International Journal of Current Research and Review
DOI: https://doi.org/10.31782/IJCRR.2022.141408

Research Article

IJCRR
Section: Healthcare

Improving Clinical Outcomes of Orbital Volume Restoration Using Peri-Operative Diagnostic Tools in Management of Orbital Fractures - A Prospective Study

Janani Narayanan[1], Vivek Narayanan[2], Saravanan Chandran[3], Karthik Ramakrishnan[4], Prashanthi Gurram[5], Abinaya Subramanian[6]

[1]Postgraduate trainee, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India; [2]Head and Professor, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India; [3]Professor, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India; [4]Associate Professor, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India; [5]Reader, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India; [6]Assistant Professor, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India.

ABSTRACT

Introduction: Accurate evaluation of change in orbital volume occurring due to trauma is of paramount importance to achieve an optimal final outcome. Thus, the purpose of this study was to assess and evaluate the orbital volume both radiological and clinical means for accurate surgical correction.

Aim: To assess the final surgical outcome using standardized clinical and radiological tools perioperatively to restore orbital volume in patients with orbital wall fractures.

Materials and Methods: A prospective interventional study of patients with unilateral orbital wall fractures which was carried out for 24 months. A thorough clinical evaluation and ophthalmological assessments including visual acuity, field of vision was performed. All patients had HRCT for volumetric assessment and assessed clinically for enophthalmos using Hertel exophthalmometer. Based on the level of enophthalmos and orbital volume change, treatment plan was formulated. Intraoperatively Hertel exophthalmometer is used to correct the predetermined enophthalmos. Postoperatively the patients are followed-up at designated intervals to assess the surgical outcome. RESULT: Road Traffic Accident (RTA) was the common etiology of orbital fractures which accounts for 84.1% (n=53) and the most common clinical sign was enophthalmos which accounted for 76.2% (n=48). The mean and standard deviation of orbital volume is 35.20 ± 4.21 and change in orbital volume is 4.29±2.76. The mean and standard deviation were calculated for all patients in different time intervals. The result showed a statistically significant difference in pre-operative phase, intra-operative phase and it maintained throughout the postoperative phase. CONCLUSION: In our study we have found that meticulous preoperative and intraoperative tools to assess in orbital reconstruction gives a desired surgical outcome. Hertel exophthalmometer and HRCT based 3D reconstructed volumetric analysis can be an excellent tool to evaluate anteroposterior globe malposition and volume change.

Key Words: Orbital volume, Orbital trauma, Orbital reconstruction, Enophthalmos, Hertel exophthalmometer, 3D reconstructed digital volumetric analysis

INTRODUCTION

Accurate evaluation of change in orbital volume occurring due to trauma is of paramount importance to achieve an optimal final outcome. Computed Tomography scan has radically increased the scope of accurate assessment based on which the contemporary reconstruction practices are structured upon.[1] Multi slice imaging and advanced computer software allows precise measurement of the dimension, area, and volume of orbital structures.[2] The change in volume of the fractured orbit becomes extremely challenging to reconstruct due to the complex orbital anatomy.[3,4] Though change in orbital volume could occur due to the fracture in any of the four walls, it occurs largely due to the defects of the floor and thin medial wall.[5,6,7]

Corresponding Author:
Dr. Janani Narayanan, Department of Oral and Maxillofacial Surgery, SRM Kattankulathur Dental College and Hospital, Tamil Nadu, India; Mobile: 9677243687; Email: jananinarayanan01@gmail.com

ISSN: 2231-2196 (Print) **ISSN:** 0975-5241 (Online)

Received: 22.10.2022 **Revised:** 12.12.2022 **Accepted:** 02.02.2022 **Published:** 20.07.2022

The orbital wall injuries constitute more than 40% of maxillofacial trauma. About 4 to 16% accounts for isolated orbital floor fractures. Orbital fractures result in volume change in most instances,which inaccurately assessed and inadequately addressed will result in post-traumatic deformities such as persistent enophthalmos, dystopia, diplopia and restricted extra-ocular movements.[8,9] These symptoms may affect the final functional and aesthetic outcome.

Enophthalmos is considered to be a pathognomonic sign of orbital wall fractures.[8] The presence of enophthalmos dictates the necessity of surgical exploration and reconstruction for superior clinical outcome. Enophthalmos is clinically evident when there is a measurable change of 2mm or more is present.[10] But early enophthalmos is difficult to assess due to the presence of periorbital edema. However, radiographic measurement of orbital volume using standardized CT scans can be helpful in detecting early enophthalmos in order to improve treatment outcomes and prevent associated complications. There are enough evidences in literature which proved that there is a direct and distinct relationship between change in orbital volume and the degree of enophthalmos.[11,12]

Thus, the purpose of this study was to assess and evaluate the orbital volume both radiological and clinical means. In this study, the measurements are planned to be taken pre-operatively to assess the change in orbital volume, intra-operatively to assess accurate surgical correction and post-operatively to assess the efficacy of correction.

AIM AND OBJECTIVES

The primary aim of our study was to evaluateperioperative orbital volume changes of the fractured and normal orbits at regular follow-ups. The secondary aim was to assess the final clinical outcome of orbital reconstruction which necessitates volume correction by intra-operative evaluation methods.

METHODOLOGY

This study is a Prospective Interventional study to assess perioperatively the orbital volume changes in patients with orbital wall fractures using standardized clinical and radiological methods. Study period was between August 2018 and March 2020. The minimum follow-up period of 6 months has been completed for all patients. The patients who reported to our institution with orbital wall fractures were included in the study. The patients were recruited either directly from the Department of Oral & Maxillofacial Surgery or from the Department of Accident and Emergency. The study comprised of a sample size of 63 patients with 53 males and 10 females. The age group ranged from 18 – 50 years with a mean range of 34 years. None of the patient showed immediate indication for surgical intervention.

Selection Criteria:

The inclusion criteria include patients of age 18 years and above diagnosed with unilateral orbital wall fractures. Presence of congenital deformities of the face such as facial asymmetry or syndromes involving the orbital cavity, such as Treacher Collin Syndrome, previous history of orbital wall fractures, bilateral orbital wall fractures, Ocular injuries or ocular diseases, such as glaucoma, cataract, or contralateral blindness, who are not willing to be a part of the study were excluded.

Pre-operative Assessment:

Clinical Evaluation:

Initially the patients went through a complete general examination fulfilling the criteria of trauma protocol. Patients who were hemodynamically stable and with GCS-15/15 were taken under Oral and Maxillofacial Surgery care.A thorough Maxillofacial examination was conducted including all inspectory and palpatory findings. Initially the patients presented with periorbital edema and ecchymosis which made the assessment of enophthalmos, hypoglobus and restriction of eye movements difficult. After resolution of the periorbital edema the patients are clinically assessed for enophthalmos, hypoglobus and restriction in eye movements. Patients were subjected to an outright Ophthalmological examination. The evaluation included visual acuity using Snellen's charting, fundus examination and diplopia charting were done.

A Hertel exophthalmometer was used to assess the clinical enophthalmos. A fixed base was assigned for each patient, ie the distance between the lateral orbital rims. The anterior most point in the sclera-corneal junction is measured on both the eyes.[13,14,15,16,17] The amount of enophthalmos was calculated by comparing the uninjured and fractured sides.

Radiological Evaluation:

High resolution Computed Tomography scan of facial bones with 0.6mm thin bone sections were done who experienced orbital trauma. Radiologically enophthalmos was measured by calculating the distance between corneal and orbital apices in affected and unaffected side. Three dimensional reconstructions for orbital volume were made by Materialise Interactive Medical Image Control System (MIMICS, Materialise, Leuven, Belgium) according to DICOM files. Gantry tilt was set to be parallel to the Frankfort horizontal plane and 0.6 mm slice thickness were used. Three dimensional orbital cavity reconstruction was done with Mimics software considering Hounsfield Units (HU): -200 to +100 HU for bony structures.To calculate the volume of bony orbital cavity, all contours along the orbital walls were included in the following boundaries:

- The anterior aspect of optic canal was considered as posterior boundary of orbital cavity.

- The line between lateral orbital rim and lacrimal bone was considered as anterior boundary of orbital cavity.

Segmenting was done along a straight line from the anterior lacrimal crest to lateral orbital wall(Figure 1).[11,12]Afterwards, the 3D structure was reconstructed (Figure 2). The difference between the two orbits, un-fractured and injured, gives the orbital volume change.

Surgical protocol:

All the surgical procedures were carried out under General Anaesthesia in an Operation Theatre (Figure 3). Using standard armamentarium and surgical protocols fixation or reconstruction of orbital wall fractures done using alloplastic material or autogenous graft (Figure 4&5).[18,19,20,21] Intra-operatively Hertel exophthalmometer is used to correct the predetermined enophthalmos (Figure 6). Post-operatively Hertel exophthalmometer was used to re-assess the clinical enophthalmos. A fixed base distance between the lateral orbital rims which was measured pre-operatively is used as a guide. Post-operatively the measurements are done on the 7th day,30th day, 3months and 6 months.

RESULTS

During the study period 65 patients with orbital wall fractures were encountered. Out of which 63 patients met the criteria for inclusion. The remaining 2 patients were excluded from the study since they were under the age of 18years. 84% (n=53) of them were males and 16% (n=10) were females. Majority of the patients were in the age group of 20-30 years (Figure 7) (n=31, 49.3%) with a mean age of 34.5 ±14.88 years. Road Traffic Accident (RTA) was the common etiology which accounts for 84.1% (n=53) followed by interpersonal violence 7.9%(n=5). The most common clinical sign was enophthalmos which accounted for 76.2% (n=48). Twenty-two patients (34.9%) had dystopia, five patients (79%) had diplopia and one patient (1.6%) had only restriction of eye movements.

All patients are classified into single, two, three and four wall defects based on preoperative HRCT images. Two wall orbital defect accounts for 47.6% (n= 30), 44.4% (n=28) of patients had single wall defect and around 7.9% (n=5) had a three wall orbital defect (Figure 8). The mean and standard deviation of orbital volume is 35.20 ± 4.21 (Table 1) and change in orbital volume is 4.29±2.76. Independent t test was done to compare the pre-operative orbital volume of normal and fractured sides (Table 2). The results showed a statistically significant difference.

Based on the number of fractured walls, enophthalmos, volumetric change and other clinical symptoms the treatment plan was decided. Undisplaced orbital wall fractures with no gross volumetric change and absence of clinical symptoms like enophthalmos, diplopia and opthalmoplegia are managed conservatively which accounts for 14.2% (n=9).

Patients with displaced orbital wall showing volume change and enophthalmos greater than 3mm underwent orbital exploration with orbital reconstruction which accounted for 14% (n=11). Patients with no gross orbital volume change but showed clinical symptoms like restricted eye movements and diplopia underwent orbital exploration which accounts for 38% (n=30). Patient with displaced orbital rims underwent either two point or single point fixation which accounted for 36% (n=28) and 12% (n=9) respectively.

Two types of statistical tests were performed in our study. Initially independent t-test was done to compare the enophthalmos values between the fractured and normal side at different time intervals. Later paired t-test was performed to compare enophthalmos values between each time interval amongst the fractured side.The mean and standard deviation were calculated for all patients in different time intervals. The results showed a statistically significant difference in pre-operative phase (Table 3) and intra-operative phase, which is maintained throughout the post-operative phase.

Comparison of Pre-op enophthalmos with other time intervals were done and results are tabulated (Table 4).There is a statistically significant difference between pre-operative enophthalmos and enophthalmos assessed at different time intervals. The mean difference and standard deviation for 3 months post-op enophthalmos with 6 months post-op is 0.083 ± 0.404 mm.

Patients who underwent orbital reconstruction are statistically analysed separately to compare with the patients who underwent single point fixation. The Hertel mean values and standard deviation are calculated**.** The mean of Hertel values at various time intervals showed a significant decrease in the enophthalmos which has been corrected intra-operatively for patients who underwent orbital reconstruction (Table 5).Whereas there is no significant difference in the Hertel values throughout the pre-operative, intra-operative and post-operative phase in patients who underwent single point fixation (Table 6).

Paired t-test was done to compare the enophthalmos values between different time intervals in patients who underwent orbital reconstruction and single point fixation. There is a statistically significant difference between pre-operative enophthalmos (Table 7) and enophthalmos assessed at different time intervals. However, we are unable to generate results for paired t-test in patients who underwent single point fixation because there no significant difference in enophthalmos values between different time intervals.

DISCUSSION

Restoration of the normal facial appearance is probably the most repeated requisition by any victim who experienced a maxillofacial trauma. The orbit being the prominent structure plays a vital role in restoring the facial balance, which constitutes the biggest challenge for the maxillofacial surgeon when dealing with orbital injuries which may be associated with significant functional and aesthetic discrepancies.Orbital fractures are often presented as dramatic symptoms like black eye or red eye even in an un-displaced fracture, which is more disconcerting to the patients. However, in some patients especially in the paediatric group shows minimal soft-tissue signs of trauma and can be easily missed out. According to Miller and Glaser, 1966, clinical signs includes periorbital edema, ecchymosis, sub-conjunctival haemorrhage, subcutaneous emphysema, diplopia in horizontal gaze, hypoglobus and enophthalmos.[8] Enophthalmos, restricted eye movements, infraorbital paraesthesia and diplopia are the most persistent clinical symptom which need a more careful assessment for proper treatment planning.In our study, the most common clinical sign was enophthalmos which accounted for 76.2%, followed by diplopia 79%. Twenty-two patients (34.9%) had dystopia and one patient (1.6%) had only restriction of eye movements.

In a retrospective study conducted by Catone et al. 27 cases of untreated orbital blow-out fractures presented with minimal ophthalmologic symptoms.[10] Of 27 patients, 2 patients had enophthalmos greater than 2mm, 1 patient had restricted ocular movement and 1 Patient had residual diplopia. Based on their clinical experience, the author suggested surgical intervention is required if there is presence of enophthalmos greater than 2mm, residual diplopia in primary gaze, restricted ocular motility which persists more than 10-14 days, and gross disruption of orbital floor as confirmed by CT. Majority of studies generally does not recommend surgical invention for diplopia; since diplopia is self-limiting.

Several theories exist for mechanism of post traumatic enophthalmos which includes enlargement of the bony orbit, increase in orbital volume, loss of ligament support, post traumatic fat atrophy, fat displacement and fat contracture.[9] The correct reduction, effective fixation of tripod zygomatic fracture and reconstruction of orbital floor are crucial for optimal results which avoids secondary enophthalmos and hypoglobus. Catone et al. detected 7% to 10% of patients undergoing conservative treatment for blow-out fractures suffered from persistent enophthalmos.[21] This is because the position of the globe immediately after trauma is usually not representative of final position which will appear after the resolution of the edema. There are chances of development of late enophthalmos as the edema resolves.[22]Correction of secondary enophthalmos and facial asymmetry are not easily achievable and showed satisfactory aesthetic results in 77% of cases.[23] Thus the outcome is better when appropriate fracture reduction and fixation is done at the first surgery. This can be achieved only if assessment of enophthalmos and orbital volume is done intra-operatively after reduction of fractures.

Shen et al. performed a retrospective study in 64 patients with delayed orbitozygomatic fractures with enophthalmos treated by surgery.[25] They reported that enophthalmos will develop later, even after surgery in some cases because of orbital fat atrophy.Whitehouse et alpresented evidence for a correlation between increase in orbital volume after orbital trauma and enophthalmos, suggesting that posttraumatic enophthalmos is caused by the dislocation of the bony fragments rather than fat atrophy or fibrosis. The authors conducted study in 11 patients with orbital blow-out fractures and confirmed that enophthalmos after blowout fractures is linearly related to increase in volume of the orbit. They concluded that each cm^3 increase in volume cause 0.77mm of enophthalmos.[24]

Forbes et al. used Computed tomographic digital data and special off-line computer graphic analysis to measure volumes of normal orbital. They reported that volumes of the bony orbit and total orbital soft tissue vary from 0% to 8% between the right and left orbits when measured in the same person which likely reflects both small anatomic differences and the accuracy of the technique used.[26] So in our study we have used unfractured orbit as control to evaluate the volume change.

Cadaveric study done by Gregory S. Parsons and Robert H. Mathog to study the traumatic effects of displaced orbital wall on globe positions and orbital volume. They determined that a 2.8% volume change resulted in a globe position change of 1mm.[27] In a study done by Hong-Ryal Jin et al. in nine patients with blowout fractures of the orbital wall, there was a relationship between the extent of fracture and enophthalmos. They reported that, defect size of $1.9cm^2$ is presented with 2mm of enophthalmos and defect size of $3.2cm^2$ was associated with 3mm of enophthalmos.[7] Dolynchuk et al. detected that if overall orbital volume difference between normal and fractured orbit was more than 4 to 5%, enophthalmos would be greater than 3mm.[28] The mean orbital volumes in this study were similar to those found in other studies, in which the same software was used. We found a significant difference in volume between the fractured and normal orbits, which is in accordance with the findings of previous studies.

The Hertel values taken intra-operatively shows reduction in enophthalmos level and restoration of the orbital volume. During the post-operative phase, the enophthalmos level remained stable which was achieved intra-operatively. Our study showed statistically significant results in measurements taken at all intervals using Hertel exophthalmometer. Hence it can be considered as the standard tool to restore the orbital volume accurately. However, Hertel exophthalmometer measures only anteroposterior position of the globe and it requires intact lateral orbital rim.[13,14,15] It cannot be used to measure enophthalmos in case of bilateral orbitozygomatic fractures. Hertel exophthalmometer gives a relative globe position and does not give accurate numerical measurement of enophthalmos in millimetres which will be helpful for surgical planning. So further innovations are required to overcome the above stated shortcomings which we encountered in this study.

CONCLUSION

Orbital reconstruction with accurate orbital volume restoration remains a challenge in Maxillofacial traumatology. With the advent of new generation imaging modalities, understanding the complex orbital anatomy and accurate orbital reconstruction for optimal functional and aesthetic results are feasible.

Surgical innovations like intra-operative navigation are a step in this direction.[29] Surgical outcome of secondary reconstruction for post traumatic deformities is usually unpredictable. Hence, accurate primary reconstruction is the goal for all maxillofacial surgeons. Surgical navigation though considered superior is not available everywhere across the world. Intra-operative usage of commonly available tools like Hertel exophthalmometer can significantly improve the final surgical outcome.

In our study sixty-three patients who had orbital wall fractures were evaluated pre-operatively by HRCT based 3D reconstructed volumetric analysis and assessed clinically for enophthalmos using Hertel exophthalmometer. Intra-operatively Hertel exophthalmometer was used to achieve the desired orbital volume correction. Post-operatively all the patients were followed-up at designated intervals. Clinical assessment using Hertel exophthalmometer confirmed the stable results of orbital volume correction which was achieved intra-operatively. Hertel exophthalmometer and HRCT based 3D reconstructed volumetric analysis can be an excellent tool to evaluate anteroposterior globe malposition and volume change.

ACKNOWLEDGEMENT

Dr. Shantanu Patil, Head and Consultant, Department of Translational Medicine and Research, SRM Medical College, Hospital and Research Centre.

ETHICAL APPROVAL

This study was approved by Institutional Ethical Committee Board (IEC NO: 1477/IEC/2018).

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Source of Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Authors' Contribution:

1. Janani Narayanan- Original research done and compilation of the data into an article
2. Vivek Narayanan- Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
3. Saravanan Chandran- Have made a substantial contribution to the concept or design of the article; or the acquisition, analysis, or interpretation of data for the article
4. Karthik Ramakrishnan- Have made a substantial contribution to the concept or design of the article and also drafted the article or revised it critically for important intellectual content
5. Prashanthi Gurram- One of the operating surgeon.
6. Abinaya Subramanian- Corrected the version to be published

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Table 1: Pre-operative orbital volume and orbital volume change

Parameters Assessed	Minimum (cc)	Maximum (cc)	Mean Difference (cc)	Std. Deviation
Orbital Volume	24.78	43.35	35.2044	4.20585
Change in Orbital Volume	0.01	13.66	4.2894	2.76467

Table 2: Comparison of orbital volume in normal and fractured sides

Parameter Assessed	Mean Difference (cc)	P Value
Orbital volume	-3.92042	0.000

Table 3: Enophthalmos values at various time intervals between normal and fractured sides

Period of Assessment	Mean difference (mm) [Enophthalmos]	P Value
Pre-op	2.917	0.000
Intra-op	0.5625	0.011
POD-7	0.5625	0.015
POD-30	0.4167	0.065
Post-op 3 Months	0.3333	0.129
Post-op 6 Months	0.3333	0.129

Table 4: Paired t –Test to Compare Enophthalmos values at all-time interval

Period of Assessment	Mean Difference (mm) [Enophthalmos]	Std. Deviation (mm)	P value
Pre-op Vs Intra-op	-2.3125	1.7644	0.000
Pre-op Vs POD-7	-2.3125	1.9036	0.000
Pre-op Vs POD-30	-2.4583	1.9565	0.000
Pre-op Vs3 Months Post-op	-2.5417	2.0207	0.000
Pre-op Vs 6 Months Post-op	-2.5417	2.0207	0.000
Intra-op VsPOD-7	0.0000	0.7438	1.000
Intra-op Vs POD-30	-0.1458	0.8749	0.254
Intra-op Vs3 Months Post-op	-0.2292	0.9944	0.117
Intra-op Vs 6 Months Post-op	-0.2292	0.9944	0.117
POD-7 VsPOD-30	-0.1458	0.4120	0.018
POD-7 Vs3 Months Post-op	-0.2292	0.6270	0.015
POD-7 Vs6 Months Post-op	-0.2292	0.6270	0.015
POD-30Vs 3 Months Post-op	-0.0833	0.4039	0.159
POD-30Vs6 Months Post-op	-0.0833	0.4039	0.159
3 Months Post-op Vs 6 Months Post-op	-0.0833	0.4039	0.159

Table 5: Group Statistics for patients who underwent orbital reconstruction (n=11)

Period of Assessment	Hertel Mean values(mm)	Std. Deviation(mm)
Pre-op	17.64	0.809
Intra-op	21.727	1.2721
POD-7	22.000	0.8944
POD-30	22.091	0.8312
3 Months Post-op	22.091	0.8312
6 Months Post-op	22.091	0.8312

Table 6: Group Statistics for patients who underwent single point fixation (n=9)

Period of Assessment	Hertel Mean value (mm)	Std. Deviation(mm)
Pre-op	21.44	1.333
Intra-op	21.444	1.3333
POD-7	21.444	1.3333
POD-30	21.444	1.3333
3 Months Post-op	21.444	1.3333
6 Months Post-op	21.444	1.3333

Table 7: Paired t-test to compare the enophthalmos values between different time intervals in patients who underwent orbital reconstruction

Period of Assessment	Mean Difference (mm) [Enophthalmos]	Std. Deviation(mm)	P Value
Pre-op Vs Intra-op	-4.0909	1.2210	0.000
Pre-op Vs POD-7	-4.3636	1.0269	0.000
Pre-op Vs POD-30	-4.4545	1.0357	0.000
Pre-op Vs 3 Months Post-op	-4.4545	1.2136	0.000
Pre-op Vs 6 Months Post-op	-4.4545	1.2136	0.000

Table 7: *(Continued)*

Period of Assessment	Mean Difference (mm) [Enophthalmos]	Std. Deviation(mm)	P Value
Intra-op Vs POD-7	-0.2727	0.9045	0.341
Intra-op Vs POD-30	-0.3636	0.9244	0.221
Intra-op Vs 3 Months Post-op	-0.3636	1.1201	0.307
Intra-op Vs 6 Months Post-op	-0.3636	1.1201	0.307
POD-7 Vs POD-30	-0.0909	0.3015	0.341
POD-7 Vs 3 Months Post-op	-0.0909	0.7006	0.676
POD-7 Vs 6 Months Post-op	-0.0909	0.7006	0.676

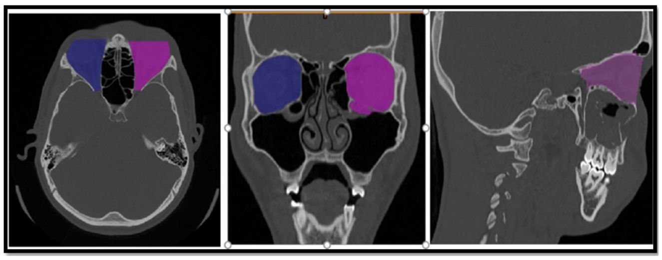

Figure 1: Volumetric Analysis in Axial, Coronal and Sagittal view using MIMICS software.

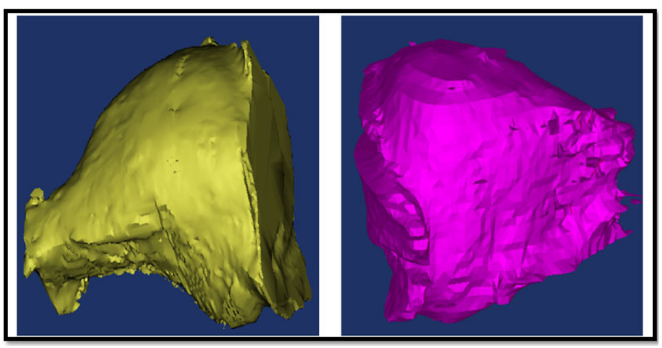

Figure 2 :3D reconstruction of Normal and Fractured orbit using MIMICS software.

Figure 3: Bilateral orbits are exposed and eyelids retracted using 4-0 Ethilon.

Figure 4: Orbital reconstruction using titanium mesh.

Figure 5: Orbital reconstruction using iliac graft.

Figure 6: Intra-operative evaluation of enophthalmos using Hertel exophthalmometer after orbital reconstruction.

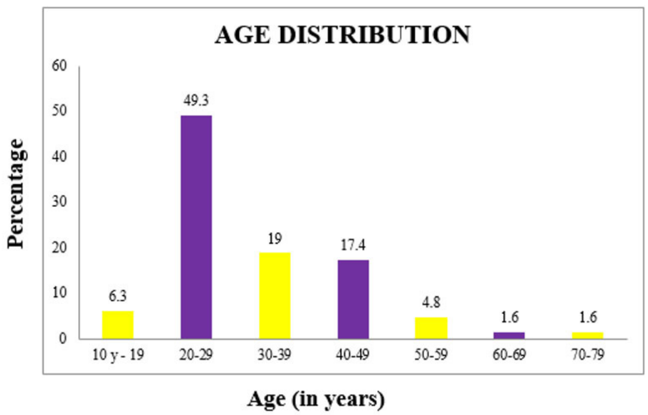

Figure 7: Distribution of age.

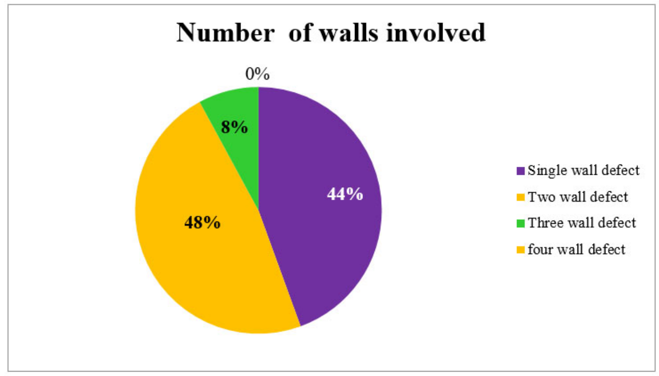

Figure 8: Number of walls involved.