior orbital rim. Moreover, the investigators found that direct trauma to the globe predisposes the area to more posterior fractures, whereas impact on the rim was associated with anterior fractures. Similar results have been found by Schaller et al. (2013) using a finite element model.

These authors showed that the worst configuration of mechanism of injury from a biomechanical point of view is simultaneous impact to the orbital rim and the globe. If the load was more concentrated on the orbital rim, then this impact would produce a fracture pattern similar to an NOE fracture seen in a clinical setting. However, if the load was more directed on the globe, then a combined floor and medial wall fracture would be seen. Interestingly, in our study, these two fractures' patterns were those most associated with severe ocular and periocular injuries and the only ones significantly associated with globe laceration and/or retinal detachment. This can be explained by the fact that in these two configurations, the globe is directly involved, unlike the Le Fort and/or orbito-zygomatic fractures that usually result from an eccentric indirect load with no impact on the eyeballs.

The main strength of the present study is that it is the only large case series to date to assess the relationship between the pure and impure configuration of orbital fractures and the concomitant association with ocular and periocular injuries. Moreover, the ophthalmological evaluation was standardized, and the clinical-radiological follow-up visits were with fully compliant patients. Data were collected during well-structured routine clinical examinations, and the physicians at that time were blinded to the goal of the study. The main weakness is inherent to the retrospective design (limited control over the data gathered and involvement of many different medical specialties in the treatment of the patients). The second limitation of our study is that data retrieval was insufficient to make any association between the presence of ocular signs and the indication for a surgical exploration. Another critique of the study is that the ocular and periocular outcome was not assessed. However, our main objective, as previously stated, was to assess the relationship between the pure and impure configuration of OFs and the risk of concomitant ocular and periocular injuries. Based on routine CT scan diagnosis, those patients at highest risk for ocular injury who would absolutely require comprehensive ophthalmologic evaluation as quickly as possible and an adapted

specific management if necessary may be identified. Thereby, a rapid identification of easily detectable risk factors for ocular and periocular injury is particularly important, as in many hospitals, the patients are not routinely referred to the ophthalmologist for a comprehensive eye examination regardless of symptoms or clinical signs. This attitude is apparent from the literature, with only a few studies reporting on a systematic ophthalmological assessment in patients with orbital fractures (Miller and Tenzel, 1967; Ioannides et al., 1988; Brown et al., 1999; Amrith et al., 2000; Cook, 2002; Jamal et al., 2009; Mellema et al., 2009; Riaz et al., 2014; Andrews et al., 2016; Malik et al., 2017; Ross et al., 2017). Moreover, in the majority of these studies, patients underwent an assessment of ocular motility and diplopia rather than a true comprehensive ophthalmological assessment.

5. Conclusion

In conclusion, the present study has demonstrated that the pure and impure distinction of orbital fractures was not clinically relevant with respect to ocular and periocular injuries.

However, our findings seem to suggest that other parameters, such as the direction of the impact and/or its magnitude rather than merely the pure or impure configuration, could be involved in determining the risk of developing concomitant ocular and periocular injuries. This undermines the traditional belief that preservation of the integrity of the orbital rim framework guarantees protection of the orbital contents from injuries.

The primary implication for clinicians is that particular attention must be paid to patients with combined medial wall and orbital floor fractures and naso-orbito-ethmoidal fractures because they are more prone to having concomitant ophthalmic injuries. This category of patients should have an immediate and systematic comprehensive ophthalmological assessment, including visual acuity, eyelid, conjunctival, corneal and pupil examination, ophthalmoscopy, slit-lamp examination, and tonometry, in addition to extraocular muscle testing.

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