Clinical and X-ray features of combat orbital trauma with post-traumatic eye loss

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Клініко-рентгенологічні особливості бойової травми орбіти, що супроводжувалась посттравматичною втратою очного яблука

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Abstract

Purpose. *To determine the clinical and X-ray features of combat orbital trauma with post-traumatic loss of the eye. Particularly, special consideration was given to the type and location of injuries of the bones of the orbit and adjacent structures, change in the bony orbital volume, and status of periorbital soft-tissue structures.*

Material and Methods. *We retrospectively reviewed medical records of 52 patients (69 affected orbits) aged 22 to 69 years who underwent treatment for orbital wounds at the Department of Maxillofacial Surgery, Bogomolets National Medical University, in 2022-2026. A commercial software package [Mimics Innovation Suite (Materialise NV, Leuven, Belgium)] was used to develop models of the affected and unaffected orbits and calculate the volumes of these orbits. Orbital fractures were classified into five categories according to Jaquiéry.*

Results. *Orbital fractures of Jaquiéry categories IV and V were most common among study patients. The mean volume of the traumatized orbit was 33.57 cm3 [median, 32.1 cm3; interquartile range, 29.5-36.4 cm3]. Of the 69 affected orbits, 36 (52.2%) had isolated orbital wall defects. Of the 52 patients, 16 (30.8%) had isolated lower-lid defects, and 26 (50.0%) had combined eyelid deformities, which constituted the majority of periorbital soft-tissue injuries. The eye was removed by evisceration in 38 (73,1%) of the 52 patients. The inferior orbital margin was the most common site of orbital bony defects (n = 19; 27.5%).*

Conclusion: *Combat wounds of the orbit vary widely in the nature and extent of the traumatic process, from isolated orbital wall fractures and eyelid defects and deformities, to massive complex wounds with multifragmented fractures, defects in bony structures and soft tissues, and extensive soft-tissue damage and cicatrization. The bony orbital volume of the affected orbits tended to change depending on the involvement of adjacent structures and the type of the fracture.*

Keywords: *maxillofacial trauma, gunshot injuries, orbital fracture, eyelid injuries, anophthalmia, CAD/CAM, combat trauma, soft-tissue injuries.*

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Резюме

Мета. *Комплексне вивчення клінічних та рентгенологічних особливостей бойової травми орбіти, що супроводжувалася посттравматичною втратою очного яблука, шляхом аналізу характеру та локалізації кісткових ушкоджень орбіти і суміжних анатомічних структур, оцін-*

ки змін об'єму кісткової орбіти, стану м'якотканинних структур періорбітальної ділянки.

Матеріал та методи. *Нами було проаналізовано дані медичної документації та комп'ютерної томографії (КТ) 52 пацієнтів (69 орбіт) віком від 22 до 66 років, які отримали поранення очниці та проходили лікування на клінічних базах кафедри щелепно-лицевої хірургії НМУ імені О. О. Богомольця. За допомогою програмного середовища Mimics Innovation Suite (Materialise NV, Leuven, Belgium) створено моделі травмованої та інтактної орбіт та проведено обчислення їх об'єму. Оцінка переломів стінок орбіти проводилася за класифікацією Jaquiéry.*

Результати. *У пацієнтів із бойовою травмою орбіти було відзначено превалювання дефектів IV і V класів за класифікацією Jaquiéry. В досліджуваній групі середній об'єм травмованої орбіти склав 33,57 см^3. Медіана об'єму травмованої орбіти становила 32.1 cm^3 (IQR: 29.5–36.4 cm^3) Серед переломів більшість пацієнтів мали ізольовані пошкодження орбіти, які склали 52,2% від загальної кількості травмованих орбіт. У 30,8% (n=16) поранених було діагностовано дефекти нижньої повіки і у 50,0% (n=26) поєднані деформації повік, що становило більшість серед пошкоджень м'яких тканин періорбітальної ділянки. Згідно з нашими спостереженнями, 73,1% (n=38) пацієнтів було проведено евісцерацію з приводу тяжкого поранення очного яблука. Найчастіше відзначалися кісткові дефекти нижнього краю очниці, які було виявлено у 27,5%.*

Висновки. *Відзначається широкий спектр бойових поранень очниці за характером і поширеністю травматичного процесу: від ізольованих уражень стінок орбіти та повік до масивних складних поранень, що супроводжуються багатоуламковими переломами, дефектами кісткових структур та м'яких тканин, значними ушкодженнями м'яких тканин з подальшим рубцюванням. Відзначено тенденцію до зміни кісткового об'єму очної ямки в залежності від залучення суміжних анатомічних структур та типу перелому.*

Ключові слова: *щелепно-лицеві травми, вогнепальні поранення, перелом орбіти, ушкодження повік, анофтальм, CAD/CAM, бойова травма, ушкодження м'яких тканин.*

Introduction

Despite the widespread use of personal protective equipment (protective helmets and ballistic spectacles/goggles) in modern warfare, severe orbital trauma is still common and accounts for a significant share of combat head and neck wounds [1, 2, 3]. Civilian casualties of missile, projectile and first personal view (FPV)-drone strikes and blasts also account for some share of total war-related casualties with head and neck injuries [4]. This wound type not infrequently results in an irreversible injury to the eye leading to eye loss. Eyelid defects and deformities and functional abnormalities associated with ocular adnexal lesions pose a particular problem [5]. Consequently, patients with these types of trauma experience a sharp decrease in the quality of life caused by functional and cosmetic abnormalities and develop significant psychic-and-emotional disorders [6].

The incidence of wartime eye injuries increased from 2.0-2.5% during World Wars I and II [7] to 5-9% during the Vietnam War [8] and 13% during operations Iraqi Freedom and Enduring Freedom. Acute visual or eye loss associated with orbital wall fractures has been reported at 0.8% [9, 10] to 1.1% [11].

The orbit is a unique anatomical structure whose parameters depend on the sex, age and facial skeleton development [12]. Damage to the orbital bones causes an increase in orbital volume, resulting in soft tissue displacement inside the socket. Additionally, anatomical changes of the anophthalmic socket over time and scarring after a high-energy trauma can cause atrophy of orbital tissues and result in the post-enucleation socket syndrome (PESS) [13]. Damage to the orbital bones, concomitant with a post-traumatic atrophic process, significantly worsens the prognosis of effective ocular prosthesis.

The available literature, however, is scarce on studies analyzing the features of combat-related orbital and periorbital trauma and the effect of a high-energy trauma on the change in the orbital volume and the status of the ocular adnexa.

The purpose of this study was to determine the clinical and X-ray features of combat-related orbital and periorbital wounds with loss of the eye. Particularly, special consideration was given to the magnitude of post-traumatic anatomical changes specific for this type of injury, the change in the orbital volume depending on the type of injury, involvement of adjacent structures and status of the adjacent soft tissues.

Material and Methods

We retrospectively reviewed medical records of patients who underwent treatment for posttraumatic orbital wall defects concomitant with anophthalmia at the Department of Maxillofacial Surgery, Bogomolets National Medical University, in 2022-2026. Of 65 medical records, 52 were selected for the analysis based on the inclusion and exclusion criteria. Inclusion criteria were the presence of combat-related periorbital and orbital wounds, eye socket wall defects accompanied by loss of the eye, presence of computed tomography (CT) images and sufficient clinical information in the medical records. Exclusion criteria were age below 18 years, patients with intact orbital bony walls, and written patient's withdrawal of consent for personal and medical information to be used in research.

This study was based on the retrospective analysis of paper medical records and electronic medical records registered in the Doctor Eleks Ehealth (Eleks Lviv, Ukraine) and MIC Health24 (Zdorovya 24, Kyiv) systems.

Microsoft Access software (Microsoft Corp., Redmond, WA) was used for data collection and processing. Medical histories were reviewed, analysis of root causes of orbital defects and eye loss was conducted, and clinical examination results and local status (the presence of periorbital and orbital contour defects and deformities and eyelid status) were assessed. CT images were reviewed to assess the type of bone structure defect, orbital bone volumes for the affected and intact orbits and their difference, and defect location.

Orbital bone volume was determined based on CT data. For this purpose, Digital Images and Communication in Medicine (DICOM) files were imported into commercial software package [Mimics Innovation Suite (Materialise NV, Leuven, Belgium)] for segmentation to distinguish the bones from soft tissues by defining a range of Hounsfeld Units that corresponds to bone density. Thereafter, 3-D models of the facial skull and face were obtained. After artefacts were removed and the models developed were edited using Boolean logic, the software tissues within the orbital space were removed semiautomatically, the models of the affected and unaffected orbits were developed, and the volumes of these models were determined in cm3. With this done, the difference between the volumes was calculated.

Axial, coronal and sagittal CT data were analyzed in detail, and multiplanar image reconstruction was performed for all patients. To standardize the evaluation of fractures and enable a unified approach to the analysis of orbital fracture data, orbital fractures were classified into five categories according to Jaquiéry [14]. CT images were reviewed to assess fracture location, extension of the bony defect and the grade of fracture displacement.

Continuous variables were checked for normality using the Shapiro-Wilk test. Normally distributed data are presented using means with standard deviations (SD), whereas medians [with interquartile range (IQR)] are used for non-normal distributions. An unpaired t-test was used for normally distributed data, and the Mann-Whitney test when data were not normally distributed. Statistical significance was set at $P < 0.05$. SPSS software (IBM SPSS, USA) was used for analysis.

The main prognostic factor was the difference in the volume between affected and unaffected orbits. Secondary prognostic factors included age, concomitant zygomatic complex fracture, the presence of orbital wall defects, and orbital wall deformities.

Results

Demographics

All 52 study subjects were males who sustained injuries due to combat. At the time of injury, mean patient age was 37.7 ± 9.5 years; the youngest patient was 22 years and the oldest, 66 years old. Additionally, 50 patients (96%) were service members, and 2 patients (4%), civilians. The left orbit was more commonly affected (34 cases; 65.4%) than the right orbit (18 cases; 34.6%). Cases were enucleated if the eye was non-salvageable after a severe injury or in the remote period after non-effective eye-preservation surgery.

Bony orbital injuries

Of the 52 patients, 35 (67%) had unilateral orbital fracture, and 32.7% had a bilateral orbital fracture with the involvement of both the anophthalmic side and the side with the preserved eye. The total number of damaged orbits found in 52 patients was 69. Of these orbits, 36 (52.2%) had isolated orbital wall defects, 8 (11.6%), orbital wall defects with concomitant linear zygomatic fracture, 5 (7.2%), multifragmented fractures, and 20 (29.0%), zygomaticomaxillary complex fractures. There was no significant difference ($p > 0.05$) in the frequency of concomitant zygomatic complex fracture, multifragmented fractures, or fractures with bony defects between patients with unilateral and bilateral orbital and periorbital wounds (Fig. 1).

Orbital fractures were classified according to Jaquiéry. Based on the review of CT scans of anophthalmic sockets, category IV and category V orbital fractures were most common (31.9%, n=22 and 14.5%, n=10, respectively), followed by type II (11.6%, n = 8), type III (10.1%, n = 7), and type I fractures (7.2%, n = 5) (Fig. 2). Seventeen patients had bilateral orbital wall fractures. Based on the review of CT scans of contralateral sockets with intact globes and orbital fractures, type I orbital fractures were most common (10.1%, n = 7), followed by type II (7.2%, n = 5), type III (2.9%, n = 2), and type V orbital fractures (2.9%, n = 2). No type IV orbital fracture was, however, found. In one patient, the orbital fracture was not classified because it did not match with the classification criteria.

Orbital volume

Orbital volume was determined in 31 patients with a unilateral orbital fracture. The mean volume of the intact orbit was 26.9 cm3 ± 2.4 cm^3, whereas that of traumatized orbit was 33.57 cm^3 (median, 32.1 cm^3; IQR, 29.5-36.4 cm^3). Therefore, the average volume difference between affected and unaffected orbits was 6.3 cm^3. The maximum volume for affected orbits was 45.8 cm^3. We reviewed CT scans of the orbit for 14 patients with isolated orbital wall fractures (Fig. 3). The mean orbital volume for patients with isolated orbital wall fractures was 29.8 ± 2.6 cm^3, versus 32.04 cm^3 for 2 patients with concomitant zygomatic complex fractures of different types, and 36.93 ± 6.26 cm^3 for 15 patients with zygomatic complex fractures with bony defects (Fig. 4). Of the 52 patients, 30.8% (n = 16) had isolated primary lower-lid defects, 26.9% (n = 14) had combined upper and lower eyelid defects, and no patient had an isolated upper-lid defect. Post-traumatic and post-operative isolated lower-lid deformities, isolated upper-lid deformities, combined upper and lower eyelid deformities and no lid deformities were seen in 32.7% (n = 17), 5.8% (n = 3), 50.0% (n = 26) and 11.5% (n=6), respectively, of those patients. No eyelid defect or deformation was seen in the preserved contralateral eye in any patient. There was no significant difference ($p > 0.05$) in the rate of eyelid defects or deformities between the cohorts, and the difference

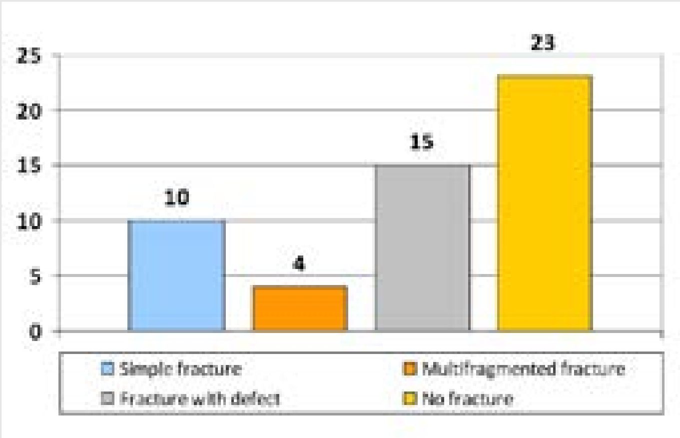


Fig. 1. Bar graph representing types of zygomatic complex fractures.

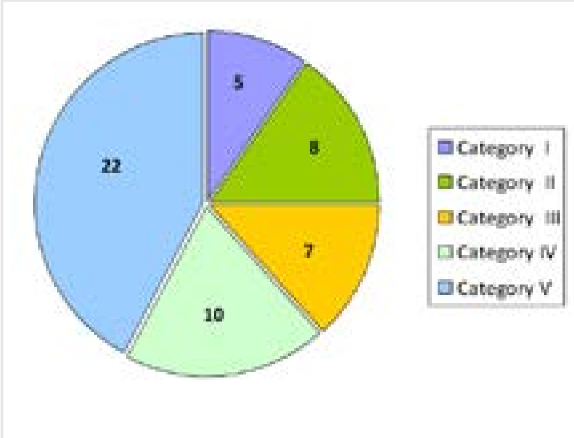


Fig. 2. Pie chart representing numbers of orbital fractures of Jaquiéry categories I to V.

in the rate of combined upper and lower eyelid deformities was not significant (p = 0.077). The eye was removed by evisceration (73.1%; n = 38), enucleation (25.0%, n = 13), or evisceronucleation (1.9%; n = 1).

Soft tissues

The type of damage to facial soft tissues (that is, the presence of any facial soft tissue wounds or cicatricial deformities) was also given attention. The infraorbital region was the most common site of facial soft tissue damage (20 patients; 38.5%), followed by the zygomatic (17 patients; 32.7%), cheek (12 patients; 22.1%), external nasal (11 patients; 21.2%), frontal (8 patients; 15.4%), parotid masseteric (4 patients; 7.7%), eyebrow (4 patients; 7.7%), and temporal (3 patients; 5.8%) regions. Soft tissues in the periorbital facial region were intact in 12 patients (23.1%) (Fig. 5).

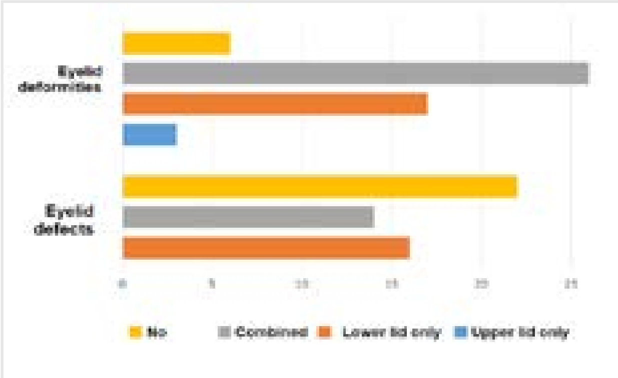


Fig. 5. Lid deformities and defects in patients with orbital wounds

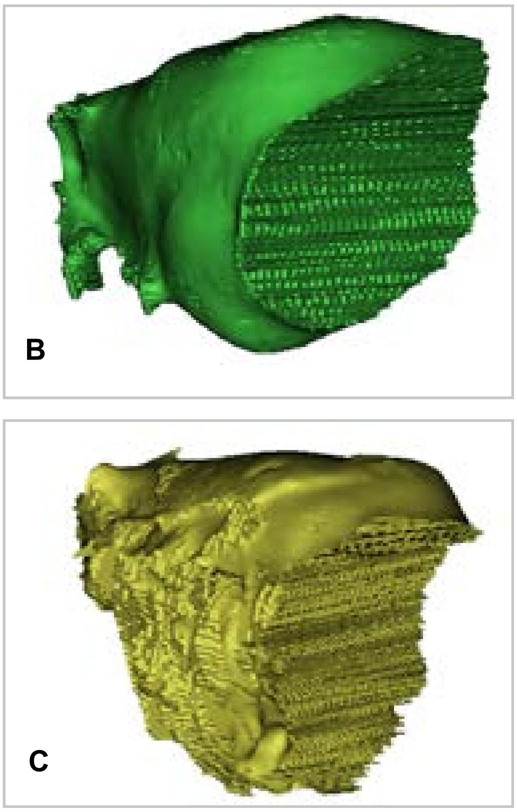
Discussion

Reed and colleagues [15] conducted a retrospective analysis at the level of a military medical center. Of the 29 eyes examined, 15 eyes underwent evisceration and 14 eyes, enucleation following ocular trauma. Orbital fractures were present in 4 cases having undergone evisceration and in 1 case having undergone enucleation for a gunshot wound. In a study by Vaca and colleagues [16], 52 (56.5%) of the 92 patients with facial skeleton fractures had a severe injury to the globe which required eye removal surgery. Jabaley and colleagues [17] reported that, of the patients with maxillofacial fractures, 6% underwent enucleation. In a study by Rubin and colleagues [18], of the 20 patients with large orbital fractures, 20% underwent enucleation. Elbeyli and Kurtul [17] reported that, of the 212 patients who were referred urgently to the department of ophthalmology, 27 (12.73%) had orbital fractures, 26 of which were open injuries and one was a closed injury.

When an orbital fracture occurs in a civilian setting, the thin orbital walls can fracture, displacing part of the orbital content to the paranasal sinuses, reducing the energy transferred directly to the globe [20]. Zhou and colleagues [21] analyzed and evaluated ocular injuries in patients with maxillofacial fractures. Motor vehicle accidents were the most common mechanism of injury. Ocular traumas were more prone to occur in patients who sustained midfacial fractures especially the patients with multiple midfacial fractures.

A shift in the paradigm for warfare tactics, however, has occurred partly due to a significant proliferation of FPV-drone use. Additionally, the incidence of facial injuries is on the rise due to insufficient protection of this body region [22]. Combat trauma is unique and heterogeneous. Our observations demonstrated that patients with blast-induced trauma frequently exhibit extensive contaminated and potentially infected facial soft-tissue wounds with foreign body involvement [23], which may be accompanied by complex maxillofacial bony fractures [24] and bony defects with potential communication with natural body cavities. However, severe orbital injuries with eye loss may be isolated with the preserved integrity of adjacent bony structures and with the fracture lines running through

A



B

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Fig. 3. Combined injury. (A) 3-dimensional (3-D) reconstruction of a computed tomography image for a patient with an orbital trauma with concomitant zygomatic complex fracture and post-traumatic eye loss; (B) 3-D reconstruction of the unaffected orbital cavity; (C) 3-D reconstruction of the affected orbital cavity .

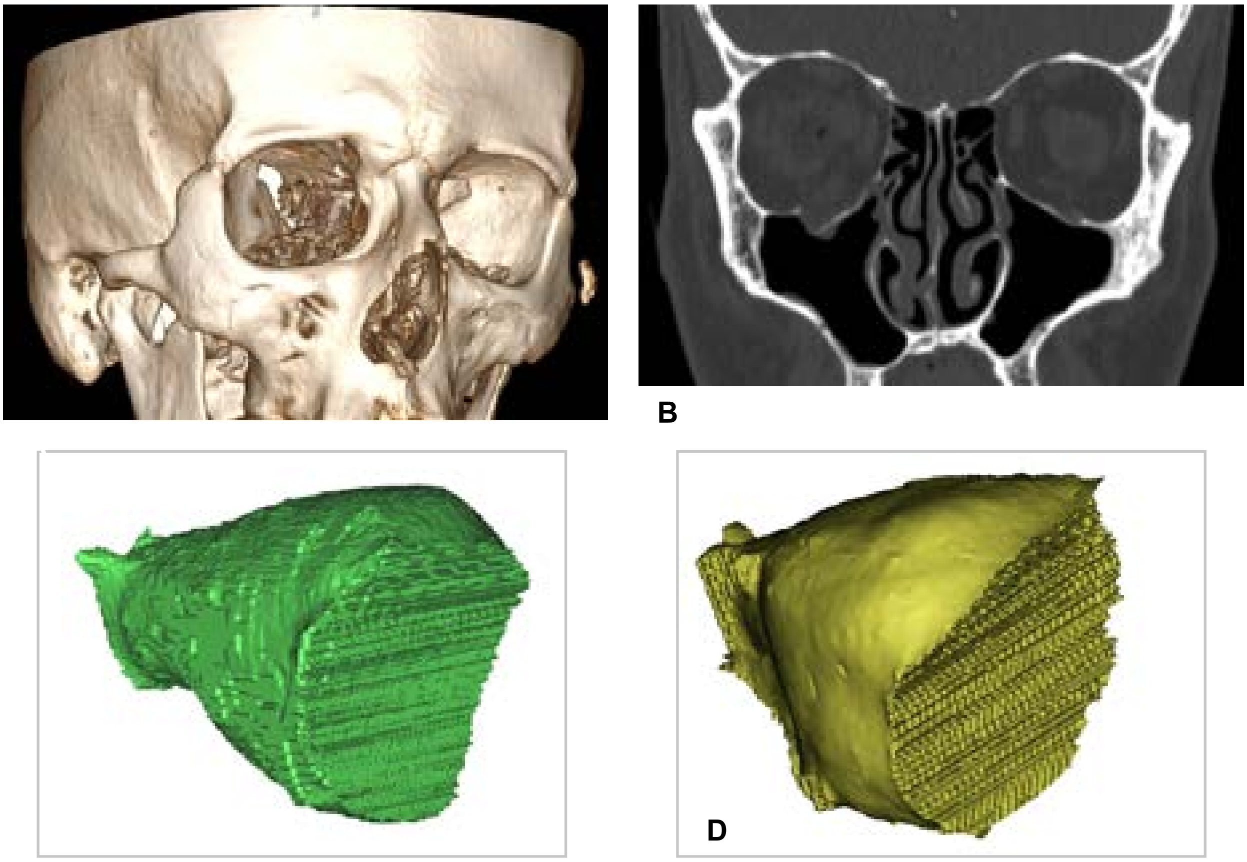

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Fig. 4. Isolated orbital injury. (A) 3-dimensional (3-D) reconstruction of a computed tomography image for a patient with isolated orbital injury; (B) coronal CT view of the affected orbit; (C) 3-D reconstruction of the unaffected orbital cavity; (D) 3-D reconstruction of the affected orbital cavity.

the medial or inferior orbital wall, and soft tissue damage found either in the lid only or, less frequently, in the lid with involvement of adjacent facial regions. Such a wide range of potential damage is caused by the combination effect of traumatic factors [25]. According to our experience, wounds developed due to the combination effect of (a) blast wave impact, (b) direct wounds from foreign bodies or fragments of personal head or eye protection, and (c) thermal factors such as impact of blast fumes or heating of munitions components resulting from a blast or high-speed movement of these components.

The average volume difference between affected and unaffected orbits was 6.3 cm^3 in the current study, which is much larger than those reported for patients with conventional peacetime fractures [26]. Correspondingly, it should be noted that the increase in bone volume resulted not only from bone fragment displacement, but also from damage and cicatrization of the soft-tissue orbital contents. Category V and category IV orbital fractures were most common whereas isolated category I and category II orbital fractures were less common among orbital fractures of the present study. Additionally, a large proportion of the wounded had concomitant midfacial fractures, including zygomatic complex fractures.

Gunshot wounds frequently result in conjunctival and eyelid defects and cicatricial deformities [27]. Lower-lid defects were more common than upper-lid defects in the patients examined. Additionally, the status of the periorbital soft-tissues is important, because marked cicatricial deformities in the infraorbital, zygomatic and buccal regions contribute to tissue deficit and tension, potentially affecting the conditions for fitting an ocular prosthesis.

Therefore, given the features of the orbital injuries found in patients with combat wounds, certain recommendations on the management of these injuries may be developed and given an appropriate scientific justification. Particularly, with regard to the reconstruction of extensive orbital wall defects, especially those concomitant with zygomatic complex fractures, patient-specific implants (PSIs) offer superior outcomes in orbital volume restoration, globe positioning, and reduced complication and revision rates compared to conventional reconstruction. This approach makes it possible to restore precisely the integrity of the orbit (particularly, the integrity in the apical region), and correct the soft-tissue volume if required [28].

Conclusion

Based on our observations, combat orbital wounds feature exhibit unique changes in orbital architecture and distorted anatomical landmarks, and are commonly seen with concomitant injuries to adjacent structures. In a large proportion of cases, such wounds are seen with concomitant bony defects, which should be taken into account in subsequent orbital reconstruction. A significantly increased orbital bone volume may require PCIs, and, under certain clinical situations, the presence of various zygomatic complex injuries can lead to the need for a staged reconstruction. The presence of various types of soft-tissue injuries warrants a multidisciplinary approach to the rehabilitation process.

Author Contributions

KMA: Conceptualization, Data Collection, Investigation, Analysis and Interpretation of Results, Manuscript Preparation; BMV: Data Collection, Methodology, Resources, Investigation; CYV, Conceptualization, Writing – Review and Editing, Supervision, Validation; POV: Writing – Review and Editing, Resources, Formal Analysis, Validation. All authors have read and approved the final version of the manuscript.

Disclaimers

The opinions presented in this article are those of the authors and do not necessarily represent those of their institutions.

Sources of support

None

Conflict of Interest

The authors declare that they have no actual or potential conflict of interest that could inappropriately influence, or be perceived to influence, the subject matter or material discussed in this manuscript.

Ethical Statement

This study did not require the approval from the Bioethics Committee.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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