“The Development of a Minimally Invasive Zygoma Fracture Repair Technique”

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Table of Contents

1. Abstract (English and French)
2. Acknowledgments
3. Preface
4. Introduction
5. Connecting Text 1: Rationale for the Lack of Objective Techniques for Zygoma Position Evaluation
6. Manuscript 1: Quantitative Topographical Evaluation of the Orbitozygomatic Complex
7. Connecting Text 2: Rationale for the Lack of Consensus Regarding the Optimal Technique of Zygoma Fracture Repair
8. Manuscript 2: Quantitative Comparison of Open Reduction and Internal Fixation Versus the Gillie's Method in the Treatment of Orbitozygomatic Complex Fractures
9. Connecting Text 3: Minimizing Sequelae of Zygoma Fracture Repair via Selective Incision Use
10. Manuscript 3: Quantitative Analysis of the Orbital Floor Defect after Zygoma Fracture Repair
11. Connecting Text 4: Rationale for the Use of Radiography to Improve Outcomes of Zygoma Fracture Repairs
12. Manuscript 4: Rapid Intra-operative Zygoma Fracture Imaging
13. Connecting Text 5: Elements Required for the Transition of the C-arm Technique to a Clinical Setting

14. Manuscript 5: C-Arm Assisted Zygoma Fracture Repair: a Critical Analysis of the First 20 Cases.
15. Summary
16. References for Introduction, Connecting Texts and Summary

1. Abstract (English)

Zygoma fractures are common and may potentially lead to negative aesthetic and functional consequences: cheek asymmetry, ocular globe asymmetry, infra-orbital nerve dysfunction. There has been a significant evolution in the treatment of zygoma fractures, with general transition from older, closed techniques to newer methods that involve greater exposure, more visualized reduction and increased stability of fixation. Little objective data is present to demonstrate the superiority of either technique. It is our hypothesis that each technique has significant disadvantages and the ultimate objective of this thesis was to develop and quantitatively demonstrate the superiority of a novel method of repair.

First, we developed a quantitative method of zygoma position evaluation and demonstrated its validity and reliability in a clinical setting. Second, we quantitatively compared the accuracy and complication rates of closed and ORIF methods, demonstrating that although increased exposure improves accuracy, it carries a significant risk of access related complications. Third, we showed that routine orbital floor exploration is not necessary in the majority of zygoma fractures and thus the relatively high-risk incision required to perform it may typically be avoided. Fourth, we developed a c-arm imaging technique that allows for visualization of the zygoma and comparison of its position to the contra-lateral, uninjured side. The accuracy of the technique was shown in a cadaver zygoma fracture model. The technique was modified for clinical use by the addition of an intra-oral incision allowing fracture reduction with the c-arm in-situ as well as miniplate placement in an inconspicuous location. Last, the

accuracy of the technique, its low complication profile and practicality were demonstrated in a clinical patient series.

Résumé (français)

Les fractures du zygoma sont communes et peuvent potentiellement mener à des conséquences esthétiques et fonctionnelles négatives: asymétries des joues, globe oculaire asymétrique, nerf infra-orbital dysfonctionnel. Il y a eut une évolution significative dans le traitement des fractures du zygoma, avec une transition générale de techniques plus anciennes et fermées, à de nouvelles méthodes qui impliquent une plus grande exposition, une réduction plus visualisée et une augmentation de la stabilité de fixation. Peu de données objectives sont aujourd'hui présentes qui pourraient démontrer la supériorité de l'une ou de l'autre technique. C'est notre hypothèse que chaque technique a des inconvénients importants et l'ultime objectif de cette thèse était de développer et de démontrer de manière quantitative la supériorité d'une méthode de réparation innovante.

D'abord, nous avons développé une méthode quantitative d'évaluation de la position du zygoma et avons démontré sa validité et sa fiabilité dans un cadre médical. En second lieu, nous avons comparé de manière quantitative la précision et les taux de complications de méthodes fermées et ORIF, démontrant que bien que l'augmentation de l'exposition permette d'augmenter le niveau de précision, elle porte un risque important de complications dues à l'accession. Troisièmement, nous avons démontré que l'exploration routinière du plancher orbital n'est pas nécessaire dans la majorité des fractures du zygoma et donc que l'incision à relativement hauts-risques nécessaire pour l'exécuter peut être généralement évitée. Quatrièmement, nous avons développé une technique d'imagerie avec arceau « c-arm » qui permet une visualisation du zygoma et une comparaison de sa position par rapport au côté contra-latéral non blessé. La précision

de la technique a été démontrée sur un modèle cadavérique d'une fracture du zygoma. La technique a été modifiée pour son utilisation médicale en y ajoutant une incision intra-oral permettant la réduction de la fracture avec l'arceau « c-arm » in-situ ainsi que le placement d'une mini plaque a un endroit discret. Enfin, la précision de la technique, son peu de risques au niveau des complications et son aspect pratique ont tous été démontrés dans une série de patients médicaux.

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INTRODUCTION

The zygoma is considered to have three important roles: two are structural, and one is functional. First, the zygoma's broad surface area and prominent location in the lateral part of the midfacial skeleton make it aesthetically critical. Its body underlies the malar eminence, while its extensions connect with the frontal bone at the fronto-zygomatic suture, the temporal bone at the zygomatic arch, the sphenoid bone in the lateral wall of the orbit, the maxillary bone in the floor of the orbit at the infra-orbital rim, and at the zygomatico-maxillary buttress.[1] Three surface anthropometric landmarks originating from the zygoma have been described.[2] The maxillozygion lies along the maxillozygomatic suture line and can be located by palpation of the most anterior protruding contours of the frontal aspect of the face.[3] The Orbitale is the lowest point of the lower orbital rim; and the Zygion is the most lateral point along the zygomatic arch. The central location of the maxillozygion on the malar eminence affords it the potential to most accurately describe the position of the zygoma. Second, the zygoma forms the lateral part of the orbital floor and lateral orbital wall, helping to determine the vertical and sagittal positions of the ocular globe. The orbital surface of the zygoma interfaces with the frontal, sphenoid and maxillary bones defining a constant orbital volume, which in an adult equals approximately 30 cm^3.[4] The Whitnall's tubercle of the zygoma provides the lateral attachment point for the ligamentous sling that encompasses the ocular globe. The ligamentous sling in conjunction with the orbital floor, directly inferior to the ocular globe, support the position of the globe on the vertical axis. The ligamentous sling in conjunction with the orbital floor, posterior to the ocular globe, support the position of the globe on the sagittal axis.[5] Third, the zygoma provides an attachment site for part of the facial musculature. It is the origin for the zygomaticus major and minor muscles which move the upper lip supero-laterally. It is also the origin for the masseter muscle which causes mandibular elevation.[1]

The zygoma's thin connecting osseous extensions and the presence of an underlying maxillary sinus make it particularly poor at withstanding applied forces. The zygoma can tolerate a force of up to 50G prior to fracturing; half of the force is required to fracture either the maxilla or mandible and a quarter of the force is required to fracture the frontal bone, all of which are immediately adjacent.[6] This structural weakness of the bone combined with its prominent position make the zygoma particularly vulnerable to traumatic forces. Several published series have identified the incidence of zygoma injuries to be between 30-40% of all facial fractures.[7] This is second only to nasal bone fractures. The most common etiologies include assault, motor vehicle collisions, sport-related injuries, and falls.

A fractured zygoma typically separates and translates at its five connecting interfaces. In some instances, the separation at 1 or more interfaces may be incomplete resulting in the rotation of the entire bone at the incomplete fracture site. The interfaces where this occurs most often include the fronto-zygomatic suture and the zygomatic arch. The direction of displacement, severity of displacement and comminution depend on the direction and magnitude of the traumatic force, respectively. In general, forces originate anterior or antero-lateral to the zygoma and result in postero-medial translation of zygoma body. Very rarely, lateral originating forces result in lateral rotation of the zygoma body around the fronto-zygomatic suture – zygomaticomaxillary buttress axis. Mild energy fractures result in minimal displacement with no comminution. Moderate energy fractures demonstrate displacement with comminution at 1 or more of the connecting interfaces, typically the infra-orbital rim and zygomatico-maxillary buttress. Severe energy injuries cause an even greater displacement with comminution sometimes extending into the body of the zygoma.[8] First, the fracture leads to loss of prominence of the maxillozygion, leading to a flat, narrow appearance of the malar eminence. The height of the maxillozygion may be variably affected. Second, as the zygoma forms a part of the orbital floors and lateral orbital wall, its displacement leads to their fracture. If the fracture causes significant enlargement of the orbital volume directly inferior to the globe, inferior globe dystopia will result. If the fracture leads to significant volumetric enlargement posterior to the globe, enophthalmos will ensue.[9] Furthermore, even if fracture displacement does not lead to a significant enlargement of the orbital volume, the antero-lateral vector of reduction required to reduce most zygomas may critically enlarge a previously small defect. Third, extension of the fracture through the infra-orbital foramen, which lies just medial to the zygomatico-maxillary junction, may cause infra-orbital nerve injury and subsequent sensory disturbances of the lateral aspect of the nasal sidewall, cheek, upper lip and maxillary dentition. Fourth, although displacement of the zygoma displaces the origin of some facial expression and masticatory muscles, thus altering their length of excursion, their function is unlikely to be altered once osseous union is achieved.

Zygoma fracture repair has undergone significant evolution throughout the last century.[10] At first, closed reduction techniques, wherein the displaced bone was repositioned through a small incision in the upper buccal sulcus, temporal fossa or anterior cheek skin, were dominate. During the mid-part of the century, a variety of stabilization techniques using inter-fragmentary wires and percutaneous pins were added.

In the final two decades, plate and screw fixation rose in popularity and became the principal method of stabilization.[11,12] The American Society of Internal Fixation (ASIF) has established principles of zygoma fracture repair, which include minimum of 3 fracture interface reduction, minimum of 2 fracture interface plate fixation and exposure of the zygomatic arch if there is arch comminution, lateral displacement of arch segments or comminution of 2 or more of the anterior buttresses.[13] Closed techniques have potential advantages: minimal sequelae of surgical exposure, decreased operative duration, and treatment costs. Open reduction and internal fixation (ORIF) techniques allow for potentially greater accuracy of repair as greater visualization of the fracture segments is achieved. However, open access has possible disadvantages. The coronal incision, used to expose the zygomatic arch, leads to a significant scalp scar with alopecia along it and the loss of skin sensation posterior to it. In addition, the approach may lead to unsightly temporal hollowing and injury to the temporal branch of the facial nerve.[14-16] Lateral orbital rim incision leaves a visible scar. Inferior eyelid approaches have the potential for creating post-operative eyelid malposition, the severity of which may range from a mild aesthetic deformity to a severe lagophthalmos with exposure keratopathy. Both trans-cutaneous and trans-conjunctival inferior eyelid approaches introduce this risk, which is thought to be caused by scarring of the middle lamella and can occur following a properly executed procedure.[17] The addition of a lateral canthotomy with cantholysis increases the exposure of the inferior rim and allows visualization of the fronto-zygomatic suture, but increases the risk of eyelid and canthal malposition.[18] Intra-oral incision is thought to be the least morbid, but its use provides limited information regarding accurate fracture reduction in cases where its comminution is present. Although

ORIF is considered by most to be the standard for repair of a fractured zygoma, many still use a variant of the original closed method due to the potential disadvantages of open access. Even among those favoring ORIF, most avoid using the coronal incision in favor of the anterior exposure, except for cases with severe comminution.[19]

Previous reports have investigated the outcomes of each type of technique in order to determine their true advantages and disadvantages, with limited success. The shortcomings of studies thus far include small sample size, non-selective inclusion criteria, lack of objective outcomes, and inadequate follow-up.[20-28] Lack of objective outcomes has been caused, at least partly, by the absence of a validated, reliable measurement technique for zygoma position. Consequently, much uncertainty among treating physicians exists with potentially sub-optimal repair outcomes.

Our clinical experience, combined with the available published data, has led us to believe that none of the currently available techniques is ideal and a hybrid method may be necessary to provide superior outcomes. The primary objective of this thesis is to develop an improved technique of zygoma fracture repair, which is accurate, has minimal sequelae of open access, and is rapid and inexpensive. To achieve the primary objective, numerous preliminary objectives needed to be fulfilled. First, an objective, quantitative technique of zygoma position evaluation needed to be developed. Second, the accuracy and complication rates of closed and ORIF techniques needed to be quantified. Third, the need for routine orbital floor exploration in zygoma fractures needed to be assessed to understand if the inferior eyelid exposure must be routinely used. In order to minimize sequelae of open access without sacrificing the accuracy of repair, intra-operative c-arm radiography was used. Fourth, c-arm views needed to visualize the zygoma were identified and the accuracy of the c-arm technique evaluated on a cadaver zygoma fracture model. Last, following adaptation to a clinical setting, the accuracy, complication rates, and practical aspects of the technique were evaluated in a patient series.

CONNECTING TEXT 1

RATIONALE FOR THE LACK OF OBJECTIVE TECHNIQUES FOR ZYGOMA POSITION EVALUATION

Objective evaluation of the zygoma position following fracture repair has been limited partly due to the lack of quantitative assessment methods.[20-28] Detailed analysis during a physical examination is not typically feasible as specialized measurement tools are not widely accessible, and a routine, reliable, validated measurement technique has not yet been identified. Similarly, photographic examination is limited by lack of image standardization, inability to obtain 3-D information from a single view and the absence of a validated evaluation technique. In the past, the plain radiographic imaging available allowed a limited view of the zygoma anatomy due to its overlap with the calvarium and other facial bones. Currently, computed tomography provides a significant opportunity for detailed analysis of the facial skeleton. Its disadvantages, however, include radiation and cost.

The zygoma is covered only by skin and thin subcutaneous tissue over the frontozygomatic buttress, zygomatic arch, infra-orbital rim and body. The zygoma body, which underlies the malar eminence, likely represents the most important area due its central location and prominence in sagittal and coronal planes. Furthermore, the zygoma body is typically the area of maximal impact and is thus most displaced following a fracture. This specific anatomy presents an opportunity to assess the position of the most important part of the zygoma and describe its movement by evaluation of the skin overying it. This type of technique would also avoid radiation, minimize costs and could be performed in a clinic.

Anthropometry is the study of sizes, weights and proportions of the human body.[2] Its techniques were initially developed by Ales Hrdlicka and later popularized in the head and face by Leslie Farkas.[2] During anthropometric evaluation, identifiable points on the head and face are marked, the head placed in a reproducible position and measurements performed. Although the points marked are on the skin surface, they typically represent an underlying osseous landmark. The measurements types include distances – measured with a sliding or spreading caliper, linear projective distances – measured with a double sliding caliper, and angles – measured with a goniometer. From these, a spectrum of secondary calculations can be performed.

Our first objective was to use the techniques of anthropometry to develop a reliable, valid method of identifying the position of the zygoma, in order to quantify its movement in patients with fractures.

The zygoma has numerous synonymous terms in the literature, most commonly: zygoma, orbitozygomatic complex (OZC), and zygomaticomaxillary complex (ZMC). OZC is a term commonly used by plastic and oculoplastic surgeons in order to bring focus to the involvement of the orbit in its fractures. ZMC is a term preferred by oromaxillofacial surgeons in order to bring focus to the involvement of the maxilla in its fractures. In the first 2 sections of the thesis, the term OZC is used. In the last 4 sections, the term zygoma is used instead, for simplicity and to underline the major bony component that is fractured and displaced.

QUANTITATIVE TOPOGRAPHICAL EVALUATION OF THE ORBITOZYGOMATIC COMPLEX

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Abstract:

The orbitozygomatic complex (OZC) is a tetrapod-shaped bone of the upper midfacial skeleton of particular clinical significance. By defining the malar prominence, it provides a significant contribution to the overall facial form. As well, it determines the volume and shape of the bony orbit, thus controling the projection and height of the ocular globe. The OZC also plays an important role in mastication by providing an origin to the masseter muscle and by protecting the coronoid process and the temporalis muscle. Moreover, the OZC is the second most frequently fractured bone on the craniofacial skeleton. A method for quantitative determination of OZC position has important applications in the fields of reconstructive and aesthetic plastic surgery.

Ten individuals were evaluated using craniofacial anthropometry techniques. The position of the OZC in three planes, x, y and z, was determined by measuring linear projective distances between OZC landmarks: maxillozygion (the most prominent landmark on the malar prominence); orbitale (the lowest point on the inferior orbital rim); zygion (most lateral point on the zygomatic arch); and cranial reference landmarks (vertex, opisthocranion, nasion).

Low variability between measurements within the same individual (< 1.5mm) underlines the reliability of the chosen landmarks and techniques in the determination of OZC position. Second, the OZC occupies a consistent position between individuals, as shown by the low inter-subject variability. Third, there is no statistically significant difference in the position of the OZC, in any plane of space, between the left and right sides of the face. Thus, our method may be used to determine the degree of OZC displacement in individuals suffering from unilateral facial trauma, or with unilateral

residual post-surgical deformity, and to calculate the amount of realignment needed to produce a symmetrical facial appearance.

1. Introduction

The orbitozygomatic complex (OZC) is a tetrapod-shaped bone of the upper midfacial skeleton. The position of the OZC is determined by its articulations with adjacent structures including the frontal bone, the greater wing of the sphenoid bone, the zygomatic process of the temporal bone, and the maxilla.

The clinical importance of the OZC is evident. First, the OZC defines the malar prominence, an area providing a significant contribution to the overall facial form.[1] Second, it determines the volume and shape of the bony orbit and thus controls the projection and height of the ocular globe.[2, 3] Third, the OZC plays an important role in mastication by providing an origin to the masseter muscle and by protecting the coronoid process and the temporalis muscle.[4] Moreover, the OZC is the second most frequently fractured bone of the craniofacial skeleton.[5]

Therefore, a method for precisely defining the OZC position would have important applications in reconstructive and aesthetic plastic surgery. This would allow for the measurement of post-traumatic or post-surgical OZC displacement, facilitating its accurate surgical correction. Such a method would also permit the comparison of different surgical techniques used for correcting OZC fractures and selecting that which produces superior facial symmetry. In addition, it could be used in the planning of malar prominence augmentation resulting in an optimally aesthetic facial appearance.

An ideal method of OZC position evaluation should be accurate and have low intra- and inter-observer variability. To facilitate widespread clinical application, this method must also be inexpensive and easy to learn. To our knowledge, such a method of reliably defining the OZC position in a three-dimensional field has not been fully developed.

The objective of this study was to create a reliable, quantitative method of defining the position of the OZC. To accomplish this goal, we used the instruments and techniques of craniofacial anthropometry to measure the position of previously identified landmarks on the OZC: the maxillozygion;[6] the orbitale and zygion[7] with respect to static cranial landmarks; the opisthocranion;, the vertex; and the nasion.[7] Subsequently, we calculated the degree of variability, which resulted from locating and measuring the position of these landmarks. Finally, we tested for the presence of inherent side-to-side facial asymmetry in the position of the OZC in normal individuals.

Thus, we have sought to validate a clinically applicable technique of defining the position of the OZC in normal individuals, its displacement following fracture, and its optimal positioning in post-traumatic reconstruction and aesthetic malar augmentation.

2. Materials and Methods

The study group consisted of ten healthy individuals, five males and five females. Their age ranged from 24 to 49 years. They were selected based on the following criteria: absence of congenital facial anomalies and absence of previous facial injuries or surgeries. Each individual was examined using a standardized protocol by one investigator.

With the individual's head oriented in the Frankfurt horizontal position using an anglemeter and a custom-built chin-rest, relevant landmarks (Table 1) were identified by palpation and marked on the skin surface using a fine-tip, washable marker (Figure 1).

Using a double-sliding caliper, linear projective distances (Table 2, Figure 2), defined as uni-dimensional vector components, were measured. Care was taken so that the caliper was applied without causing indentation of the soft tissues (Figure 3).

All of the measurements were first performed on the left and then on the right side of the individual's face. All the steps, including head positioning, landmark identification and distance measurement, were performed in triplicate to increase the accuracy of the data and to allow for the calculation of intra-skull variability.

The linear projective distances used in the final analysis were means of the three measured values. Statistical analysis was performed using two-tailed, matched-pair Student's t-test.

3. Results

Mean values and standard deviations of OZC projection (mz-op), height (mz-v, or-v) and lateral position (mz-n, zy-n), for each side of the face are presented in table 3. Matched-pair Student's t-test results, comparing the left with right sides of the face, are also found in the table 3 and contains means of standard deviations of each linear projective distance measurement within each individual. The latter standard deviations represent inter-measurement variability, which consists of errors in landmark localization and measurement technique, and inherent instrument imprecision.

A. OZC Projection

The mean value of OZC projection (mz-op) in the ten individuals equalled 156.9 mm on the left and 157.4 mm on the right, with standard deviations of 9.1 mm and 8.9 mm, respectively. The result of matched-pair Student's t-test, comparing OZC projection on the left with the right side of the face equalled 0.434. A value of less than 0.05 was defined to be statistically significant. Mean inter-measurement variabilities equalled 1.1 mm and 1.4 mm on the left and right sides of the face, respectively.

B. OZC Height

OZC height was defined by two measurements, mz-v and or-v. The mean values of these linear projective distances equalled 114.6 mm and 109.6 mm on the left, and 114.6 and 109.4 on the right, respectively. The result of matched-pair Student's t-test, comparing OZC height on the left with the right side of the face equalled 0.837 and 0.721, for mz-v and or-v, respectively. Mean inter-measurement variabilities for all individuals equalled 1.3 mm and 1.5 mm, for mz-v and or-v respectively.

C. OZC Lateral Position

The lateral positioning of the OZC was defined by mz-n and zy-n. The mean values of these linear projective distances equalled 36.5 mm and 59.1 mm on the left and 37.7 mm and 60.3 mm on the right, respectively. The result of matched-pair Student's t-test, comparing OZC height on the left with the right side of the face equalled 0.133 and 0.072, for mz-n and zy-n, respectively. Mean inter-measurement variabilities for all individuals equalled 1.0 mm and 0.8 mm, for mz-n and zy-n respectively.

4. Discussion

The OZC is of great clinical significance in the field of plastic surgery. Not only is it frequently fractured and displaced,[8] but it also is a crucial area for aesthetic facial enhancement. Therefore, a method for precise assessment of OZC position would be a great tool for reconstructive and aesthetic plastic surgeons.

Several skin surface landmarks overlying the OZC have been previously identified.[6-8] The thin soft tissue in this area allows these landmarks to accurately reflect the underlying facial skeleton.[6] Using the latter characteristics and the techniques of craniofacial anthropometry, we have described the position of the OZC in a three-dimensional field (figure 4).

To locate the OZC on the z-axis, we used mz-op; on the y-axis, we used mz-v and or-v; finally on the x-axis, we used mz-n and zy-n. Importantly, these values represent linear projective distances, that is, components of three-dimensional vectors in a single plane: z, y, or x. Thus, displacement of the OZC can be separately assessed in each plane.

First, our data indicate that the position of the OZC can be reliably defined in a three-dimensional field using the described anthropometric methods. The mean intra-subject (inter-measurement) variability was very low, ranging from 0.7 to 1.5 mm. Surface facial asymmetry of 2 mm was shown to be discernible to a trained physician 50% of the time.[8] The calculated values are below this threshold and, hence, clinically insignificant. This indicates a high degree of precision in landmark identification,measurement technique, and a low instrument error. The data validate the use of our methods to reliably determine the position of the OZC in a clinical setting.

Second, the mean inter-subject variability in the position of the OZC ranged from 2.9 to 9.1 mm, very small values relative to the total linear projective distances. Thus, the

OZC occupies a consistent position between different individuals. Gender-matching of the individuals would probably further reduce this variability. This data may be used to determine the desired, normal position of the OZC in patients with deformities secondary to facial trauma or congenital anomalies.

Third, there is no statistically significant difference in the position of the OZC in any plane of space between the left and right sides of the face. Therefore, our method may be used to determine the degree of OZC displacement in individuals suffering from unilateral facial trauma or with unilateral residual post-surgical deformity, and to calculate the amount of realignment needed to produce a symmetrical facial appearance. This method may also be used to compare the accuracy of different surgical techniques used for repair of OZC fractures.

In our study, we used two linear projective distances to define the position of the OZC in the y and x planes, respectively. The complex can displace in six directions: three translations in the x, y and z axes; and three rotations around the x, y and z axes.[9] Two landmarks in each plane are needed to describe each movement. Otherwise, a rotation around one landmark, or around one axis, may not reveal any change in the position of those landmarks even though the entire OZC had been displaced.

To summarize, we have developed and validated a reliable, objective technique of defining the position of the OZC. We hope that this simple method will provide an alternative to subjective evaluations of the OZC in patients suffering from trauma or presenting with post-operative facial asymmetry. As well, we wish to encourage the current trend of quantitative, objective evaluation in craniofacial surgery.

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Table 1. Anthropometric landmarks and their definitions.

Anthropometric Landmark	Definition
maxillozygion (mz)	the most anteriorly prominent point on the frontal aspect of the face, found below the lateral third of the bony orbit [5]
orbitale (or)	the lowest point on the inferior orbital rim
zygion (zy)	the most lateral point on the zygomatic arch
vertex (v)	the highest point on the head when the head is oriented in the Frankfurt horizontal position
opisthocranion (op)	the most posterior point on the head when the head oriented in the Frankfurt horizontal position
nasion (n)	the point in the midline of both the nasal root and the nasofrontal suture
porion (po)	the highest point on the upper margin of the cutaneous auditory meatus
Frankfurt horizontal (FH) position	orientation of the head in which the line connecting the orbitale and the porion is parallel to the ground

Table 2. Linear Projective Distances and their Definitions.

Linear Projective Distance	Definition
mz-op	OZC projection, represents the position of OZC in the z-plane
mz-v, or-v	OZC height, represent the position of the OZC in the y-plane
mz-n, zy-n	lateral position of the OZC, represent the position of the OZC in the x-plane

Table 3. Mean positions of the OZC in three planes on the left and right sides of the face, their standard deviations (sd1) and means of standard deviations (sd2) of measurements within each subject.

OZC Position	Left Side			Right Side			p-value
	Mean (mm)	Sd1 (mm)	Sd2 (mm)	Mean (mm)	Sd 1(mm)	Sd2 (mm)	
mz-op	156.9	9.1	1.1	157.4	8.9	1.4	0.434
mz-v	114.6	5.1	1	114.6	4.9	1.3	0.837
or-v	109.6	5.0	1.1	109.4	5.2	1.5	0.721
mz-n	36.5	2.9	.9	37.7	3.0	1.0	0.133
zy-n	59.1	4.0	.7	60.3	3.2	.8	0.072

Figure Legends

Fig 1. Anthropometric landmarks identified: maxillozygion (mz), orbitale (or), zygion (zy), opisthocranion (op), vertex (v) and nasion (n).

Fig 2. Linear projective distances measured: OZC projection (mz-op), OZC height (mz-v), OZC lateral position (mz-n).

Fig 3. Example of a measurement performed using the double-sliding caliper.

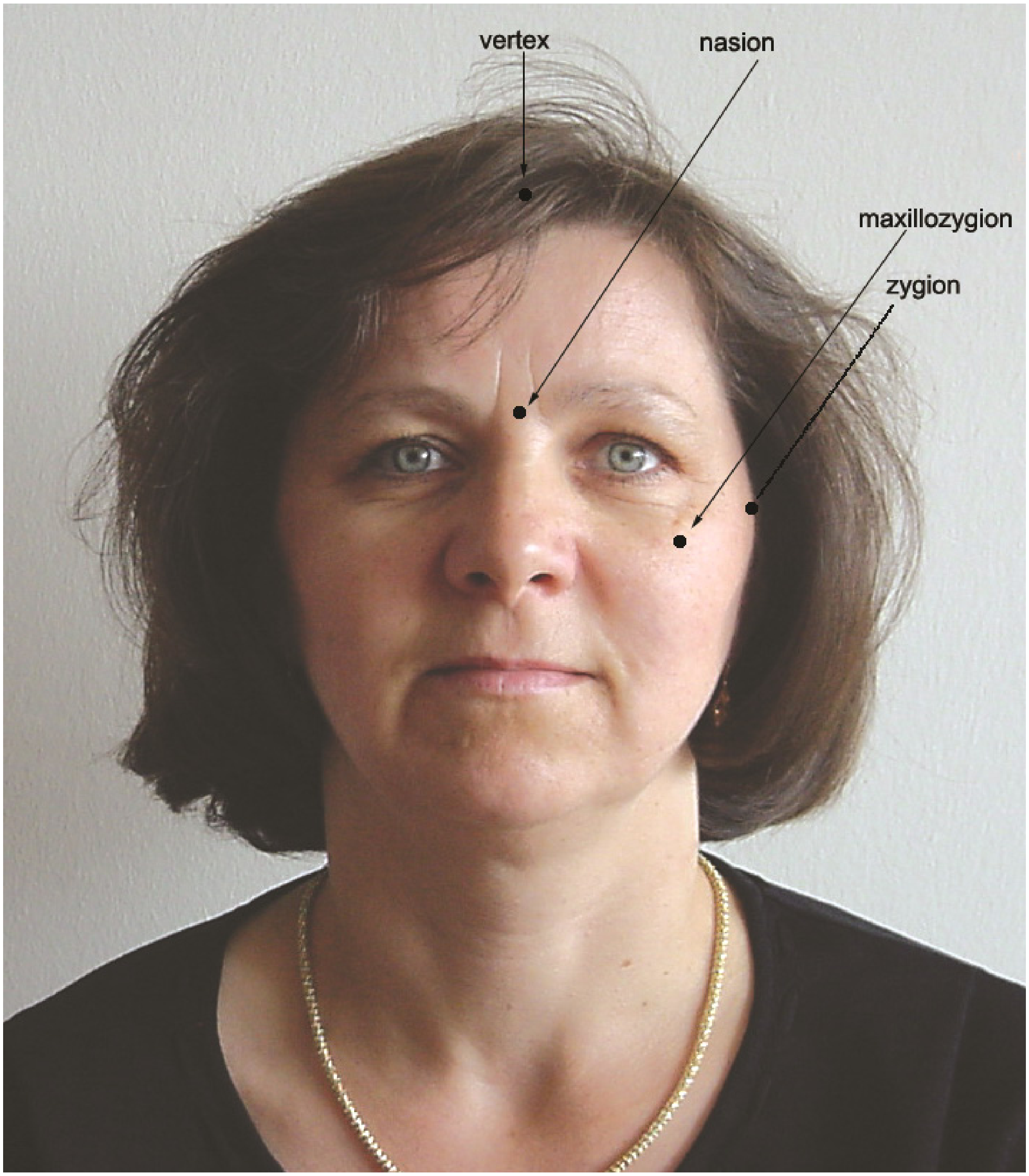

Figure 1

Figure 2

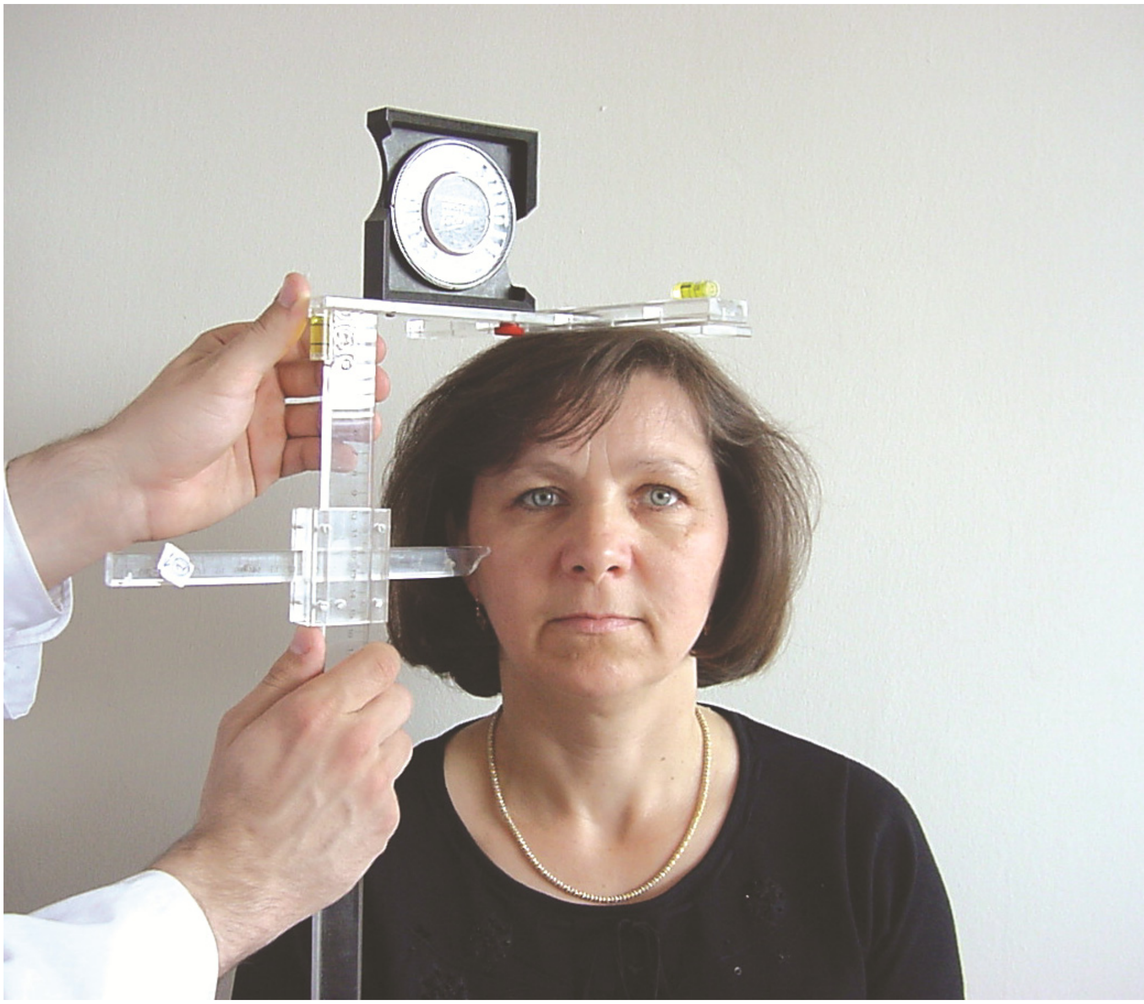

Figure 3

CONNECTING TEXT 2

RATIONALE FOR THE LACK OF CONSENSUS REGARDING THE OPTIMAL TECHNIQUE OF ZYGOMA FRACTURE REPAIR

The two most frequently used technique types of zygoma fracture repair include ORIF and closed reduction.[13] Many variants of ORIF exist and are differentiated by location of incisions, sites used for reduction accuracy, and sites used for fixation. Most surgeons choose to avoid the coronal incision, due to associated risks and additional operative time, unless absolutely necessary, and instead perform ORIF through anterior access incisions.[19] In anterior ORIF, a combination of inferior eyelid, lateral orbital rim and upper buccal sulcus incisions is used. Variants of closed reduction exist as well and are differentiated by the location of incisions used for placement of the reducing instrument. The Gillie's technique, which utilizes an instrument placed underneath the body of the zygoma through a temporal scalp incision, is likely the most commonly used.[19]

As previously described, both procedure types used to treat zygoma injuries have potential advantages as well as drawbacks. Prior reports objectively evaluating these are lacking due to small sample size, non-selective inclusion criteria, lack of quantitative outcomes, and inadequate follow-up.[20-28] The failure of these reports to objectively assess the accuracy of various techniques at repositioning the zygoma is critical, as this is the primary goal of the operation. The first study of this thesis has shown that the maxillozygion, in conjunction with previously described anthropometric landmarks, can be used to reliably determine the position of the zygoma in a three-dimensional field and then compared to the contra-lateral side of the face to determine asymmetry.

The objective of the second study of this thesis is to objectively evaluate the advantages and disadvantages of the principally contrasting techniques. Each aspect of repair is assessed: accuracy of zygoma repositioning, ocular globe position, post-operative infra-orbital nerve sensation, and negative sequelae of open access. The ultimate goal of this analysis is to identify aspects of repair that are critical for accurate skeletal re-alignment, as well as those that should be avoided due to a high complication profile. This will subsequently allow for the synthesis of a superior, hybrid technique of repair.

QUANTITATIVE COMPARISON OF OPEN REDUCTION AND INTERNAL FIXATION VERSUS THE GILLIES METHOD IN THE TREATMENT OF ORBITOZYGOMATIC COMPLEX FRACTURES

Marcin Czerwinski, MD

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Abstract

The orbitozygomatic complex (OZC) is the second most frequently fractured bone of the craniofacial skeleton. Its precise repair is essential for the proper re-establishment of facial symmetry, ocular globe position and infraorbital nerve function. Numerous surgical techniques have been developed to repair OZC fractures, ranging from reduction without direct visualization of alignment at any fracture site, to wide surgical access with open visual alignment of all articulating buttresses and their rigid fixation using miniplates (ORIF). Due to lack of objective data to convincingly support the use of one technique, controversy regarding the optimal method of OZC fracture repair remains. In this study, uniform study groups were selected by the review of patient's past medical and surgical histories, evaluation of pre-operative computerized tomography scans and operative reports. Subsequently, quantitative end-points including OZC position, ocular globe projection and ION function were measured to objectively compare the accuracy of repair produced by the Gillies procedure and ORIF. Negative sequelae resulting from cutaneous access incisions were tabulated. The results demonstrate that ORIF produces superior realignment of the OZC compared to Gillie's repair, that is, a smaller difference in the position of the OZC between the injured and non-injured sides of the face. The differences in OZC projection, height and lateral position in patients treated using ORIF were 1.4 mm, 1.4 mm and 1.6 mm respectively. Gillie's repair resulted in differences in OZC projection, height and lateral position of 7.5 mm, 5.6 mm and 4.1 mm respectively. P-values obtained equalled 0.0003, 0.01 and 0.06, respectively. Visible cutaneous scarring was present in 4 patients treated using ORIF, and lower lid shortening was present in 3 patients. To our knowledge, this study is the first study to objectively show

that open reduction and internal fixation results in superior position of the OZC in treating non-comminuted, moderately displaced fractures of the OZC, than does Gillie’s repair. Consequently, this surgical technique is less likely to necessitate secondary corrective surgery, which is fraught with difficulties and is best avoided. While negative sequelae from lower lid and frontozygomatic buttress accesses were substantial in this population, the recent introduction of transconjunctival and upper lid blepharoplasty incisions may minimize these drawbacks.

1. Introduction

The OZC is the second most frequently fractured bone of the craniofacial skeleton.[1] Commonly, the entire complex is separated from its adjoining articulations and displaced in a posterior, inferior and lateral direction.[2] This fracture has several clinically important consequences. First, it disrupts the normal, symmetrical position of the malar prominence and causes significant facial deformity.[3,4] Second, it may enlarge the volume of the bony orbit and result in enophthalmos and ocular globe dystopia.[5,6] Third, it interrupts the infraorbital canal and causes dysfunction of the infraorbital nerve (ION). Consequently, precise reconstruction of the OZC is essential to restore these deficits.

Numerous surgical techniques have been developed to repair OZC fractures. These range from reduction without direct visualization of alignment at any fracture site to wide surgical access with open visual alignment of all articulating buttresses and their rigid fixation using miniplates (ORIF). Many investigators have compared the accuracy of these techniques in order to identify which results in superior facial symmetry, ocular globe position and ION function. Their use of non-uniform study groups[7-9] and subjective evaluation methods[10-15] have not yielded conclusions that convincingly support the use of a single technique. In addition, insufficient emphasis has been placed on the potential negative sequelae of extensive access incisions. As a result, controversy regarding the optimal method of OZC fracture repair remains.

The objectives of the present study were to objectively compare and identify the superior method of OZC repair among the two most frequently used methods at the McGill University Health Centre (MUHC): the Gillies repair and anterior ORIF. The coronal incision was excluded as it is considered to be fraught with complications and is unnecessary for the majority of zygoma fractures. Quantifiable end-points, including OZC position, ocular globe projection, and ION function were measured in uniform study groups. Additionally, negative surgical sequelae in each study group were tabulated.

2. Materials and Methods

The present study was reviewed and approved by the MUHC Research Ethics Committee.

A. Inclusion Criteria

The study groups were assembled by reviewing medical records of patients who underwent OZC repair at the Montreal General Hospital (MGH) between the June 1996 and August 2002. Patient selection was a three-step process, with disqualification occurring at each of the following: past medical and surgical history review, assessment of OZC fracture pattern and severity based on pre-operative computerized tomography (CT) scans (figure 1), and review of the operative report identifying the surgical technique used. Disqualification criteria are presented in table 1. Patients who fit the inclusion criteria and agreed to participate in the study were examined according to a standardized protocol at the MGH Plastic Surgery Clinic.

B. End-points

Quantitative end-points measured include: position of the OZC, ocular globe projection and ION function. All the measurements were performed on the injured and non-injured sides of the face. In addition, presence of negative sequelae due to cutaneous access incisions, namely visible cutaneous scarring and lid shortening, was assessed. Data collection was blinded to the surgical technique used in OZC repair.

First, the position of the OZC in three planes was defined using craniofacial anthropometry as described elsewhere.[16-18] All the measurements were first performed on the injured and then the non-injured sides of the individual's face. All the steps, including head positioning, landmark identification and distance measurement, were performed in triplicate. Values used in final analysis represent the means of these three measurements. Residual post-operative displacement was defined as the difference in the position of the OZC between the non-injured and injured sides of the face.

Ocular globe projection was measured using the Naugle exophthalmometer (figure 2). This instrument measures the position of the corneal apex with reference to the superior orbital rims. Therefore, it is more accurate than the commonly used Hertel exophthalmometer, which uses landmarks that are displaced in OZC fractures.[19] The measurements were performed in triplicate. Residual post-operative enophthalmos was defined as the difference in ocular globe projection between the injured and non-injured sides of the face.

ION function was tested using Semmes-Weinstein Monofilaments (SWM) and Mackinnon-Dellon Disk-Criminator to evaluate cutaneous pressure threshold and innervation density of slowly adapting fibers, respectively. These modalities have been shown to adequately evaluate ION function following injury.[20,21] Testing was performed 1.5 cm below the infraorbital rim on the pupillary vertical line on the non-injured and then the injured side of the face.

SWM were applied perpendicularly to the skin surface and pressure was increased until visible bending of the filament was observed. The probes were applied consecutively, beginning with the thinnest filament (marked 1.65) and progressing to the thickest (marked 6.65). The thinnest filament, which elicited perception and localization of pressure was recorded.

The initial two-point testing distance was 25 mm and was gradually decreased to 2 mm. The testing stimulus was randomly switched between one and two points. Progression to a smaller two-point distance was done each time a patient would answer 2 out of 3 questions regarding the stimulus correctly. The smallest two-point distance at which the patient answered 2 out of 3 questions correctly was considered the maximum 2 point discriminatory ability.

Hypoesthesia was defined as a measurable difference in ION function between the injured and non-injured sides of the face. Percentage of patients with hypoesthesia in each study group was calculated.

C. Statistical Analysis

Statistical analysis of the data was performed using a one-tailed, independent variable Student's t-test.

3. Results

One hundred and fifty-three patients underwent OZC repair at the MGH between the June 1996 and August 2002. Of these, 73 fulfilled all of the criteria outlined in the materials and methods section. Twenty-four eligible patients agreed to participate in the study; 12 were treated using Gillies repair and 12 using ORIF.

There were 14 males and 10 females, their average age was 48. Causes of OZC fracture in this group, in descending frequency, were motor vehicle collisions, personal altercations, sports-related injuries, and falls. There were no statistically significant differences in demographic characteristics among the two study groups.

Data describing residual post-operative displacement in the position of the OZC between the injured and non-injured sides of the face for the two study groups is presented in table 2. Increasing displacement in either the x, y or z planes indicates greater amount of post-operative facial asymmetry. Asymmetry in OZC projection (mz-op) in patients treated using Gillies repair equalled 7.5 mm, and in those treated using ORIF it equalled 1.4 mm. This difference was statistically significant, p-value 0.0003. Asymmetry in OZC height (mz-v) in patients treated using Gillies repair equalled 5.6 mm; in those treated using ORIF, it equalled 1.4 mm. The OZC height asymmetry was statistically significant, p-value 0.01. Asymmetry in the lateral position of the OZC (mz-n) in patients treated using Gillies repair was 4.1 mm; in those treated using ORIF, it equalled 1.6 mm. The difference in asymmetry in the lateral position of the OZC between the two study groups approached but did not reach statistical significance, p-value value 0.06. Surface facial asymmetry of 2 mm was shown to be discernible to a trained physician 50% of the time.[2] Hence, asymmetry in OZC position, in all three planes, was clinically significantly smaller in patients treated using ORIF compared to Gillies repair.

Figure 3 demonstrates worm's view photographs of patients representing each study group. Differences in OZC projection can be visually ascertained.

Data describing residual post-operative difference in ocular globe projection between the non-injured and injured sides of the face for the Gillies and ORIF treated patients is presented in table 3. Mean ocular globe projection in Gillies treated patients was restored to within 1.09 mm of the non-injured side, in those treated using ORIF it was restored to within 1.23 mm. The difference between the two study groups was not statistically significant, p-value 0.832.

Percentage of patients with ION hypoesthesia, as tested using SWM and the Mackinnon-Dellon Disk-Criminator, for Gillies and ORIF treated patients is shown in table 4. Using SWM, 9 of 12 of patients treated using Gillies repair had decreased sensation on the injured side of the face, compared with 8 of 12 patients treated using ORIF. Using Mackinnon-Dellon Disk-Criminator, 9 of 12 patients treated using Gillies repair had decreased sensation on the injured side of the face, compared with 8 of 12 patients treated using ORIF. By chi-square analysis, this difference was not statistically significant.

Incidence of negative sequelae of the Gillies procedure and ORIF is presented in table 5.

4. Discussion

Accurate surgical repair of OZC fractures is essential to minimize the unfavourable aesthetic and functional sequelae of this prevalent injury. Controversy exists as to the optimal method of surgical repair. Gillies and ORIF repair of the zygoma are popular methods that remain widely utilized. Proponents of open reduction and internal fixation argue that this method yields superior outcomes because of improved fracture exposure and bone stabilization. Surgeons favouring the Gillies repair claim it produces equivalent results, is easier, and has fewer sequelae from the surgical access. However, minimal objective, reliable data exist to support the use of either technique.

To our knowledge, the present study is the first to assess objective clinical end-points relevant to the repair of OZC fractures. The frequency and severity of negative sequelae were also tabulated. Patients sustaining OZC fractures of the same pattern and severity were recalled to measure anthropometric landmarks and sensory endpoints.

The results demonstrate that ORIF produces superior realignment of the OZC compared to Gillies repair. Zingg has reported that surface facial asymmetry greater than 2 mm is clinically visible.[11] Residual fracture displacements in the ORIF study group demonstrated a measurably decreased OZC projection of 1.4 mm, OZC height of 1.4 mm and OZC lateral position of 1.6 mm when the injured side was compared with the normal side. Since the calculated mean surface topographic difference was less than 2 mm, the ORIF treated group had residual deficits which were clinically insignificant. In contrast, the Gillies treated group had measurable residual mean deficits in OZC projection of 7.5 mm, OZC height of 5.6 mm and OZC lateral position of 4.1 mm, all exceeding the 2 mm threshold for a visible clinical deformity. Consequently, this study is the first to objectively demonstrate that ORIF produces a significantly more symmetrical facial appearance than Gillies repair.

Several reasons may account for the more symmetrical OZC position obtained using ORIF. First, direct fracture exposure allows for visual alignment of the vertical and horizontal buttresses, which determine OZC projection, height, and lateral position. Second, this wide exposure permits better mobilization of the displaced complex and use of a reduction force vector, which is exactly the inverse of that which produced the fracture. Gillies repair limits reduction vector possibilities due to poor OZC control. Third, superior OZC position may be due to greater fracture stability from internal fixation, thus preventing post-reduction displacement secondary to the pull of masseter muscle or subsequent trauma.

No difference in ocular globe projection was detected in either treatment group. This likely represents the selection bias created by excluding injuries involving blowout fractures to the floor of the orbit. This exclusion permitted creation of more uniform and comparable study populations. This process likely selected out an OZC fracture subpopulation who would have had a low incidence of enophthalmos.

Residual sensory deficits occurred in 75% of patients treated using Gillies repair and 67% of patients treated using ORIF. The method of surgical repair did not significantly influence post-traumatic ION dysfunction in this study population.

We have shown that ORIF significantly improved the OZC position when compared to Gillies repair. Persisting surgical sequelae from this method of fracture repair consisted principally of lower lid shortening with increased scleral show, and visible cutaneous scarring at the frontozygomatic buttress. The principal lower lid access used in this series was through the subcilliary incision, the route most frequently associated with lid shortening.[22] This approach is now avoided in favour of the transconjunctival incision. Cutaneous scarring at the frontozygomatic buttress can be minimized by using the upper lid blepharoplasty approach or not exposing the buttress at all, since it is frequently only a pivot point for OZC fractures, without any step-off.

In conclusion, this study is the first to objectively show that open reduction and internal fixation results in precise position of the OZC in treating non-comminuted, moderately displaced fractures of the OZC. Consequently, this surgical technique is less likely to necessitate secondary corrective surgery, which is fraught with difficulties and best avoided. While negative sequelae from lower lid and frontozygomatic buttress accesses was substantial in this population, the recent introduction of transconjunctival and upper lid blepharoplasty incisions may minimize these drawbacks.

We hope this study will continue to encourage the use of ORIF for the treatment of OZC fractures and support the current trend of objective evaluation of surgical outcomes.

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Table 1. Patient disqualification criteria.

Review Step	Disqualification Criteria
Past medical and surgical history	presence of congenital craniofacial anomalies
	presence of previous craniofacial injuries (skeletal or soft tissue) or surgeries
	presence of concurrent fractures of the craniofacial skeleton, other than the OZC fracture
	time interval between fracture and surgery greater than 8 days
	time interval since the surgery of less than 12 months (this interval was chosen as the ION has shown the capacity to regenerate for up to 12 months following traumatic injury (15))
OZC fracture pattern and severity	any fracture pattern and severity, based on pre-operative axial scans (acquisition interval between 1.5 and 3.0 mm) and coronal reformats, other than a unilateral, non-comminuted fracture of the OZC with displacement of the complex of at least 20 mm in the posterior, inferior and lateral directions (2) (moderate energy fractures) (figure 1)
Surgical technique	repair of the OZC using surgical techniques other than Gillies repair or ORIF. Gillies repair was defined as open reduction of the OZC by a temporal insertion of an elevator, without direct visualization of alignment at the fracture sites or fixation. ORIF was defined as reduction and rigid miniplate fixation of the OZC at the frontozygomatic buttress (FZB), infraorbital rim (IOR) and zygomaticomaxillary buttress (ZMB) using cutaneous or mucosal access incisions directly over these sites.
	need for orbital floor reconstruction using autografts or synthetic implants
	need for secondary corrective surgery

Table 2. Differences in post-operative position of the OZC between the injured and non-injured sides of the face, for both Gillies and ORIF treated patients.

OZC position	ORIF		Gillies		p-value
	difference (mm)	SEM	difference (mm)	SEM	
projection	1.4	0.028	7.5	0.051	0.0003
height	1.4	0.028	5.6	0.057	0.01
lateral position	1.6	0.027	4.1	0.050	0.06

Table 3. Difference in ocular globe projection between the injured and non-injured sides of the face for both Gillies and ORIF groups.

Ocular Globe Projection	ORIF		Gillies		p-value
	difference (mm)	SEM	difference (mm)	SEM	
	1.23	0.312	1.09	0.265	0.832

Table 4. Number of patients with decreased sensation in ION distribution, as compared to the non-injured side of the face.

Sensory Test	Number of Patients with Decreased Sensation on Injured Side	
	ORIF	Gillies
Semmes-Weinstein Monofilaments	8/12	9/12
Mackinnon-Dellon Disk-Criminator	8/12	9/12

Table 5. Incidence of Negative Sequelae.

Negative Sequela	ORIF	Gillies	Fisher's test
cutaneous scarring	4/12	0	.093
lid shortening	3/12	0	.217

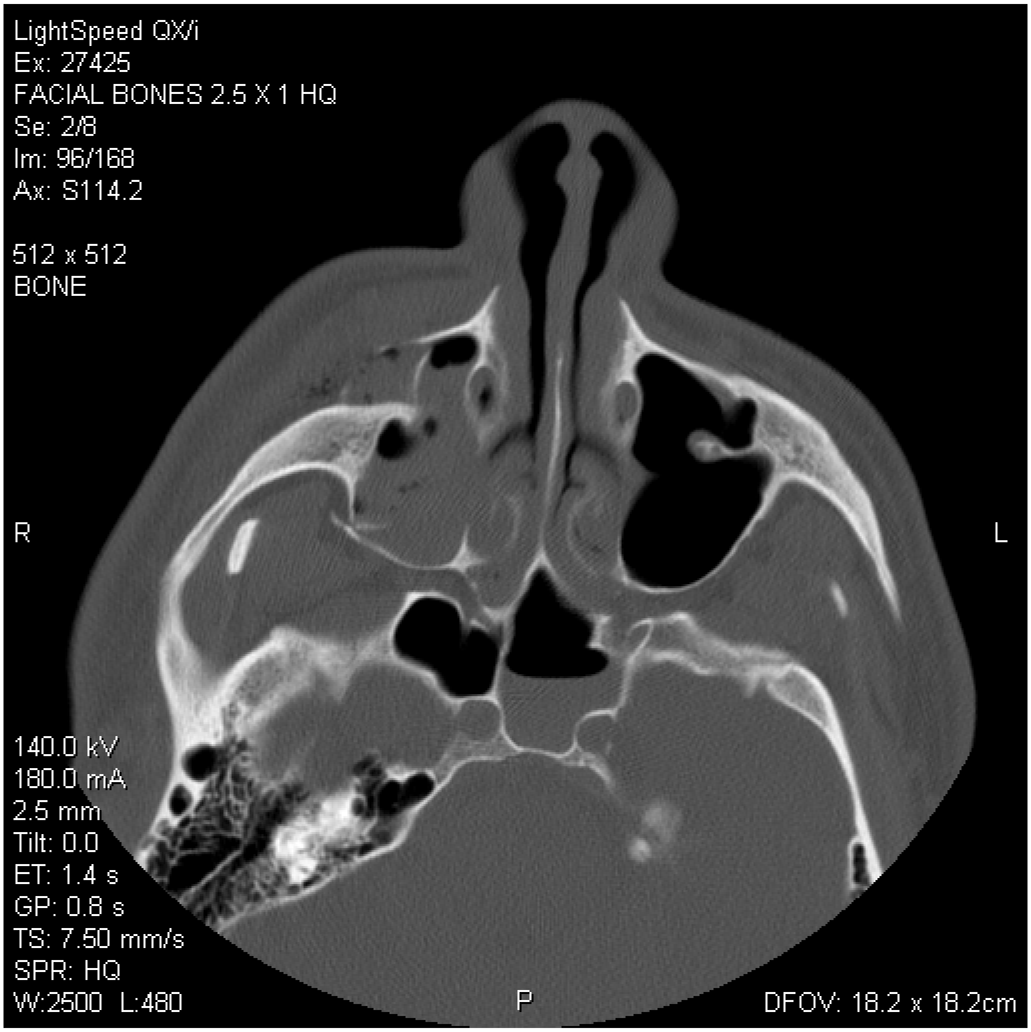
Figure Legends

Figure 1. Pre-operative CT image demonstrating pattern and severity of OZC fracture of the patients included in the study.

Figure 2. Measurement of ocular globe projection using Naugle exophthalmometer.

Figure 3. Worm's view images depicting OZC projection in patients treated using Gillies repair (left) and ORIF (right).

Figure 1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Ex: 27425
FACIAL BONES 2.5 X 1 HQ
Se: 2/8
Im: 96/168
Ax: S114.2
512 x 512
BONE
R
L
140.0 kV
180.0 mA
2.5 mm
Tilt: 0.0
ET: 1.4 s
GP: 0.8 s
TS: 7.50 mm/s
SPR: HQ
W:2500 L:480
P
DFOV: 18.2 x 18.2cm

Figure 2

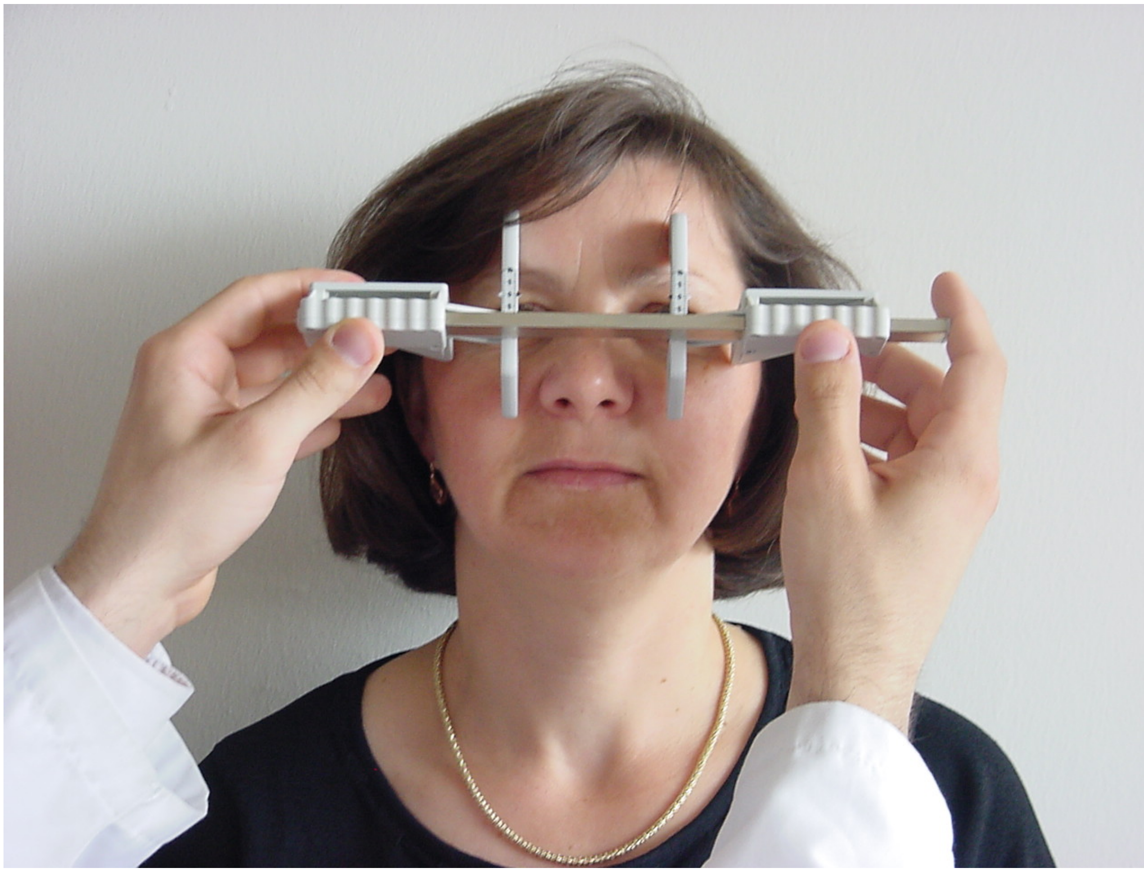
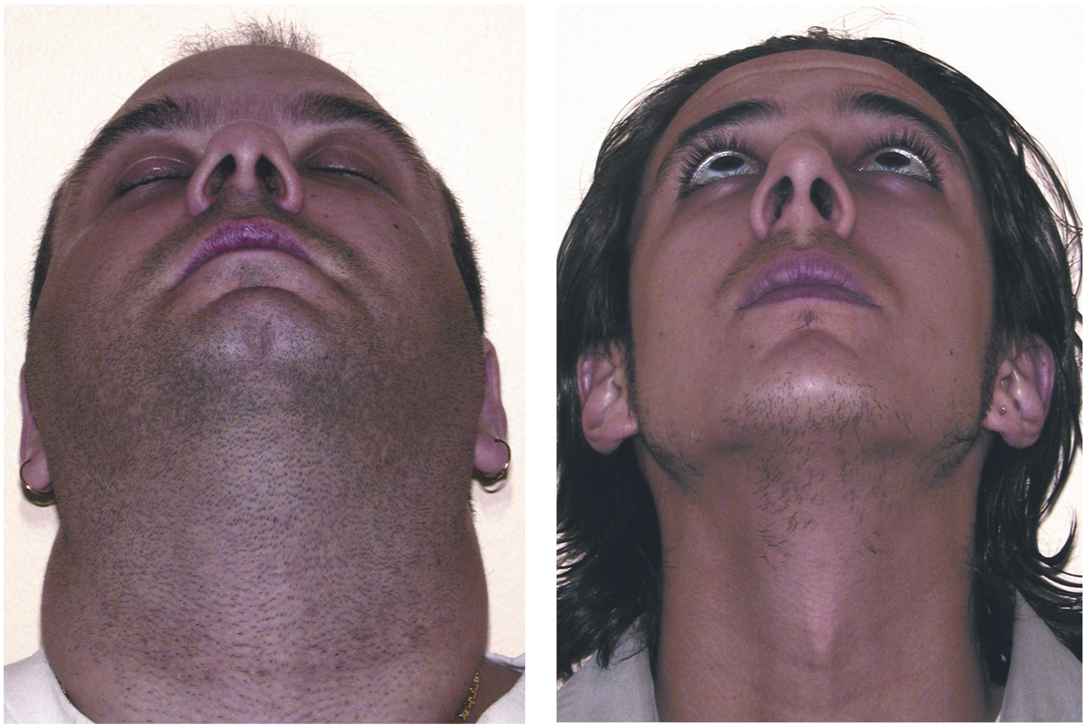


Figure 3.



CONNECTING TEXT 3

MINIMIZING SEQUELAE OF ZYGOMA FRACTURE REPAIR VIA SELECTIVE INCISION USE

Sequelae of open access appear to be the biggest disadvantage of ORIF techniques of zygoma fracture repair. The coronal incision leads to a significant scalp scar with alopecia along it, loss of skin sensation posterior to it and may cause unsightly temporal hollowing and temporal branch of facial nerve injury.[14-16] The lateral orbital rim incision leaves a scar in a highly visible area. The second study of this thesis has identified that in 25% of the cases, exposure of the inferior orbital rim and placement of a plate along it, results in a visible eyelid malposition. This appears to be corroborated by recent literature citing a 7% risk of complications following inferior eyelid exposure for orbital floor fractures.[17] Importantly, this risk appears to be present in any type of lower eyelid incision and can occur even despite a meticulous surgical technique. It is hypothesized to occur due to middle lamellar adhesions. The eyelid malposition may range from mild scleral show to severe ectropion with exposure keratopathy. Once established, it is exceedingly difficult to correct surgically.[29-30]

An improved technique of zygoma fracture repair should thus have the accuracy of open techniques without the need to perform any of the above listed incisions. Incisions are typically performed for assessment of reduction accuracy and/or fixation hardware placement. The inferior eyelid incision may also be placed to assess and/or reconstruct the orbital floor. In our experience, in the majority of cases a fractured zygoma does not lead to a significant orbital floor defect or extra-ocular muscle entrapment, as can be identified on the pre-operative CT and physical examination, respectively. Because in most cases, however, the zygoma is postero-medially displaced, an antero-lateral reduction vector is required and may occultly increase the size of the orbital floor defect past threshold. If this does occur, then routine orbital floor exploration should be performed to prevent the development of ocular globe dystopia and enophthalmos. This has not been previously investigated.

The objective of the third part of this thesis is to determine if zygoma fracture repair causes a significant enlargement of the orbital floor defect and thus if routine floor exploration is needed. If it is not, then this higher risk approach may potentially be avoided in any future technique of zygoma repair.

QUANTITATIVE ANALYSIS OF THE ORBITAL FLOOR DEFECT AFTER ZYGOMA FRACTURE REPAIR

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Abstract:

Background

Moderate-energy zygoma fractures frequently result in a postero-medially displaced bone fragment. Closed reduction using a force vector directed in an antero-lateral direction frequently produces stable repair of these injuries. Exploration of the orbital floor (OF) is not routinely undertaken. However, as the zygoma forms a significant portion of the OF, realignment may create an unrecognized OF defect. Routine OF exploration may be unnecessary and carries the risks of eyelid malposition, scarring and extra-ocular muscle injury. Our goal was to quantitatively describe the effect of zygoma reduction on OF defect size and identify predictors for floor exploration.

Methods

Retrospectively, patients with moderate energy zygoma fractures were identified. Fractures inadequately reduced on the post-operative CT-scan or those which underwent OF exploration were excluded. The sizes of pre-operative and post-operative floor defects from CT-scans were measured. Globe projection was measured. Statistical analysis was performed using student's t-test.

Results

Out of 102 identified patients, 15 satisfied the inclusion criteria. The average pre- and post-operative OF defects measured 0.3 and 0.6 cm^2, respectively. This difference approached statistical significance, but was clinically insignificant except in 1 patient.

Similarly, globe projection was clinically similar between the repaired and unaffected sides, except in the same patient.

Conclusion

In majority, repair of moderate energy zygoma fractures does not clinically significantly increase OF defect or produce enophthalmos. In patients with significant displacement of the zygoma at the level of OF with comminution of floor fragments, the reduction maneuver may create a critical size defect and we believe should be followed by floor exploration.

1. Introduction

A fractured zygoma is most frequently displaced in a posterior and/or medial direction as a result of the traumatic force vector. This displacement occurs through either a translation of the entire bone or rotation of its body around a buttress, commonly the fronto-zygomatic. As the zygoma is displaced, the orbital floor (OF) fractures and causes its segments to displace in one of three patterns. First, the fragments may collapse into the maxillary sinus (figure 1), creating a defect in the OF. Second, severe comminution of the fragments may lead to OF folding in a harmonica-like arrangement (figure 2). Last, the segments may overlap in a telescoping fashion (figure 3). The latter two patterns are almost never associated with an OF defect on the pre-operative CT scan.

Anatomic zygoma realignment requires an antero-laterally directed reduction vector. OF exploration is indicated if there is evidence of extra-ocular muscle entrapment or the OF defect on the pre-operative CT scan equals or exceeds 2 cm^2. The antero-lateral surgical repositioning of the zygoma, however, can theoretically cause the previously comminuted or telescoped OF fragments to fall, creating an unrecognized OF defect. Furthermore, a previously small defect area may be enlarged past the 2 cm^2 threshold. Consequently, the pre-operative CT scan may be undersensitive in detecting all zygoma fractures requiring OF exploration and repair.

The critical size defect of 2cm^2 leads to a 10% increase in orbital volume and to a clinically significant enophthalmos of 3 mm.[1] A thorough review of the literature reveals a 3-4% incidence of enophthalmos in zygoma fracture patients in whom OF exploration was deemed unnecessary.[2,3] Potentially, in a subset of these fractures, an unrecognized critical OF defects were created during repair. This is important because the high incidence of zygoma fractures may result in a significant number of enophthalmos cases. Correction of post-traumatic enophthalmos is challenging, requiring on average 2.6 lengthy surgical procedures.[4,5]

Routine OF exploration can identify all patients who need its repair, but has many disadvantages including ectropion, which may reach 7% even with the transconjunctival approach; entropion; orbital hemorrhage; and extra-ocular muscle injury.[6,7] Given that only a minority of fractured zygoma OF's require exploration based on the current criteria, the additional morbidity that would be imparted to the remaining patients to exclude the potential of enophthalmos development appears unjustified.[8]

The objectives of this study were to identify the effect of zygoma repair on orbital floor defect size in patients who did not have pre-operative indications for OF repair and to correlate the size of the post-operative defect with ocular globe projection. In addition, we wished to determine predictors mandating OF exploration in this subset of patients in order to increase the sensitivity of the current guidelines.

2. Methods

The present study was reviewed and approved by the McGill University Health Centre (MUHC) Research Ethics Committee.

Patients were selected through a retrospective medical record review of all zygoma fracture patients treated at the MUHC hospitals between 2002 and 2007. Demographic data, fracture anatomy and details of the surgical procedure were ascertained from admission forms, CT scans and the operative notes, respectively. Selection criteria included presence of both pre- and post-operative facial CT scans (1.25

mm slice thickness), presence of an isolated, unilateral, moderate energy-type zygoma fracture[9], absence of pre-operative indications for and no OF exploration, and confirmation of accurate zygoma repair.[10]

Accuracy of zygoma realignment was performed by comparison of side-to-side zygoma projection, width and rotation, as visualized on the post-operative axial CT scan. Projection was defined as the distance between the coronal midline and the most anterior point on the zygoma body, width as the distance between the sagittal midline and the most lateral point on the zygoma body. Rotation was defined by the presence of separation or overlap at the level of the sphenozygomatic suture without significant change in zygoma body projection or width. Discrepancy between the repaired and unaffected sides of the face greater than 1 mm in any of the three parameters indicated inaccurate reduction. Only patients with accurate reduction were selected to exclude the confounding effect of zygoma malreduction on OF defect size and orbital volume.

Quantitative end-points included size of OF defect area (pre- and post-operative) and difference in ocular globe projection between the repaired and unaffected sides, and were calculated only on the selected patients. OF defect areas were calculated in two-steps. First, using very accurate CT imaging software (error margin <.1 mm) (Voxel Q, Picker International) OF defect lengths were measured on all slices of coronal reformats of axial CT scans. OF defect was defined as herniation of orbital contents secondary to loss of osseous support. Second, the OF defect area was calculated, knowing the lengths of defects, number of involved slices and slice thickness, using a previously validated formula.[11] Correction for OF convexity was not performed as on the short defect lengths, the OF approximates a straight line rather then a circle. Ocular globe projection was measured using the Naugle exophthalmometer (figure 4). This instrument measures the position of the corneal apex with reference to the superior orbital rims and thus is more accurate than the commonly used Hertel exophthalmometer in zygoma fracture patients.[12] Residual post-operative enophthalmos was defined as the difference in ocular globe projection between the repaired and non-injured sides of the face.

Statistical analyses of differences between pre- and post-operative OF defect areas and of differences in globe projection between repaired and unaffected facial sides were performed using one-tailed students t-tests. Statistical significance was chosen as $p \leq .05$.

3. Results

In total, 102 patients with zygoma fractures were identified, of whom 15 fulfilled the selection criteria. The mean age of selected patients was 40.6 years; all were male, mechanisms of injury included assault (8 patients), falls (6 patients) and motor vehicle collision (1 patient). Mean duration of patient follow-up from injury to time of study measurements was 28 months. Most of the patients underwent reduction using a Gillie's-type closed technique. Plating was performed in some, at the zygomaticomaxillary (5) and the frontozygomatic (1) buttresses.

Measurements of pre- and post-operative OF defect areas are presented in table 1. The mean pre- and post-operative OF defect sizes were .3 cm^2 and .55 cm^2, respectively. This increase in size approached statistical significance, $p = .07$. Clinical significance, however, was only reached in patient # 13, in whom the OF defect increased from .5 cm^2 to 2.5cm^2.

Data describing differences in ocular globe projection between the repaired and non-injured sides of the face are presented in figure 5. Mean globe projection on the non-injured side was 11.8 mm, versus 11.3 mm on the repaired side. This decrease was statistically significant, $p = .026$. Clinically significant enophthalmos of 2 mm was only found in patient #13.

Analysis of the fracture pattern in patient # 9 revealed the presence of significant postero-medial translation at the level of the inferior orbital rim and OF, with comminution and harmonica-like folding of the OF fragments (figure 6). Other fractured zygomas were displaced as a result of rotation around the frontozygomatic buttress, or due to small translational movements of the entire bone with ensuing small displacement of the OF.

4. Discussion

Moderate energy trauma to the cheek region frequently results in a fracture of the zygoma with its displacement in a postero-medial direction. Repair necessarily requires "pushing" the bone frontward and out and potentially creates a defect in the floor of the orbit. Because the current criteria for OF exploration are based on the pre-operative CT scan, significant OF defects potentially created by zygoma realignment will be unrecognized. Failure to repair an OF defect greater than 2 cm^2 results in enophthalmos, the repair of which is challenging and frequently unsuccessful. Routine OF exploration to prevent the potential complication, however, is unjustified due to surgical morbidity.

This is the first quantitative study assessing the effect of zygoma reduction on the internal orbit. Ellis et al previously studied 67 patients with repaired zygoma fractures and did not find an increase in the OF defect.[13] Their study provided great initial insight, but lacked uniform patient selection, floor area measurements and statistical analysis.

Our results demonstrate that there is an increase in OF defect area caused by the operative reduction of a zygoma fracture. The increase in defect size correlates with a decrease in globe projection. Both measurements reach statistical significance, but are not clinically significant in the majority of the studied patients.[14/15]

One individual with a small pre-operative OF defect developed a clinically important disruption of the floor measuring 2.5 cm^2 and consequent 2 mm of enophthalmos. Here, the injuring mechanism translated the zygoma postero-medially with significant displacement at the level of the inferior orbital rim and OF with comminution and folding of its segments (figure 6). Reduction to pre-operative position required a large movement at the level of the floor with subsequent sagging of the comminuted segments into the maxillary sinus and loss of ocular globe support (figure 7). In patients where the OF fragments were displaced in an overlapping fashion, a similar magnitude of reduction movement did not produce a significant defect after the floor fragments slid into position. In other zygoma fractures without significant displacement at the level of the floor (small posteromedial translations, rotations around the frontozygomatic buttress which cause most of the shift to occur at the zygomaticomaxillary buttress level) the amount of movement at OF level required to restore zygoma anatomy was small. Consequently, in the latter patients, fracture realignment did open a small defect which was, however, still clinically insignificant.

Our results have direct influence on operative decisions. We believe that most moderate energy zygoma injuries without pre-operative indications for OF exploration do not need the procedure after the zygoma is replaced to its pre-morbid position. Patients with large, but not critical, defects should undergo OF exploration as the reduction will likely push the size of the defect past threshold. Last, patients with significant displacement at the level of the inferior orbital rim and thus the OF, especially with concomitant OF comminution, should be carefully analyzed, as the only such patient in this study developed significant enophthalmos due to loss of floor support. Before further recommendations are outlined for this patient subset, more work remains to be done.

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Table 1. Measurements of pre- and post-operative orbital floor (OF) defect areas

Patient Number	Pre-Operative OF Defect	Post-Operative OF Defect
1	0.44	1.73
2	0.67	0.9
3	0.05	0.22
4	0.74	0.26
5	0.35	0.26
6	0.27	0.26
7	0.12	0.17
8	0.26	0.31
9	0	0.38
10	0	0
11	0.73	0.98
12	0.39	0
13	0.50	2.50
14	0	0.19
15	0.16	0.12
SEM	0.07	0.16
t-test		0.07 *

* One-tailed P value equals 0.07.

Legends

Figure 1. Orbital floor fracture demonstrating fragments collapsing into the maxillary sinus

Figure 2. Orbital floor fracture with severe comminution of the fragments which lead to the floor folding in a harmonica-like arrangement

Figure 3. Orbital floor with segments overlaping in a telescoping fashion

Figure 4. Ocular globe projection being measured by the Naugle exophthalmometer

Figure 5. Data demonstrating the differences in ocular globe projection between the repaired and non-injured sides of the face in mm^2

Figure 6. Pre-operative CT scan of patient 9 with the injuring mechanism displacing the zygoma postero-medially. Significant displacement at the level of the inferior orbital rim and the orbital floor with comminution and folding of its segments is observed

Figure 7. Post-operative CT of the same patient demonstrating accurate realignment at the level of the inferior orbital rim but sagging of the floor fragments into the maxillary sinus causing loss of ocular globe support.

Figure 1

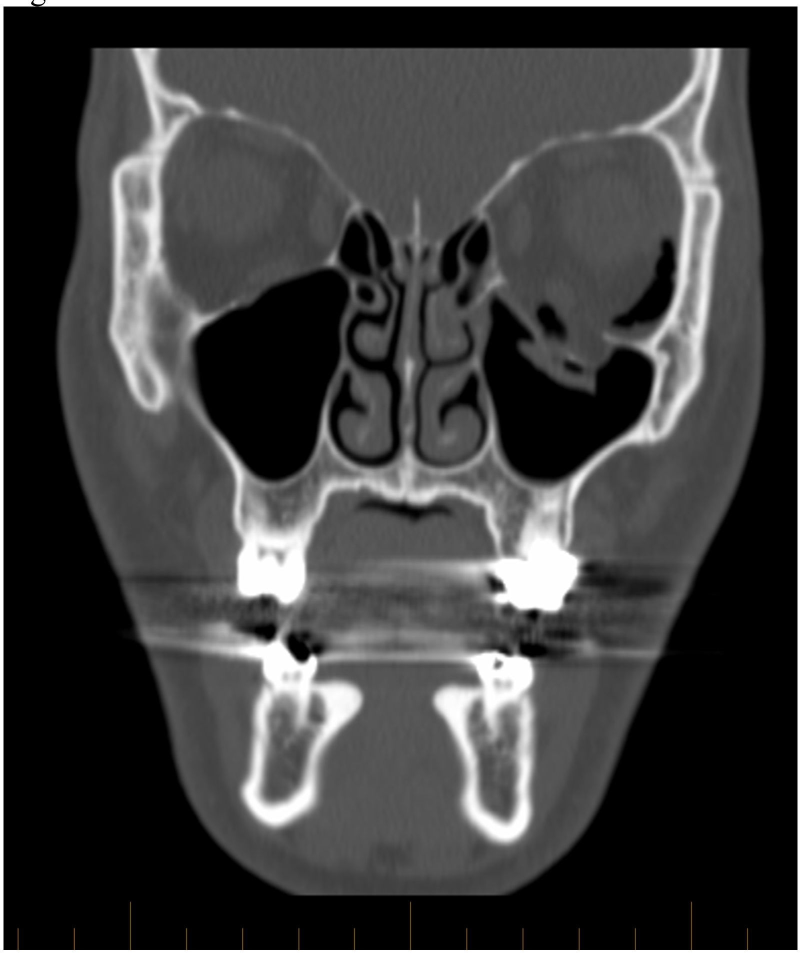


Figure 2

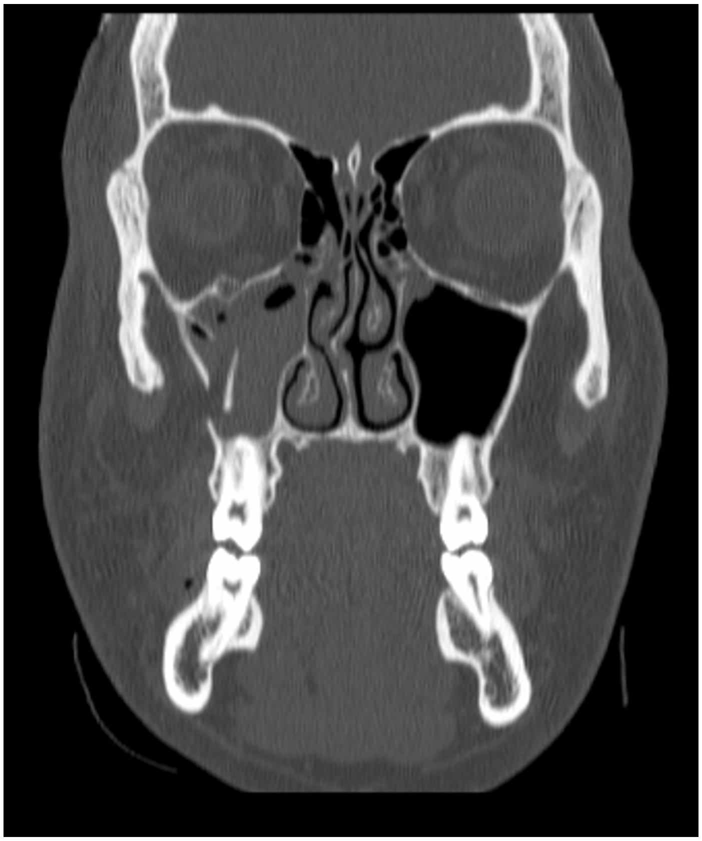


Figure 3

Figure 4

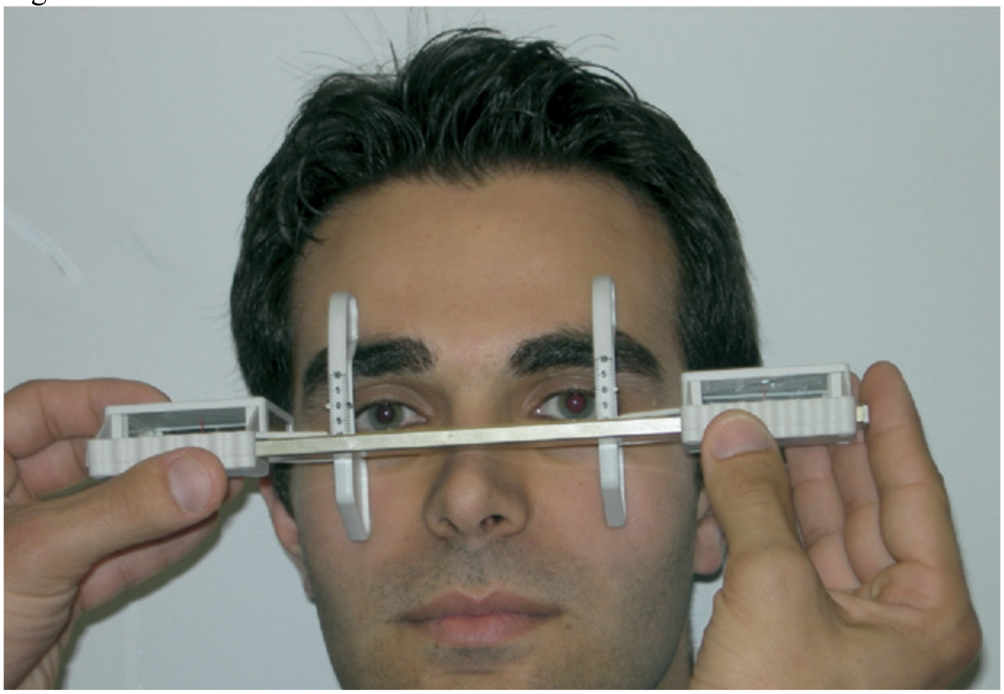


Figure 5

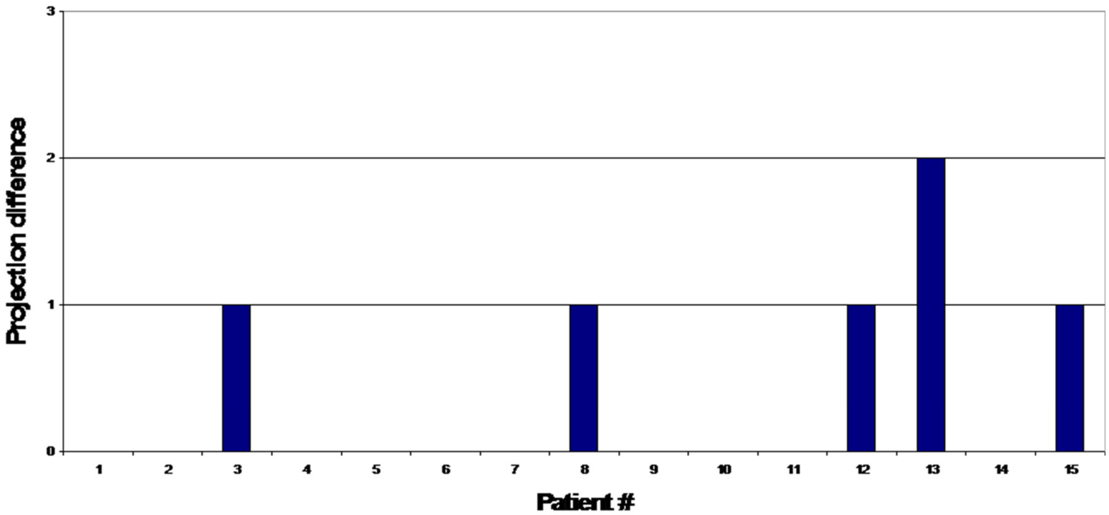

Projection difference
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Patient #

Figure 6

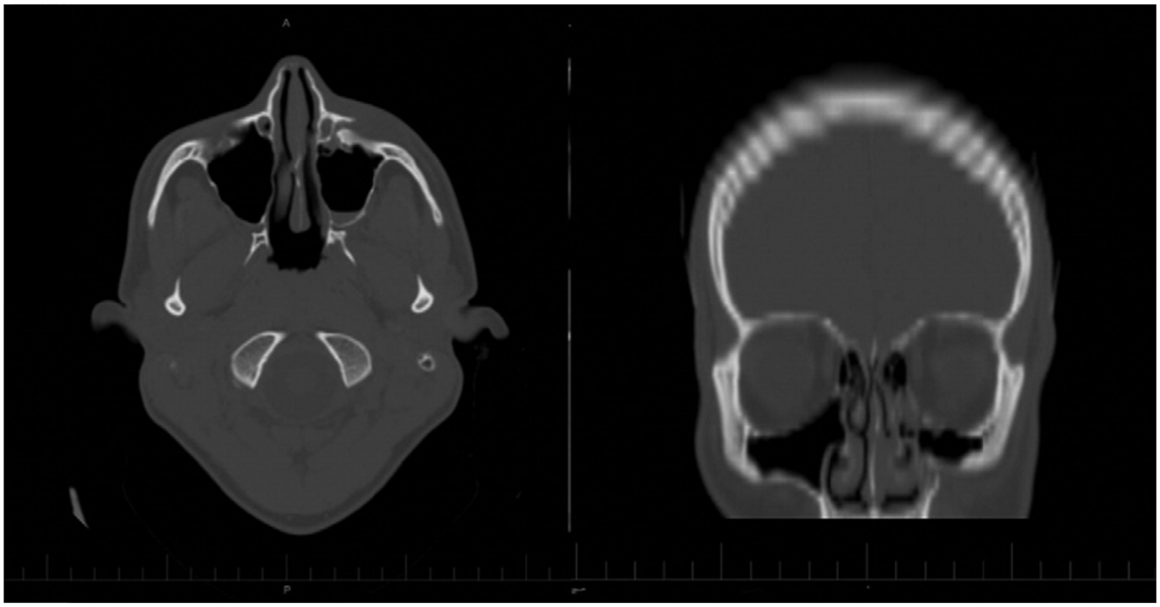
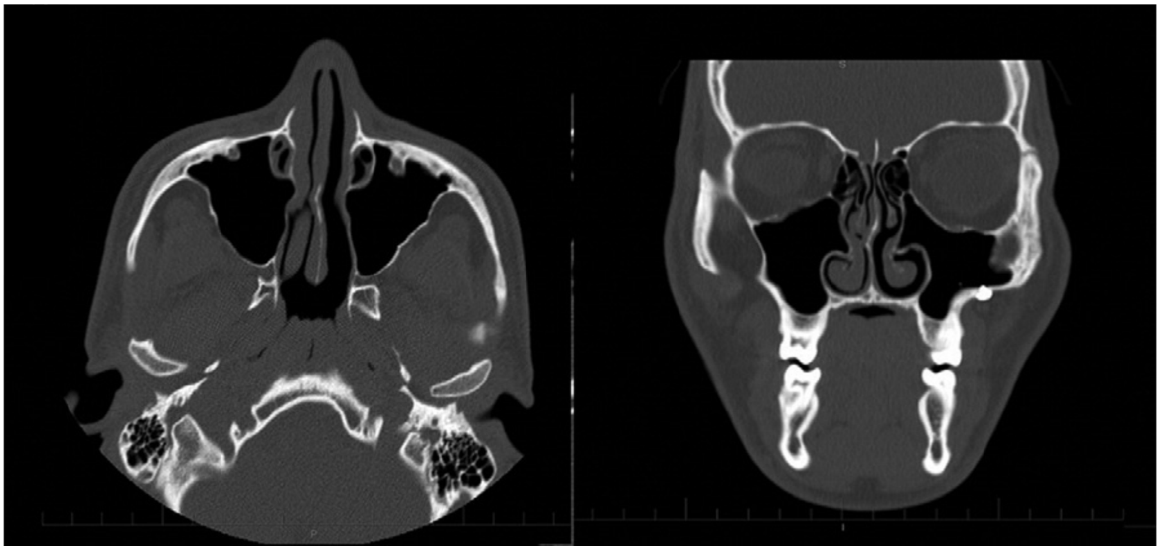


Figure 7



CONNECTING TEXT 4

RATIONALE FOR THE USE OF RADIOGRAPHY TO IMPROVE OUTCOMES OF ZYGOMA FRACTURE REPAIRS

The ability to visualize the fractured bony fragments is important for accurate re-alignment. Visualization may be performed in one of 3 ways: direct exposure, endoscopic-assisted exposure and radiographic imaging. Fracture interfaces that provide the most useful information for accurate zygoma realignment include the sphenozygomatic suture, zygomatic arch and zygomatico-maxillary buttress.[31-35]

The sphenozygomatic suture may be exposed via an inferior eyelid incision with canthotomy and cantholysis, or via a coronal approach. The zygomatic arch exposure requires a coronal incision. Prior work has shown both of these approaches to have a significant risk of negative sequelae.[14-16] The zygomatico-maxillary buttress may be exposed through the upper buccal sulcus, an access site that is relatively innocuous. This interface is theoretically important for accurate reduction. In practice, however, its frequent comminution limits its usefulness as a sole guide to the realignment of the entire zygoma.

The endoscope has been introduced to explore the orbital floor and zygomatic arch through small, inconspicuously located incisions. This technique has not gained widespread popularity for these applications due to a steep learning curve, additional operative time, and limited information.[36-39]

Intra-operative radiography can be used to visualize fracture sites most important for appropriate reduction of the entire zygoma without their direct surgical exposure, thus limiting negative sequelae.[40] Intra-operative computed tomography and c-arm imaging are the two modalities that have been used most often in surgery. CT provides the most detail, but at the expense of significant radiation, added operative time and financial costs. Furthermore, not many surgery facilities possess mobile CT scanners. C-arms, on the other hand, are widely available, inexpensive, easy and fast to use and potentially use lower doses of radiation. On average, a maxillofacial CT uses 200-300 mA as compared to 1-2mA for a low dose c-arm image, representing a 100-300 fold reduction in radiation dose.

The objective of the fourth study of this thesis is to identify intra-operative c-arm views which could be used to visualize the zygoma and test the accuracy of these views at repositioning the zygoma following a fracture in cadaver specimens.

RAPID INTRA-OPERATIVE ZYGOMA FRACTURE IMAGING

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Abstract

Background:

A fractured zygoma frequently results in an aesthetically displeasing facial asymmetry. Open reduction and internal fixation may accurately realign the facial skeleton but often with undesirable sequelae of open access and hardware placement. Our objective was to develop a precise technique of intra-operative zygoma fracture imaging using a c-arm to permit anatomic fracture realignment while reducing the extent of skeletal exposure required. The simplicity and accessibility of this method should allow its widespread clinical application.

Methods:

First, using a model skull, the relative positions of the c-arm required to adequately depict zygoma projection, width, arch contour and zygoma rotation were defined. Second, diverse zygoma fracture types were created in 6 cadaver heads with a Mini Bionix machine, repaired using c-arm guidance and accuracy confirmed with post-operative CT. Third, after defining optimal OR setup, the accuracy in a clinical case was assessed. In the cadaver and clinical cases, OR duration was noted.

Results:

Two C-arm views were defined. The zygoma projection view, in which the C-arm is at 70-90° to skull's coronal plane, allows visualization of projection, width, and contour. The rotation view, in which the C-arm is at 70-90° to skull's sagittal plane, allows visualization of zygoma rotation. Post-operative CT imaging confirmed anatomic repair in all cadaver and clinical cases. Average OR duration was less than 30 minutes, with OR times decreasing with each subsequent surgery.

Conclusions:

We have developed an accurate technique of intra-operative zygoma fracture imaging and reduction guidance. This technique may decrease the risks of open access by potentially limiting direct skeletal exposure to buttresses where skeletal stabilization is required. In addition, this method is simple and rapid to learn and use and readily accessible in most hospitals.

1. Introduction

The zygoma is the second most frequently fractured bone of the craniofacial skeleton.[1] Low energy injuries result in its separation at the articulating buttresses and minor displacement. Moderate and high energy injuries lead to increasing displacement and comminution. Fracture sequelae parallel trauma severity and include: facial asymmetry, enophthalmos and ocular globe dystopia.

Surgical repair techniques are those of traditional non-visualized reduction or more modern open reduction and internal fixation (ORIF). The non-visualized reduction techniques involve: 1. accessing the zygoma through a small incision either behind the temporal hairline (Gillies), directly on the cheek (Carroll-Girard) or in the upper buccal sulcus (Keen) and 2. its reduction using an instrument placed underneath its body. Realignment is achieved without direct skeletal visualization and relies on transcutaneous buttress palpation, external appearance of the cheek prominence or the presence of an auditory click. Actual confirmation of reduction is reliant upon post-operative CT imaging. ORIF involves exposure and reduction of the zygoma through a combination of buccal sulcus, lower and upper eyelid and coronal approaches in addition to miniplate fixation of at least two to three of the buttresses.

We previously reported on the objective outcomes between these two zygoma fracture repair methods,[2] demonstrating that each has disadvantages. ORIF produces superior realignment of the zygoma but often leads to undesirable sequelae related to open access (visible scars, eyelid malposition, scalp anaesthesia, temporal hollowing) and hardware placement (pain, palpability, exposure). Increasing degrees of zygoma comminution and displacement demand greater exposure in order to fully visualize repair accuracy, with correspondingly greater potential for negative sequelae. The Gillies' technique does not leave any surgical stigmata but may lead to an increased number of complex secondary reconstructive procedures due to its inferior accuracy. Consequently, currently ORIF is the presumed state of the art repair option.

Many technical adjustments have been developed to minimize the negative sequelae of ORIF. These may be divided into two categories, minimizing the complications of open access and those of rigid fixation. Techniques used to lessen the morbidity of open access include: using a lesser number of incisions and placing them in aesthetically inconspicuous locations, using endoscope-assisted repair and anatomically restoring and supporting the dissected soft-tissue envelope. Techniques of intra-operative fracture imaging, may also limit the extent of required direct skeletal exposure while permitting a high degree of reduction accuracy. Several methods of intra-operative zygoma imaging have been described.[3-9] The clinical application of these techniques has been limited; however, due to limited skeletal visualization (c-arm techniques), technical difficulty (ultrasound techniques), high costs, prolonged operative time and limited equipment availability (intra-operative CT techniques).

Our objective was to develop a novel technique of intra-operative zygoma imaging using a c-arm. This technique should be accurate in demonstrating zygoma fracture anatomy and in aiding the restoration of pre-injury facial symmetry, potentially decreasing the need for extensive zygoma exposure. Furthermore, this method should be fast and easy to learn and to use in order to facilitate its widespread clinical application. The nearly ubiquitous presence of c-arms in hospitals should significantly reduce costs. Our study was divided into three components. First, in the anatomical study, C-arm views and settings required to visualize the zygoma were delineated. Second, in the cadaver study, the accuracy of the technique was confirmed. Last, using a clinical case, intra-operative feasibility of the technique and its accuracy were assessed.

2. Anatomical Study

The purpose of this component of the study was to: 1. determine optimal C-arm positions to accurately visualize the zygoma, 2. identify C-arm settings to allow for best skeletal definition.

2.1 Methods

In an operating theater the following materials were used: GE OEM 9800 C-arm, soft-tissue stripped cadaver skull (model skull), and a custom fabricated radiolucent skull holder. The model skull was positioned within the holder such that the Frankfort Horizontal line was at 90 degrees to the base of the holder. The skull was secured with 2 45mm long titanium screws on each side (Fig 1). Various positions and settings of the C-arm were investigated to allow for accurate zygoma imaging.

2.2 Results

Two C-arm views were identified. We have named these the zygoma projection view and the zygoma rotation view. The views are at 90 degrees to each other, allowing for three-dimensional visualization.

The zygoma projection view was achieved by placing the axis of the C-arm at 70-90° to model skull's coronal plane and at 0° to model skull's sagittal plane. The xray generator was positioned caudally and the image intensifier cranially, allowing for the diverging xrays to project the zygoma body and arches beyond the calvarium. The skull is initially positioned in the Frankfort horizontal and then hyper-extended until the zygoma projects above the supraorbital rim. Using this view, accurate assessment of zygoma projection, width and arch contour, in addition to comparison with the contralateral unaffected side for symmetry, could be made (Fig 1A).

The zygoma rotation view was achieved by placing the C-arm axis at 70-90° to model skull's sagittal plane and at 0° to the model skull's coronal plane. The skull half on the side of the xray generator is higher on the resultant image. The image obtained allowed for visualization of the lateral orbital rims which normally are parallel, enabling detection of zygoma rotation around the axis of its body. In addition, the frontozygomatic suture can be seen (Fig. 1B).

The following manual C-arm settings were deemed optimal: power at the 50-65 kV range and current at the 1-2 mA range. The image can be further enhanced by collimation. Automatic C-arm setting is inappropriate as the C-arm increases the kV output to transmit xrays through the dense cerebrum, consequently whitening out the craniofacial skeleton. Thus, initial automated settings must be adjusted. The ideal monitor output settings include: 0 contrast, <1/3 maximal brightness. Table 1 identifies the optimal C-arm parameters, angulations, and patient positioning.

3. Cadaver Study

The purpose of this component of the study was to demonstrate, using a cadaver zygoma fracture model, the accuracy of the C-arm assisted technique.

3.1 Methods

Six formaldehyde preserved human heads were obtained. The cadaver heads were mounted in a custom fabricated stainless steel head holder and a right sided zygoma fracture was created in each head using a 858 Mini Bionix machine (MTS Systems Corporation, MN) Two force vector directions were used: straight anterior to posterior (Fig 2A) and anterior to postero-medial (45° to sagittal plane) (Fig 2B). Three magnitudes of displacement were created: 1.5 cm, 2.0 cm, and 2.5 cm. In total, six types of zygoma fractures were created, reflecting a wide spectrum of fracture pattern and energy.

Skulls were then re-mounted on the radiolucent head holder as previously described. Pre-operative axial (0.625mm slice thickness) CT scans were obtained for each cadaver head. Subsequently, the skulls were taken to the operating room. The set-up used is shown schematically in figure 8. Using C-arm positions and settings determined in the Anatomical Study, pre-operative projection and rotation views of the zygoma were obtained. The C-arm was then moved-out to the side by several inches to facilitate the surgeon's access to the patient. Fracture reductions were performed by placing a Bristow elevator underneath the zygoma body through an incision behind the temporal hairline (Fig 3). Using the buried end of the elevator as a lever arm, the fingers of one hand as the axis of rotation and the other hand as a force applier, the zygoma body was moved in an antero-lateral direction. Post-reduction, the C-arm was moved-back-in, and projection and rotation views were obtained. On the projection view, zygoma body projection and width and zygomatic arch contour were assessed and compared to the contralateral uninjured side. The rotation view was assessed for angulation of the two lateral orbital rims as well as separation at the fronto-zygomatic suture. If these showed inaccurate zygoma alignment, the C-arm was moved-out to the side again and the reduction maneuver was repeated. The time of the procedure and the number of audible clicks during reduction were documented. Post-operative axial (0.625mm slice thickness) CT scans were obtained to assess accuracy of the repair.

3.2 Results

In all cases, anatomic zygoma fracture repair was achieved with accurate restoration of zygoma projection, width and arch contour. Figures 4 and 5 show pre- and post-operative CT scans of all cadaver zygoma fracture cases. Figure 6 (anterior to postero-medial vector, 1.5 cm displacement) shows representative intra-operative C-arm projection and rotation views pre and post-reduction.

The average time of fracture repair was approximately 10 minutes. The total time required for operative set-up, reduction with pre and post C-arm images was less than 30 minutes. The number of audible clicks during reduction differed among skulls from one to three.

4. Clinical Case

The purpose of this component of the study was to demonstrate feasibility and accuracy of our technique in a real clinical scenario.

4.1 Methods

Figure 7 demonstrates pre-operative CT scan of a right moderate energy zygoma fracture in a 30 year old male who sustained the injury in a football game.

Using the C-arm assisted technique presented in the Cadaver Study the patient's zygoma fracture was reduced. Post-reduction the fractured was deemed stable (due to relatively small extent of comminution) and thus no fixation was used. Operating room set-up used is shown schematically in Figure 8. C-arm positions and settings were the same as used in the Anatomical Study.

Immediate post-operative CT scan was performed. The patient was instructed to avoid pressure on the right side of the face, as well as hard foods, for four weeks. A six week post-operative CT scan was performed to confirm stability of the repair.

4.2 Results

Both immediate and 6 weeks post-operative CT scans demonstrated nearly anatomic fracture repair (Fig 7). Figure 9 shows intra-operative C-arm zygoma views.

5. Discussion

Late complications of zygoma fracture repair result from either exposure sequelae or inadequate reduction and/or fixation. Facial scarring, eyelid malposition and symptomatic hardware are not trivial. Malunion with resultant facial asymmetry and globe malposition are significantly more problematic and may require osteotomies, repositioning, and bone grafting.[10,11]

The techniques of zygoma ORIF have significantly improved our ability to achieve anatomic reduction and stable fixation. Since the original description, modifications have been developed to minimize the sequelae of wide-open access while preserving a high degree of repair accuracy, namely: placing a smaller number of inconspicuous incisions, using endoscope-assisted repair and restoring the anatomy of the disrupted soft tissue envelope. Intra-operative fracture imaging may further aid in decreasing the extent of exposure required, but has not gained widespread clinical acceptance. Thus far, the most accurate technique of intra-operative zygoma fracture imaging has been through the use of mobile computerized tomography. This scanner, however, is not widely available and costly (the price of Mayfield Scanmate™ is 200,000 USD) to purchase. Furthermore, the technique is cumbersome to apply: in the 1 published series, each patient required 1-2 scans to confirm accurate head positioning (15-65 mins) and then 1-3 scans to confirm accurate repair (15-45 mins). This significantly raises the operative time and more importantly increases the radiation exposure to the patient (200-300 mAs each CT scan).[9,12] Intra-operative zygoma fracture ultrasonography has also been described; its accuracy approaches 85% but drops below 80% with increasing facial edema. Ultrasound equipment is not widely available in operating rooms, and its purchase costly. The technique has a steep learning curve and the images are very difficult to interpret in fractures not isolated to the zygomatic arch.[5-8] Until now, in facial trauma, intra-operative plain roentgenography has been limited to the zygomatic arch. C-arms, however, are available in nearly all trauma hospitals operating rooms, are relatively easy to use and emit a low dose of radiation. This modality, thus, represented an area of significant potential.[3, 4]

We have developed a novel technique of intra-operative zygoma imaging and fracture reduction guidance using a c-arm. First, using a model skull we defined two new c-arm views (zygoma projection, zygoma rotation) which permit accurate depiction of zygoma projection, width, arch contour and zygoma rotation. The inherent bilaterality of the views allows comparison to the uninjured side of the face for symmetry. Second, using the above views, we repaired a wide spectrum of cadaver zygoma fractures. Post-operative CT imaging uniformly confirmed anatomic reduction. Third, after defining optimal OR setup, we performed a clinical case of a moderate energy zygoma fracture. Immediate and six week post-operative CT scans demonstrated anatomic fracture repair.

We have shown that this intra-operative imaging technique is valuable in demonstrating zygoma fracture anatomy and guiding its accurate reduction. All cadaver (6/6) and clinical (1/1) cases demonstrated anatomic fracture realignment on post-operative CT scans without direct skeletal visualization at surgery. Thus this technique may potentially decrease the extent of exposure required, limiting it to only those buttresses where stabilization is desired. As a first example, in low energy injuries where small amount of comminution is present at anterior buttresses only, the C-arm technique may potentially be used without any direct exposure or with exposure and fixation at the zygomatico-maxillary buttress only (low-morbidity). As a second example, in moderate energy fractures where the zygomatic arch must be visualized for reduction due to extensive comminution at the anterior buttresses, this can be effectuated using the C-arm avoiding the need for coronal exposure and its associated drawbacks, and allowing fixation at the anterior buttresses only. In fractures where the orbital floor defect is clinically insignificant, the reduction maneuver does not significantly increase the defect size and thus floor exploration is unnecessary.[13,14] In those with a clinically significant defect, the zygoma may potentially be reduced using the C-arm technique, the orbital floor may be explored via a transconjunctival incision and fixation placed at the infra-orbital rim, if necessary depending on the extent of comminution. Currently, however, our clinical experience with this technique is limited and more cases must be performed in order to better clarify its indications. In addition, the technique is fast and simple: each of the cadaver and clinical cases took less than 30 minutes to complete and no radiology technicians were needed.

We believe this technique is more accurate than single-incision approaches to zygoma reduction and fixation (for example: upper buccal sulcus), as it allows visualization of three zygomatic buttresses (frontozygomatic, infraorbital, zygomatic arch) which are located on three different axes (x, y, z). This permits the surgeon to visualize and correct the position of the entire zygoma in three dimensions by controlling all six types of movements (three translational, three rotational).[6] This, by definition, may not be accomplished when looking at only one or even two of the buttresses.

Although this technique is very simple, there exists a learning curve in the initial c-arm adjustment and recognition of skeletal anatomy. After two to three cases, however, the method can be used effectively with short operating times and minimal adjustments. More important are its potential patient benefits: less invasive facial skeleton exposure through a more limited number of incisions while anatomically restoring pre-injury facial anatomy and minimizing the duration of the general anaesthesia. Future directions include outcomes measures of the technique in a clinical series.

6. **References**

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Table 1.

View	Zygoma Projection	Zygoma Rotation
C-arm Parameters	Current: 1-2 mA Power: 50-65 kV, lower by decrements of 2 as needed Collimation as needed Contrast Level 0 Brightness 1/3 Maximal Intensity	Current 1-2: mA Power: 50-65 kV, lower by decrements of 2 as needed Collimation as needed Contrast Level 0 Brightness 1/3 Maximal Intensity
C-arm Positioning and Angulation	C-arm Base to side opposite the fracture Monitor to side of fracture Xray generator caudally Image intensifier cranially **C-arm 70-90° to skull's coronal plane** **C-arm 0° to skull's sagittal plane** Laser guide passes parallel to zygoma projection	C-arm Base to side opposite the fracture Monitor to side of fracture Xray generator to side opposite the fracture (places non-fractured side higher on the resultant image) Image intensifier to side of the fracture **C-arm 70-90° to skull's sagittal plane** **C-arm 0° to skull's coronal plane** Laser guide passes through lateral orbital wall of fractured side Increase the angle away from the horizontal until both rims non-overlapping and visible
Patient Positioning	Supine Initial head positioned in Frankfort horizontal Hyperextend neck as needed until cheek prominence is anterior to supra-orbital rims	Supine Head positioned in Frankfort horizontal

Figure Legends

Figure 1A. C-arm positioning to achieve the zygoma projection view at 70-90° to skull's coronal plane and 0° to skull's sagittal plane so that the laser guide beam passes parallel to the affected zygoma projection. The corresponding image is shown allowing for comparison of malar projection, arch width, contour and asymmetry between sides.

Figure 1B. C-arm positioning to achieve the zygoma rotation view at 70-90° to skull's sagittal plane and 0° to skull's coronal plane. The corresponding image is shown allowing visualization of parallelism between lateral orbital rims.

Figure 2. Unilateral right sided zygoma fractures were created in cadaver skulls using an 858 Mini Bionix (MTS Systems Corporation, MN). The force was directed in an **A)** anterior to posterior or **B)** anterior to postero-medial directions.

Figure 3. Positioning of the Bristow elevator beneath the zygoma body visualized using C-arm.

Figure 4. Pre-operative and post-operative thin cut axial CT scans of anterior to posterior displaced right unilateral zygoma fractures in 3 cadaver skulls demonstrate the accuracy of fracture reduction using the C-arm guided Gillies' technique. The cadaver skulls were subjected to increasing force to achieve 1.5 cm, 2.0 cm, and 2.5 cm of displacement from left to right columns.

Figure 5. Pre-operative and post-operative thin cut axial CT scans of anterior to postero-medially displaced right unilateral zygoma fractures in 3 cadaver skulls demonstrate the accuracy of fracture reduction using the C-arm guided Gillies' technique. The cadaver

skulls were subjected to increasing force to achieve 1.5 cm, 2.0 cm, and 2.5 cm of displacement from left to right columns.

Figure 6. Pre-operative (**upper row**) C-arm zygoma projection (**left**) and zygoma rotation (**right**) images in a representative cadaver skull (anterior to postero-medial vector, 1.5 cm displacement). Note the asymmetry in malar projection, facial width, and arch contour between the affected right side and non-affected left on the pre-operative projection views and loss of lateral orbital rim parallelism on the rotation views. Post-reduction (**lower row**) zygoma projection and rotation images demonstrate re-established malar and arch symmetry as well as parallel lateral orbital rims.

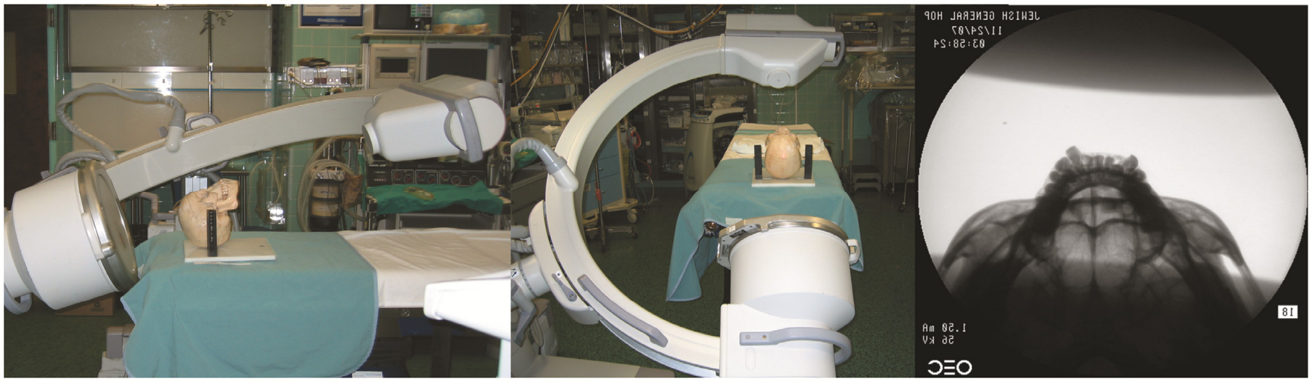
Figure 7. Pre-operative (**top row**) thin cut axial CT scans of the right unilateral zygoma fracture at the level of the zygomatic arch (**left column**), malar projection (**middle column**) and spheno-zygomatic suture (**right column**) in our clinical case. Immediate post-operative corresponding CT images (**2nd row**) and at 6 weeks axial (**3rd row**) and coronal (**4th row**) demonstrate the accuracy of fracture reduction and its stability using the C-arm guided Gillies' technique.

Figure 8. Schematic diagram depicting ideal operating theatre positioning of patient, anaesthesia equipment, C-arm components and personnel for ease of use and efficiency. The set-up depicted is for a right sided zygoma fracture.

Figure 9. Clinical case pre-operative C-arm zygoma projection image on the left. Note the asymmetry in malar projection, facial width, and arch contour between the affected right side and non-affected left zygoma. Post-reduction zygoma projection right image demonstrates re-established malar and arch symmetry.

Figure 1

A.



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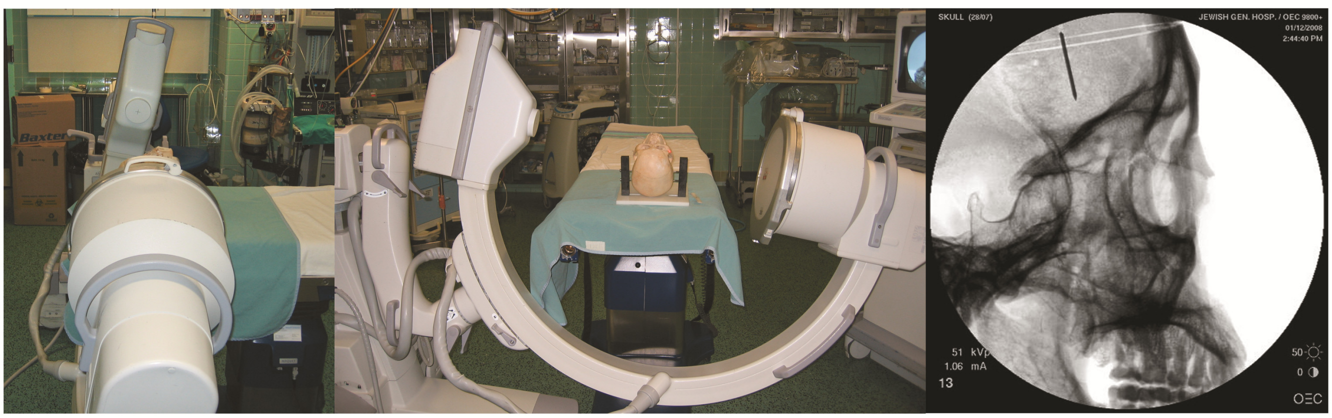
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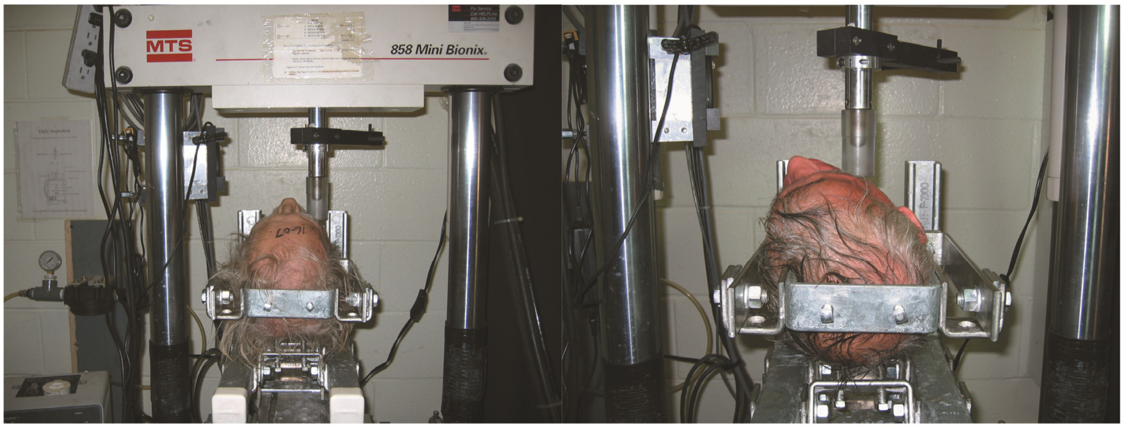
Figure 2



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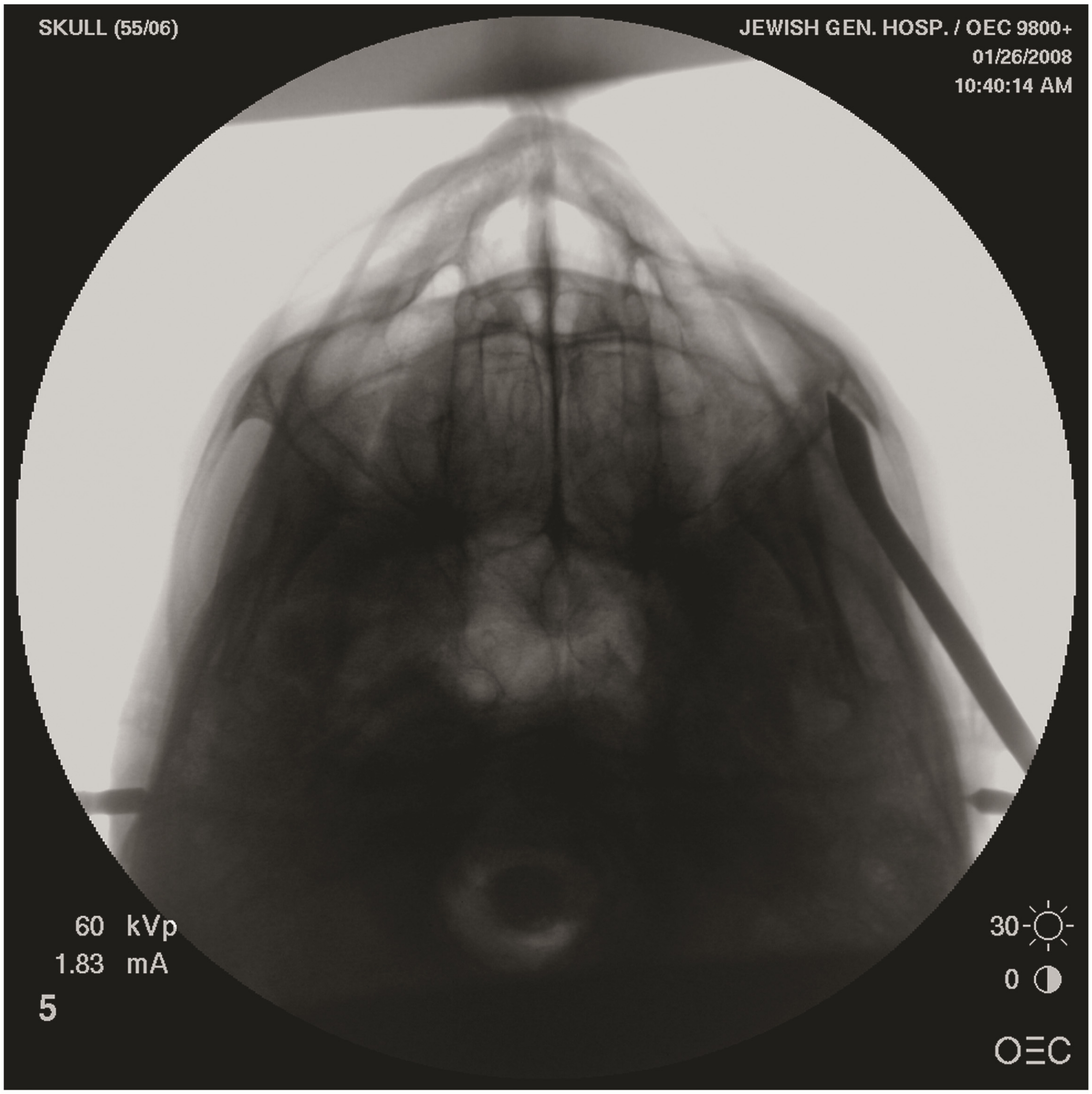
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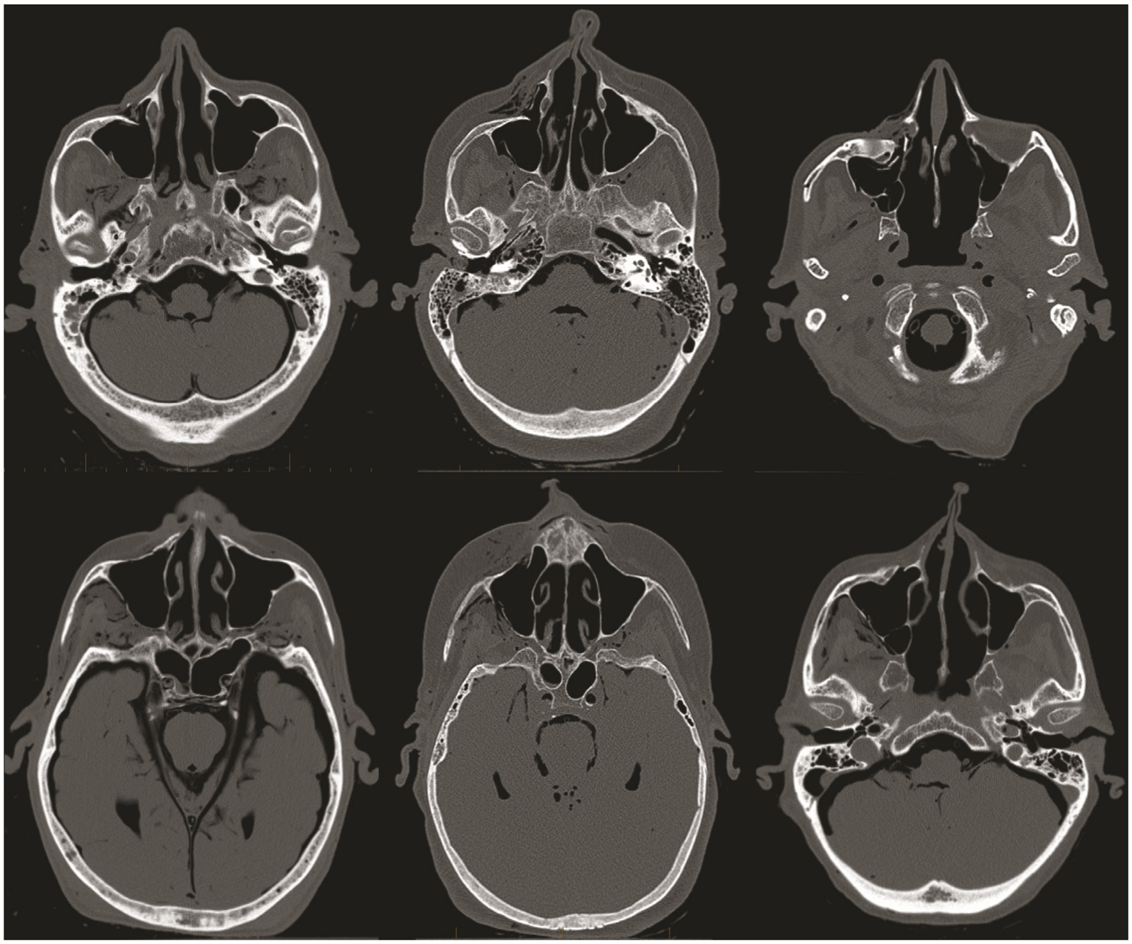
Figure 4



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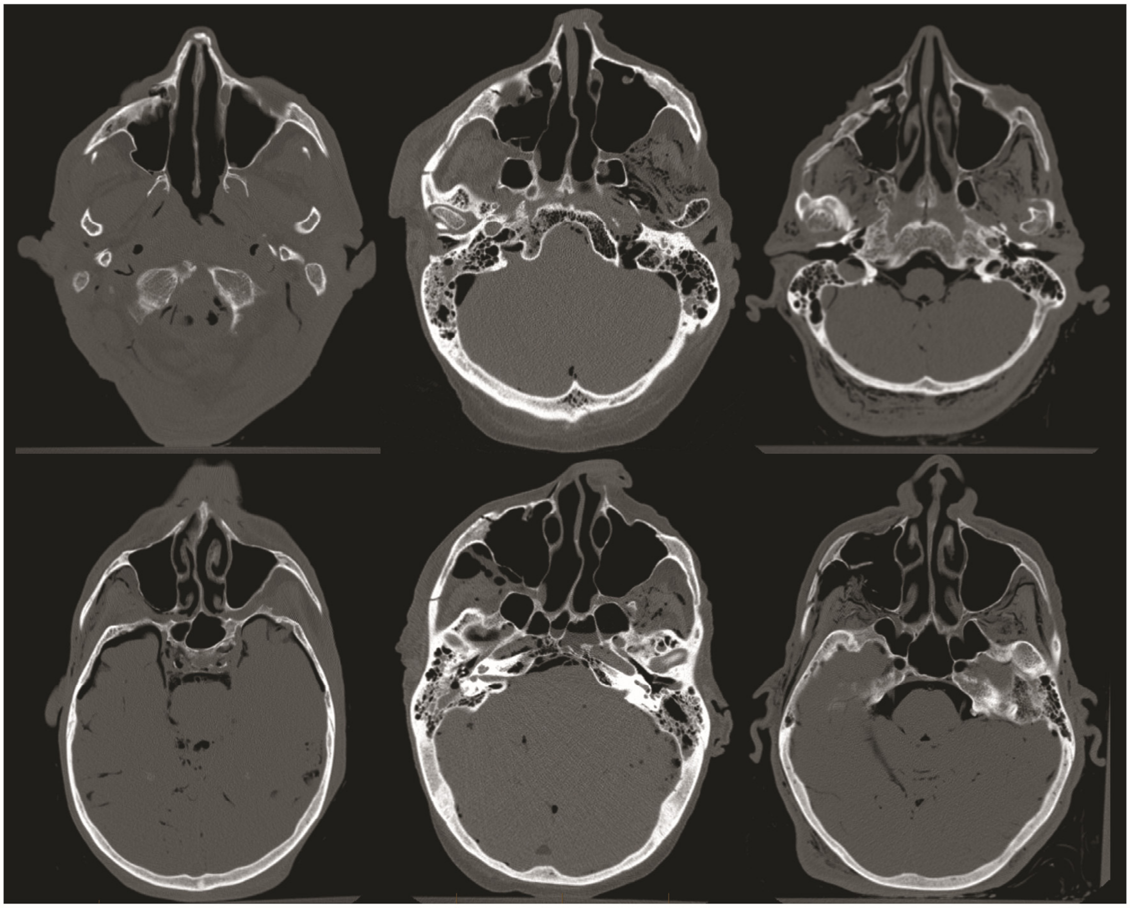
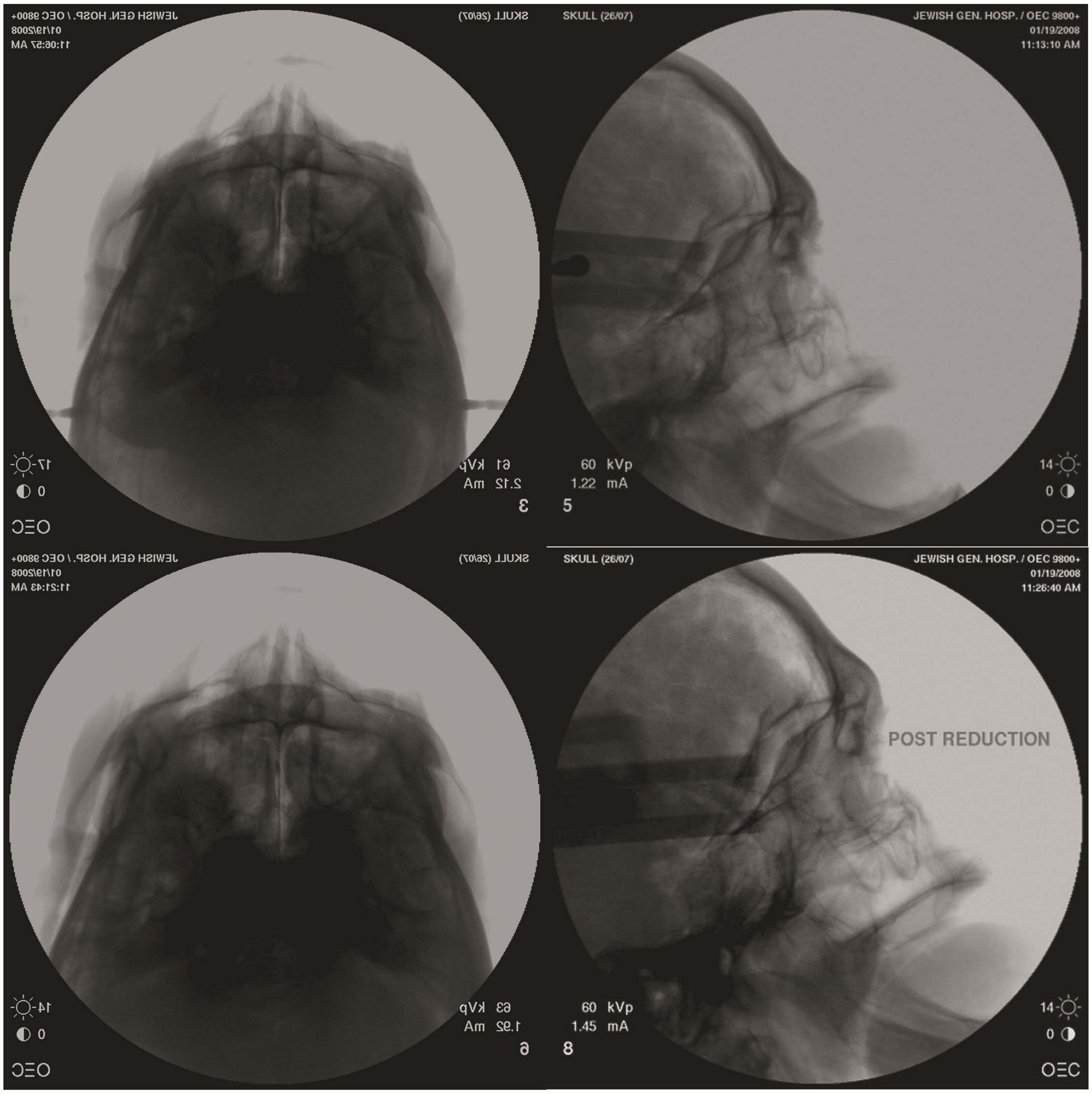


Figure 6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8

Figure 7

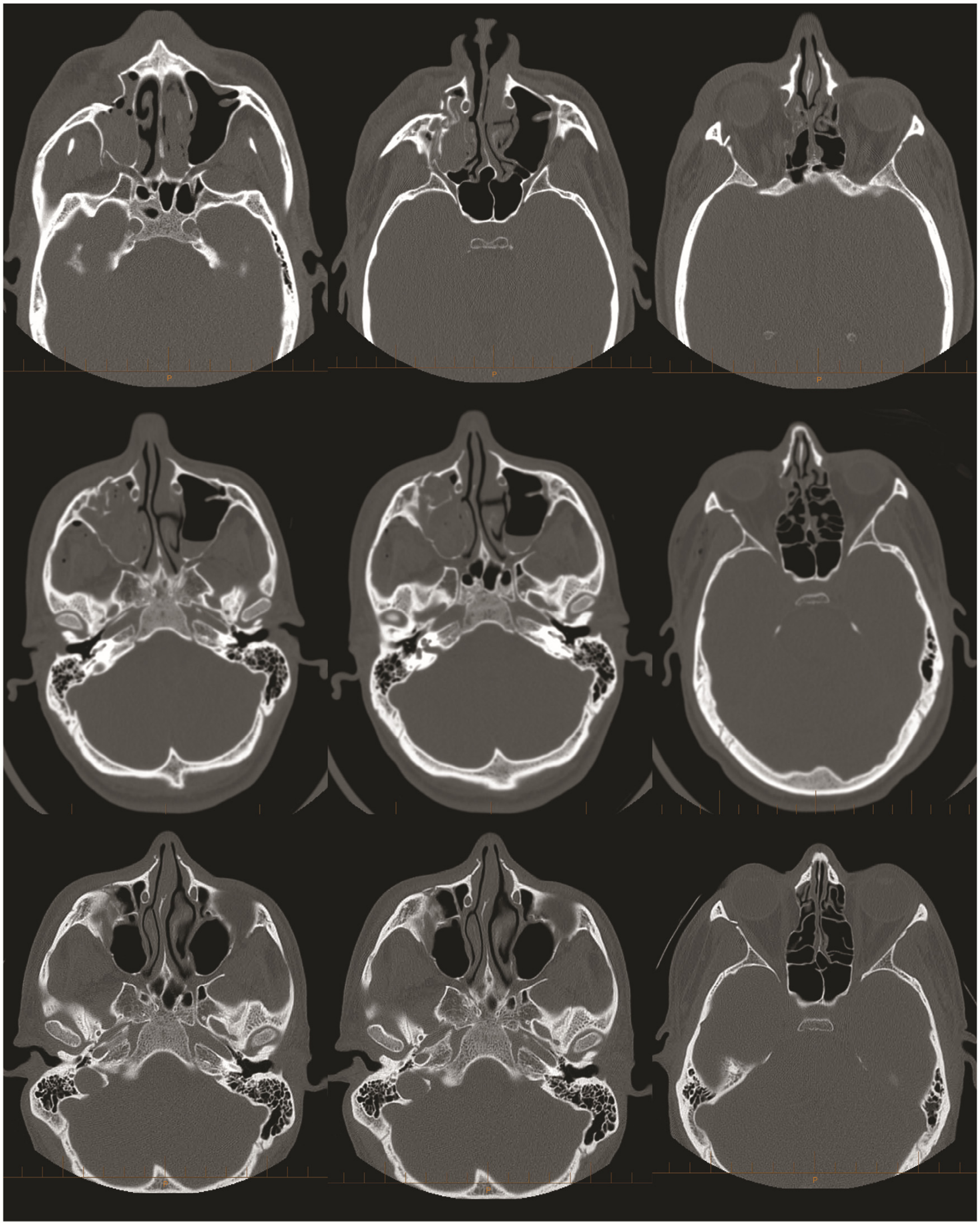
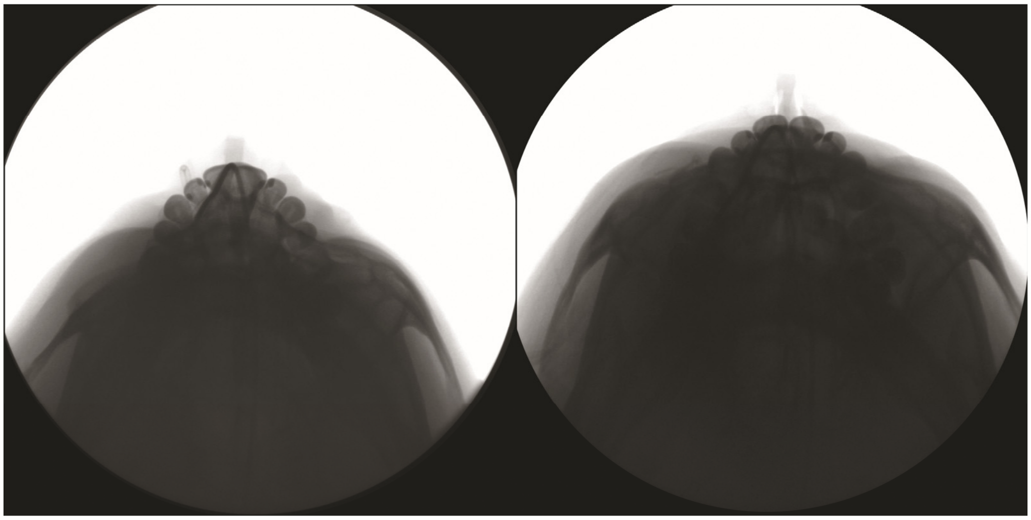


Figure 8

Figure 9



CONNECTING TEXT 5

ELEMENTS REQUIRED FOR THE TRANSITION OF THE C-ARM TECHNIQUE TO A CLINICAL SETTING

In the fourth study of this thesis, c-arm views necessary to visualize the zygoma were identified and a surgical technique utilizing them accurately repositioned a variety of zygoma fractures in a cadaver model. No fixation was used given the absence of significant displacing forces in a cadaver specimen. In a real clinical scenario, fixation is likely needed, although the number and location of stabilizing plates is uncertain. While initially a 3-point fixation was believed to be required, studies since have shown that a single point of fixation is likely sufficient in most zygoma fracture cases.[41-44] The fronto-zygomatic suture, infra-orbital rim and zygomatico-maxillary buttress have been shown to provide greatest fixation strength.[45-47] Given the already discussed negative sequelae of accessing the fronto-zygomatic suture and infra-orbital rim, it was decided to use the relatively complication free upper buccal sulcus incision for hardware placement. Furthermore, use of an upper buccal sulcus incision would allow for fracture reduction until satisfactory zygoma position and fixation placement with the c-arm in position, thus potentially further decreasing operative time. Placement of fixation hardware in this location is also relatively innocuous as compared to the fronto-zygomatic suture (visibility, palpability) and infra-orbital rim (palpability, eyelid malposition).

Two additional changes to the protocol were performed. First, our experience with the c-arm technique demonstrated that the information provided by the second, rotation, view was limited. This view was introduced in the theoretical event of rotation around the central part of zygoma body. In none of the cases was the zygoma rotated in this manner that its displacement could not be noted from the projection view. Thus, in order to decrease radiation exposure and limit operative time, we decided to not utilize the rotation view. Second, we chose to locate the maxillozygion on post-operative computed tomography image instead of on skin surface. This technique change allowed a more detailed analysis, did not require additional instruments, and could be performed at any time post-operatively.

The objective of this final study of the thesis was to objectively evaluate accuracy, complication rates and practical aspects of the c-arm zygoma imaging technique combined with a single intra-oral incision for reduction and plate placement.

C-ARM ASSISTED ZYGOMA FRACTURE REPAIR:

A CRITICAL ANALYSIS OF THE FIRST 20 CASES.

Marcin Czerwinski, MD

H Bruce Williams, MD

Abstract:

Background:

Currently used open reduction and internal fixation (ORIF) techniques of zygoma fracture repair are not optimal, as exposure of those sites allowing for accurate reduction or those needed for strong fixation has the highest possibility of negative consequences. The objective of the present study is to present a single incision, single fixation site zygoma fracture repair technique using a single zygoma c-arm view and to quantitatively determine the accuracy, complication rate and practical aspects of it in a clinical series.

Methods:

In a prospective study, consecutive patients with isolated, unilateral, displaced zygoma fractures, not requiring orbital floor exploration treated using a c-arm assisted repair technique at our institution between 2009-2011 were included. Objective outcomes assessed included accuracy of zygoma realignment (using post-operative CT scan), ocular globe projection symmetry (using Naugle exophthalmometer), complication rate and operative duration. Statistical analysis was performed using a Student's t-test.

Results:

In total, 20 patients were included. Differences in zygoma projection, width and height between the uninjured and repaired sides of the face were clinically significant (>3 mm) in the first patient only. Average differences for all 20 patients were clinically and statistically insignificant. Differences in ocular globe projection between the uninjured and repaired sides of the face for each patient were all 2 mm or less. Average difference for all 20 patients was also clinically and statistically insignificant. No major complications occurred and average operative duration was 76 minutes.

Conclusions:

The present study demonstrates that the c-arm assisted zygoma fracture repair technique is accurate, has a low complication rate, can be performed quickly and with relatively low difficulty.

1. Introduction

Zygoma fracture repair has undergone significant evolution over the last century.[1] At first, closed reduction techniques, wherein the displaced bone was repositioned through a small incision in the upper buccal sulcus, temporal fossa or anterior cheek skin, predominated. Inconsistent results led way to increased exposure and the addition of a variety of stabilization techniques using inter-fragmentary wires and percutaneous pins during the mid-part of the last century. In the final two decades, plate and screw fixation rose in popularity and became the principal method of stabilization.[2,3]

The evolution in the treatment of zygoma fractures has led to several important discoveries. First, the spheno-zygomatic suture, zygomatico-maxillary buttress and zygomatic arch offer the most information regarding the accuracy of reduction.[4-8] Second, exposures of the infra-orbital rim, fronto-zygomatic process and zygomatic arch are fraught with the most complications.[9-13] Inferior eyelid incision and dissection has a risk of post-operative malposition (14% if performed trans-cutaneously, 1.5% if performed trans-conjunctivaly).[9] Eyelid malposition may be functionally disabling and is very challenging to correct, requiring aggressive management.[14,15] Addition of a lateral canthotomy and cantholysis to improve fronto-zygomatic and spheno-zygomatic buttress exposure is difficult to repair anatomically, creating the potential for permanent lateral canthal asymmetry.[13] Coronal exposure leads to anaesthesia posterior to the incision, possible temporal branch of facial nerve injury and may cause unsightly temporal hollowing.[10-12] Third, in most instances of zygoma fracture without a critical-sized orbital floor defect, routine orbital floor exploration is unnecessary, as zygoma reduction does not typically increase the orbital floor defect size past critical threshold.[16] Last, fixation at the fronto-zygomatic and/or zygomatico-maxillary buttresses leads to more stability.[17-19] The number of interfaces requiring fixation is still controversial. The immediate strength necessary is likely not the same as in an uninjured individual, given the significantly lower post-injury bite forces.[20] The amount of fixation needed may also vary with the extent of comminution and bone thickness at each of the fracture sites. While initially a 3-point fixation was believed to be required, studies since have shown that a single point of fixation is likely sufficient in most zygoma fracture cases.[21-24]

Currently used ORIF techniques of zygoma fracture repair are not optimal, as exposure of those sites allowing for accurate reduction or those needed for strong fixation has the highest possibility of negative consequences. Furthermore, as exposure of the entire zygoma at once is not possible, the fracture interfaces serve only as an indicator for the position of zygoma body and can be misleading, especially in instances of comminution with loss of usable bone at fracture sites. To circumvent these shortcomings, surgeons have attempted to increase the extent of visualization while decreasing surgical exposure. The endoscope has been introduced to explore the orbital floor and zygomatic arch through small, inconspicuously located incisions.[25-28] While useful, this technique has a steep learning curve and adds operative time. Intra-operative CT scanners have been used for verification of accurate re-alignment, but add significant radiation risk, operative time and cost, and are not widely available.[29] Furthermore, an intra-operative CT cannot be used throughout acquisition of reduction, thus mistakes identified necessitate repetition of the repair process.

An ideal technique for zygoma fracture repair would allow for visualization of the entire zygoma, or its interfaces most important for accurate realignment through inconspicuous incisions, and minimal (but stable) fixation through these same access points. The technique would be fast, inexpensive, easy to learn and use. The c-arm has the potential to demonstrate osseous anatomy without any incisions, is easy to use, widely available and inexpensive. Although the c-arm produces radiation, typically it is significantly lower than the amount emitted by CT scanners. We have previously reported on a c-arm imaging technique that allows for intra-operative visualization of zygoma body projection, arch contour and angulation and their comparison to the contra-lateral uninjured side.[30] The objective of the present study is to present a single incision, single-fixation-site zygoma fracture repair technique using a single zygoma projection view and to quantitatively determine the accuracy, complication rate and practical aspects of it in a clinical series.

2. Methods

A strict patient management protocol was prospectively designed and rigorously followed. All patients presenting to the Scott and White Memorial Hospital regional level-1 trauma center, beginning in October 2009, with an isolated, unilateral, displaced zygoma fracture, not requiring orbital floor exploration, followed the protocol. All fracture energies were included. Isolated zygomatic arch fractures were excluded.

Pre-operative assessment included evaluation by an attending plastic surgeon and a full ophthalmologic examination. Post-operatively, the patients were followed by an attending plastic surgeon at 2-weeks and 3-months. Pre- and 24-hour post-operative 2.0 mm cut axial maxillofacial CT scans with coronal reformatting were obtained.

Repair was performed by a single surgeon (MC), using a modified c-arm assisted zygoma fracture repair technique, in the following fashion: The patient was intubated, using an oral RAE tube, their head positioned on a horseshoe Mayfield headrest in a slightly extended position and their neck, chest and abdomen covered with a lead apron. Following injection of 1% lidocaine with 1:100,000 epinephrine solution, an upper buccal sulcus incision on the side of the fracture was performed and sub-periosteal dissection of the zygomaticomaxillary buttress carried out. Then, the c-arm was positioned; its long axis in line with the mid-sagittal axis of the patient's body, and the plane of the c-arm at a tangent to the zygoma body in order to project its image above the frontal bone. The x-ray source of the c-arm was located anterior to the patient's abdomen and image intensifier cranial to the patient's head (figure. 1 *Left*). An image was obtained using pulse acquisition only at a reduced radiation dose (60-65 kVp, 2-2.5 mA). It is important to set the reduced dose in the manual mode, as the automatic setting results in a higher dose, preventing proper image acquisition. This view allows for visualization of zygoma body projection and width, zygomatic arch contour and angulation and the comparison to the contralateral, uninjured side (fig. 1 *Center, Right*). With the c-arm in position, a Kelley elevator was placed through the upper buccal sulcus incision, underneath the junction of the zygomatic arch and body. Using an antero-lateral reduction vector, the zygoma was reduced, until a repeat c-arm image demonstrated accurate position. Subsequently, an L-shaped 0.7 mm titanium plate was bent to shape, placed along the zygomatico-maxillary buttress and secured with 4-6 5mm screws. Closure was performed using a 4-0 Polysorb running, horizontal mattress suture.

Retrospective review of medical records of patients who followed this protocol between October 2009 and October 2011 was approved by the local IRB. Objective outcomes assessed included accuracy of zygoma realignment, ocular globe projection symmetry, complication rate and operative duration. Accuracy of zygoma realignment was determined from post-operative CT scans (figure. 2). Zygoma projection was defined as the linear projective distance from the posterior edge of the sella turcica to the maxillozygion on an axial CT image. Zygoma width was defined as the linear projective distance from the skull base mid-sagittal axis to the maxillozygion on an axial CT image. Zygoma height was defined as the linear projective distance between the maxillozygion and the fronto-zygomatic suture on coronal reformatted CT image. Differences between the uninjured and repaired sides were calculated and represented the severity of zygoma position asymmetry. Ocular globe projection was measured using the Naugle exophthalmometer, and differences between sides calculated (figure. 3). Complications assessed included surgical site infection, incisional dehiscence, visible cutaneous scarring, eyelid malposition (scleral show, ectropion, entropion), temporal hollowing, diplopia, infra-orbital nerve dysfunction, re-operation and bail-out of the attempted surgery rates. Operative duration was defined as the time from surgical incision to closure as noted in the operative log. Statistical analysis was performed using two-tailed Student's t-tests.

3. Results

In total, 20 patients with unilateral, isolated, displaced zygoma fractures without a significant orbital floor defect, excluding isolated arch fractures, were evaluated during this period. All patients underwent c-arm assisted repair; 15 patients were male, 5 were female. Average patient age was 41 years. The most common mechanisms of injury included MVC (n=8), fall (n=6) and assault (n=5).

Differences in zygoma projection, width and height between the uninjured and repaired sides of the face for each patient are presented in figure 4. Average difference in 3-dimensions was clinically significant (>3 mm) in only the first patient. Average differences for all 20 patients, in zygoma projection, width and height between the uninjured and repaired sides of the face are presented in figure 5, and were all less than 2 mm. All were clinically and statistically insignificant.

Differences in ocular globe projection between the uninjured and repaired sides of the face for each patient are presented in figure 6, and were all 2 mm or less. Average difference for all 20 patients, is presented in figure 7, and was less than 1 mm. This was also clinically and statistically insignificant.

There were 2 intra-oral partial incisional dehiscences, which healed by secondary intention. There were no instances of surgical site infection, visible cutaneous scarring, eyelid malposition, temporal hollowing, diplopia, permanent infra-orbital nerve anaesthesia or re-operation. In all cases, the c-arm assisted technique was completed.

Operative duration for each case is presented in figure 8. Average time for all cases was 76 minutes. Linear regression demonstrated gradual decrease in operative duration with surgical experience, with the average of the last 3 cases being 39 minutes.

4. Discussion

Critical analysis of results has led to a significant improvement in the outcomes of zygoma fracture repairs over the last century.[1-3] Selective exposure, assessment of reduction at largest fracture interfaces and limited fixation using low profile hardware has become the mainstay in the treatment of these injuries. This approach, however, is not ideal as exposure of those sites allowing for accurate reduction or those needed for strong fixation also carries the most undesirable sequalae of open access, including eyelid malposition, visible scaring, risks of facial nerve injury and temporal hollowing.[9-15] For this reason, many surgeons have explored alternative methods for the visualization of buttresses most accurate in guiding reduction. The c-arm assisted technique allows for visualization of nearly the entire zygoma without an incision and comparison to the contralateral uninjured side.[30] Theoretically, because exposure for accurate reduction is not required, fixation can be performed at an interface that is both strong and can be approached without significant disadvantages.

The present study demonstrated that this technique is highly accurate. The asymmetry in the position of the zygoma between the un-injured and repaired sides of the face was less than 2 mm in all but the first patient. The average differences in zygoma projection, width and height between the uninjured and repaired sides of the face were less than 2 mm. These differences are considered clinically insignificant and are similar to those results previously reported with traditional ORIF.[31] The individual ocular globe projection differences between the uninjured and repaired sides of the face were 2 mm or less in all patients. The average ocular globe projection difference was less than 1 mm. These differences are also considered indiscernible to the average observer at a conversational distance and are similar to results previously reported with traditional ORIF.[31]

There were only 2 complications in this study and no patients required a re-operation. Each incisional dehiscence healed uneventfully without a change in standard management. There were no instances of post-operative eyelid malposition, as compared to a 25% incidence previously reported with ORIF.[31] Post-operative eyelid malposition may potentially become functionally disabling leading to lagophthalmos and corneal irritation, and is very difficult to correct surgically.[14,15] The origin of post-incisional eyelid malposition is unclear, but it is thought to be the result of middle lamellar adhesion to surrounding structures.[14] Its occurrence is unpredictable and may follow a technically successful eyelid approach; and thus, its complete avoidance can only be achieved by not transgressing any portion of the eyelid. By design, there were no instances of visible cutaneous surgical scarring, which is significantly less than the 10% previously reported with traditional ORIF.[31]

The c-arm assisted zygoma fracture repair technique has a gradual learning curve. The required c-arm settings, position of the c-arm relative to the patient and understanding the components of the obtained image are specific to this technique and relatively easy to learn. The upper buccal sulcus incision, intra-oral reduction and zygomaticomaxillary buttress fixation are similar to traditional ORIF. Because only a single incision and single plate fixation are performed, the technique can be performed expeditiously once a thorough understanding of its specifics is achieved. With some experience and assistance, exposure, reduction and fixation can be performed with the c-arm in position. The average operative duration for the last 3 cases in this series was 39 minutes. In no cases did the technique have to be aborted or converted to another surgical approach. Given that the c-arm is widely available in most hospital centers, surgeons can perform this technique without additional expenses.

The technique does have several shortcomings. First, not every patient is an excellent candidate. Patients with congenitally deficient malar projection (negative vector orbit) and prominent frontal sinus are more difficult to image, requiring greater hyperextension of the neck allowing projection of the zygoma body above the frontal sinus. Second, not every fracture type can easily be treated. Zygoma fractures with comminution of the body should be avoided, as the intra-oral reduction maneuver repositions the body and relies on the integrity of the entire bone to accurately position its buttresses. Furthermore, old zygoma fractures can be more difficult to mobilize with this approach, as only the zygomatico-maxillary buttress can be directly disimpacted. Third, although the c-arm does emit radiation, this technique uses low-dose non-fluoroscopic views only and most repairs can be performed with 15 images or less. Consequently, the cumulative dose is likely significantly less than with a typical maxillofacial CT.

In summary, the present study demonstrates that the c-arm assisted zygoma fracture repair technique is accurate, has a low complication rate, can be performed quickly and with relatively low difficulty.

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Figure Legend:

Figure 1. *Left:* Intra-operative set-up demonstrating positions of patient, c-arm and monitor, radiology (background) and scrub (foreground) technicians. *Center and Right:* Pre- and post- repair intra-operative c-arm images of a patient with a right zygoma fracture demonstrating initially decreased projection and width of the zygoma body as compared to the uninjured left side.

Figure 2. Accuracy of zygoma realignment was determined from post-operative CT scans. *Left:* Zygoma projection was defined as the linear projective distance from the posterior edge of the sella turcica to the maxillozygion, zygoma width as the linear projective distance from the skull base mid-sagittal axis to the maxillozygion on an axial CT image. *Right:* Zygoma height was defined as the linear projective distance between the maxillozygion and the fronto-zygomatic suture on coronal reformatted CT image.

Figure 3. Ocular globe projection was measured using the Naugle exophthalmometer.

Figure 4. Differences in zygoma position between the treated and uninjured sides of the face for each patient. The light blue line represents differences in cheek projection. The dark blue line represents differences in cheek width. The orange line represents differences in cheek height. The red line demonstrates average asymmetry in 3 dimensions. Clinically significant asymmetry was present in only the first patient.

Figure 5. Average differences in zygoma projection, width and height between the treated and uninjured sides of the face among all patients. All differences were clinically and statistically insignificant.

Figure 6. Differences in ocular globe projection between the treated and uninjured sides

of the face for each patient.

Figure 7. Average difference in ocular globe projection between the treated and uninjured sides of the face for all patients. This difference was clinically and statistically insignificant.

Figure 8. Operative duration decreased with time, as noted by the linear regression line. The average time for the last 3 cases in the series was 39 minutes.

Figure 1


stryker
FLUORO
LIH 1
4
11.03.11
18.09
/2
FLUORO
LIH 1
11.03.11
18.39
/2

Figure 2

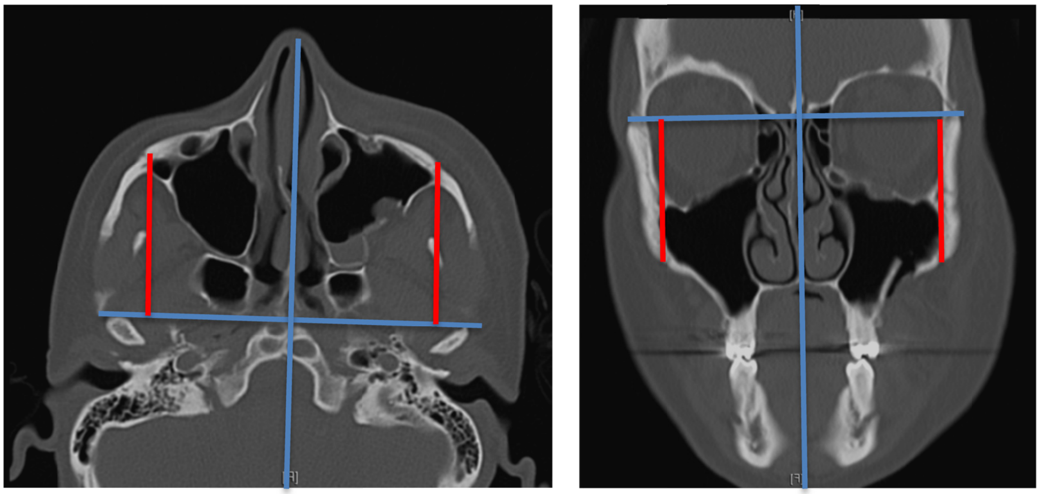


Figure 3.

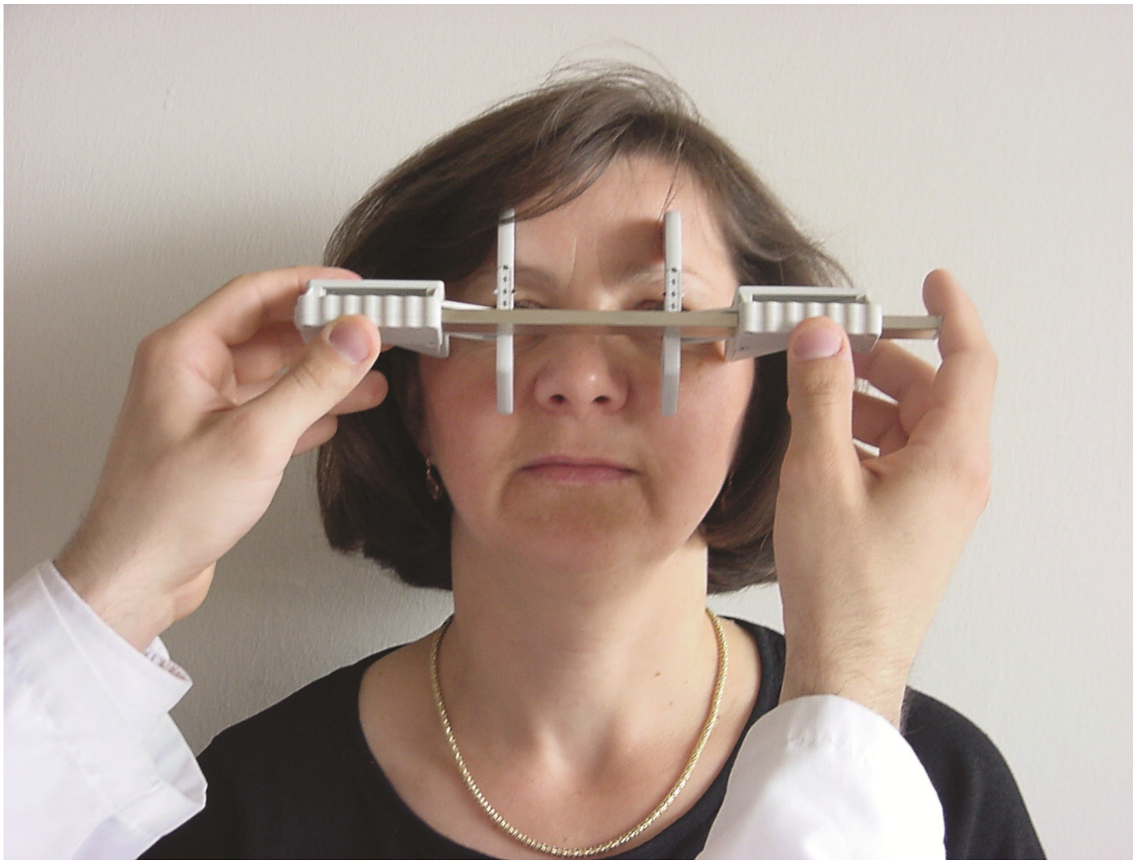


Figure 4.

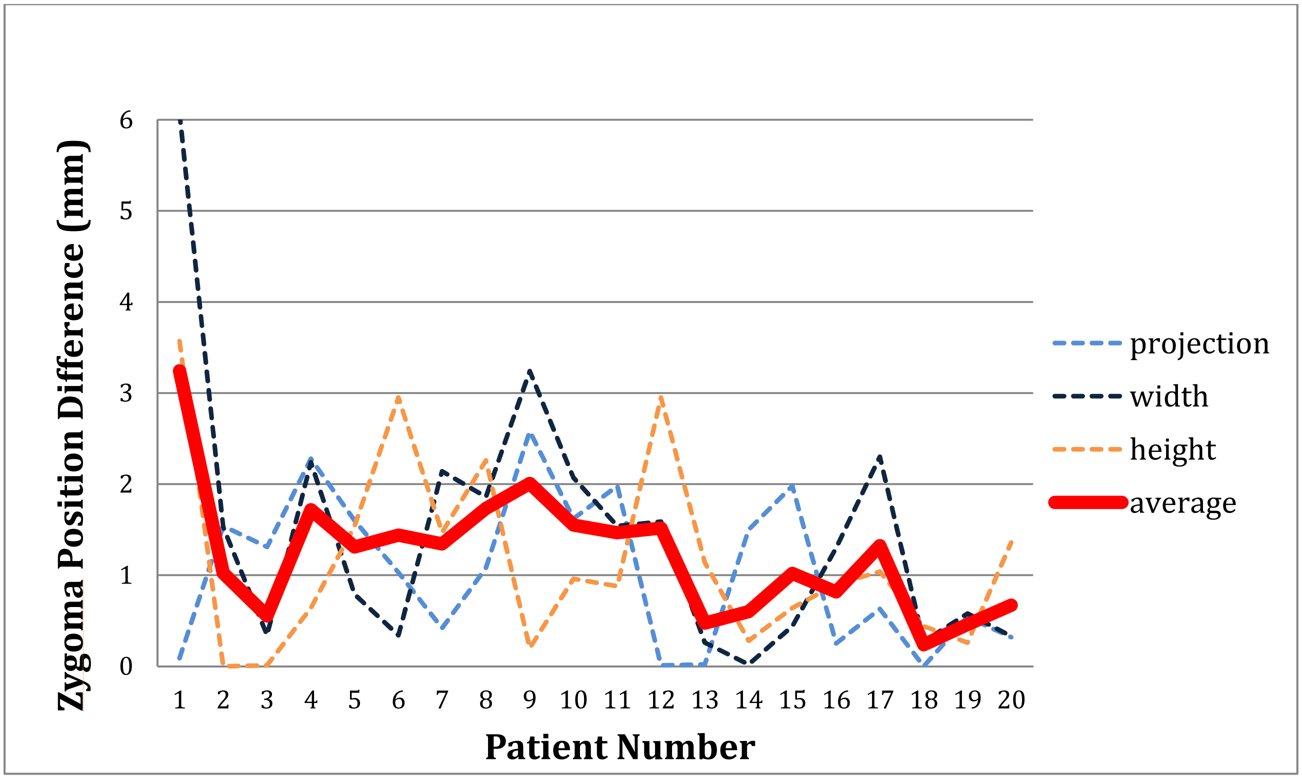
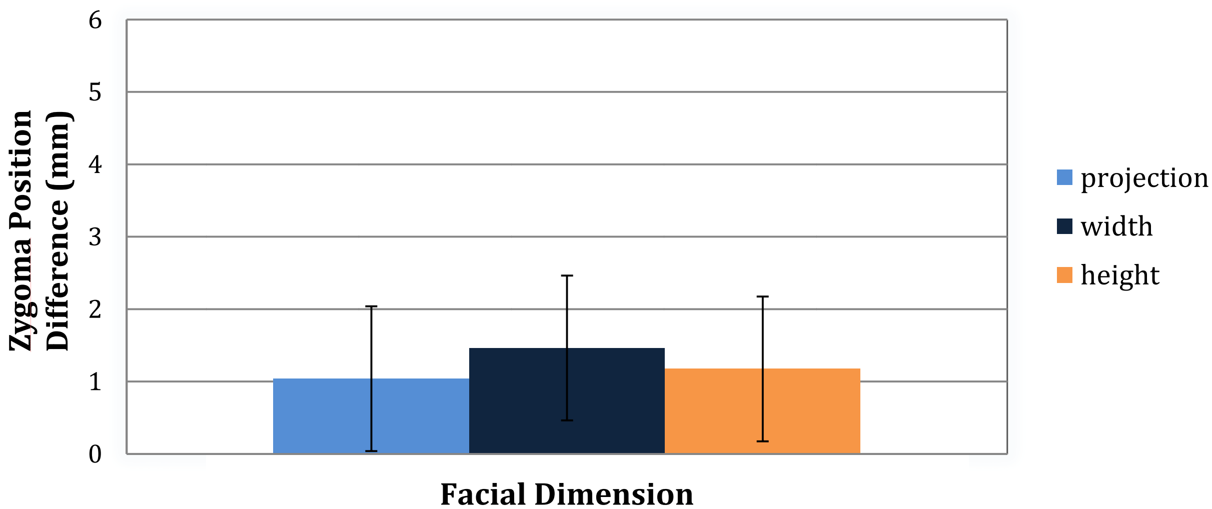

Zygoma Position Difference (mm)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Patient Number
projection
width
height
average

Figure 5.



6
5
4
3
2
1
0
Zygoma Position Difference (mm)
Facial Dimension
projection
width
height

Figure 6.

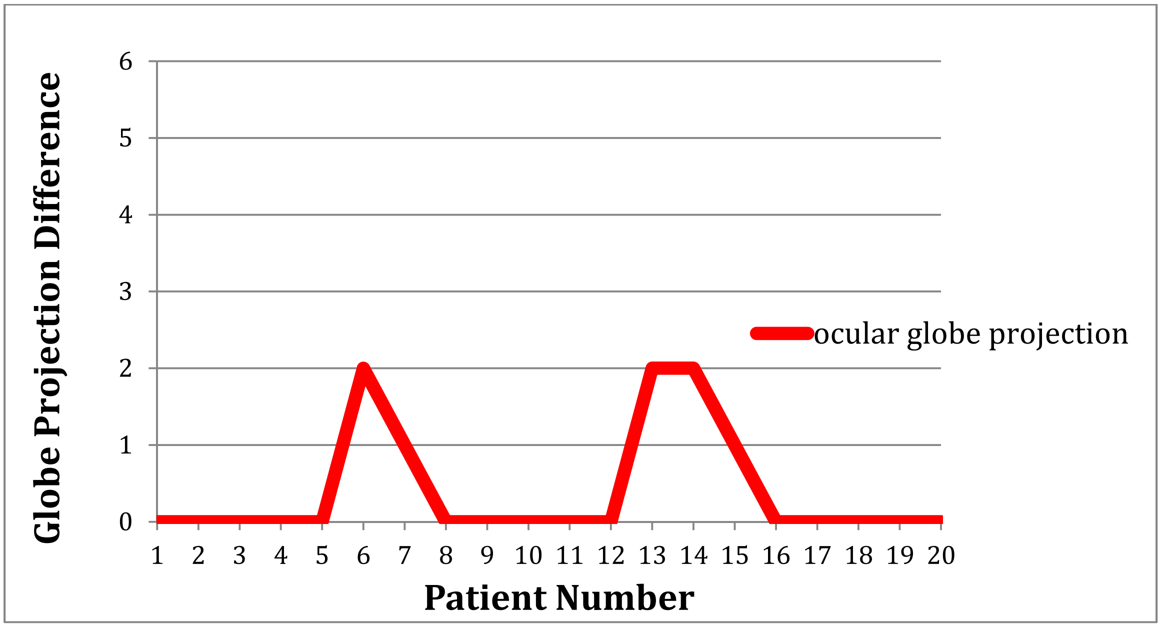

Globe Projection Difference
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Patient Number
ocular globe projection

Figure 7

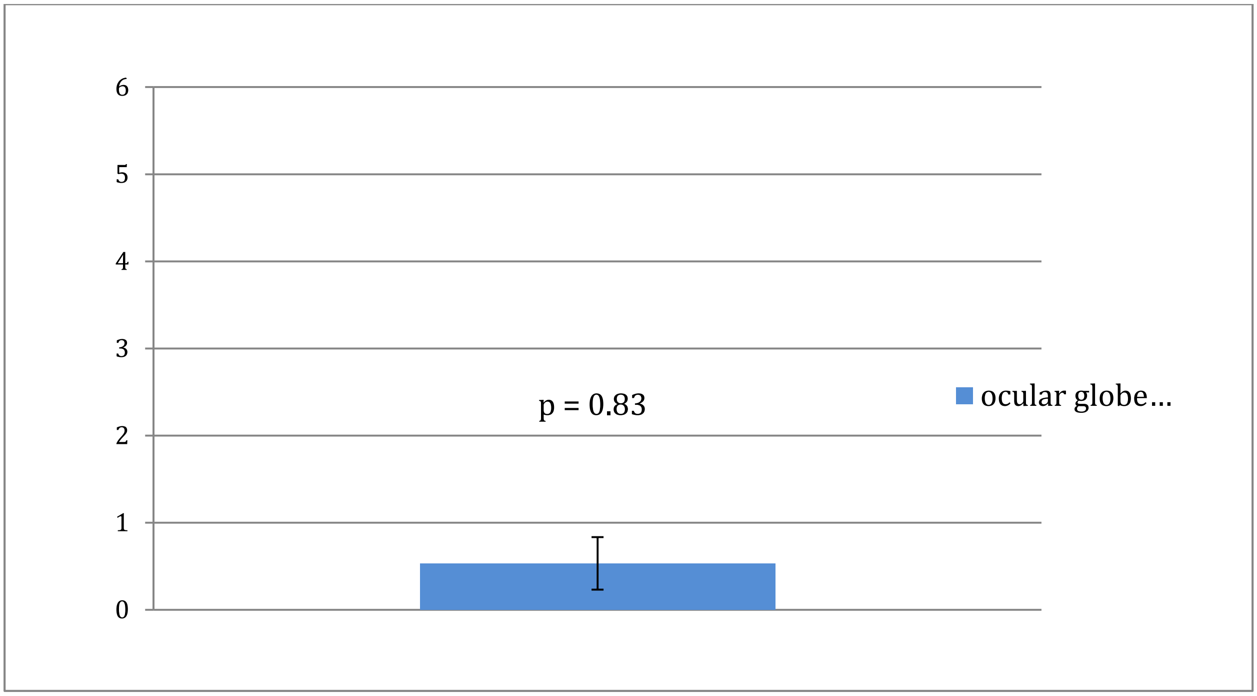
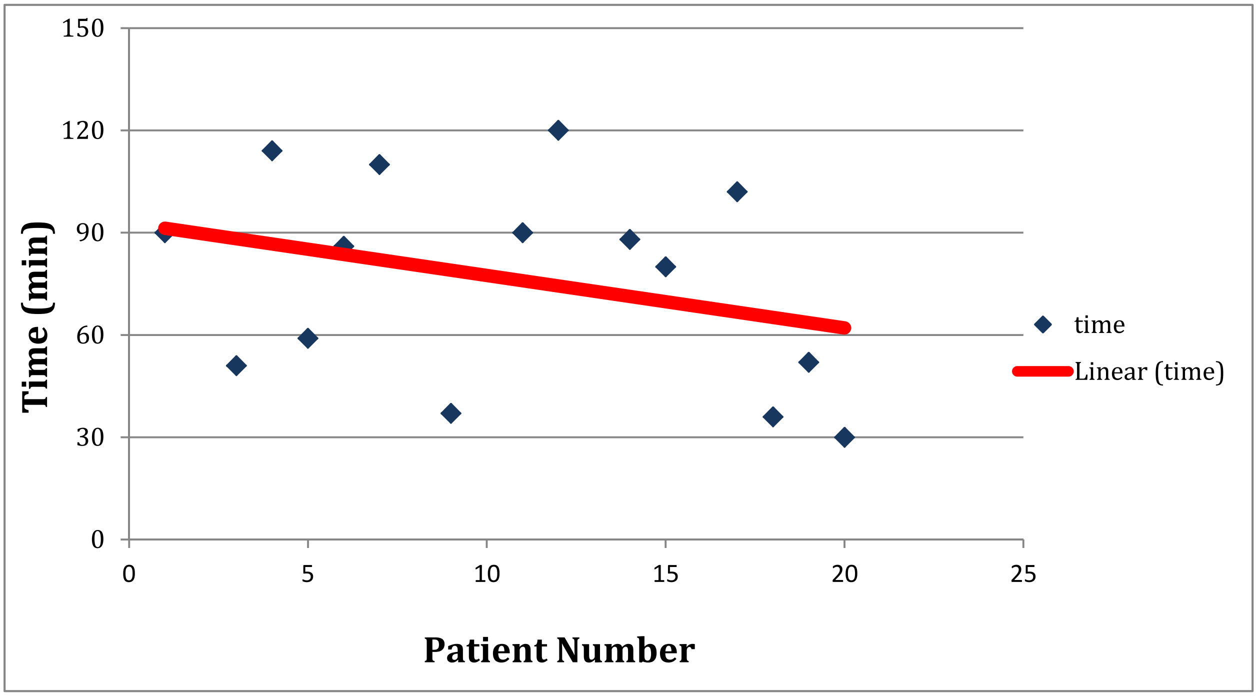


Figure 8



150
120
90
60
30
0
Time (min)
0
5
10
15
20
25
Patient Number
time
Linear (time)

SUMMARY

Zygoma fractures are common and may result in significant negative sequelae, including: cheek malposition with asymmetry, ocular globe displacement and infra-orbital nerve malfunction.[7,20-28] Many repair methods have been introduced, ranging from closed reduction through inconspicuous incisions to multi-point exposure, reduction, and miniplate fixation. The ultimate objective of this thesis was to develop a novel technique of repair with outcomes superior to any of the previously used methods. The thesis consisted of 5 sections.

In the first thesis study, head and face anthropometric techniques were used to develop and validate a method of identifying a central point on the zygoma, representing its position in a three-dimensional plane. Furthermore, previously uninjured individuals were assessed with this technique to demonstrate no significant, side to side asymmetry.

In the second thesis study, the quantitative method for the assessment of zygoma position was used to conclusively demonstrate the increased accuracy of open reduction repair methods. There were no differences in ocular globe position and infra-orbital nerve function between techniques. Careful tabulation of complications demonstrated that open techniques carry significant disadvantages, including a 33% risk of visible cutaneous scarring and a 25% risk of visible eyelid malposition.

In order to minimize complications, incisions that are particularly problematic should be avoided. These include the coronal incision, the lateral orbital rim incision, and the inferior eyelid incision. The inferior eyelid approach is used not only to reduce and fixate the zygoma fracture, but to explore and potentially reconstruct an orbital floor defect. Although in most cases of zygoma fracture, the pre-operative orbital floor defect is not large enough to warrant repair; the antero-lateral reduction of the body may decompress floor fracture fragments and create an occult but significant defect. The third thesis study disproved this hypothesis, thus creating an opportunity for the development of a technique that would not require transgression of the inferior eyelid.

In order to avoid the sequelae of open access while maintaining the accuracy of techniques that directly expose fracture interfaces, intra-operative c-arm radiography was chosen as an operative adjunct. This was selected instead of intra-operative computed tomography due to its decreased radiation, widespread availability, ease of use, and reduced cost. In the fourth study, c-arm views required to image the zygoma on a skull model were defined. The technique was successfully tested on a cadaver zygoma fracture model.

In the fifth thesis study, the c-arm technique was refined by the inclusion of an only the zygoma projection view and the addition of a miniplate on the zygomaticomaxillary buttress through an upper buccal sulcus incision. The technique was used on a clinical series of patients in which its excellent accuracy and low complication rates were objectively demonstrated. Furthermore, the practical aspects of the new method became apparent with operative time of the last 3 patients in the series being just over 30 minutes each. Although the image obtained using the c-arm is not as detailed as a CT, it appears to suffice for anatomic realignment with drastically lower radiation exposure, operative time and cost.

In summary, the technique developed in the course of this thesis has immediate applicability in the treatment of zygoma fractures. Although patients with old fractures, severe comminution extending into the body, and those requiring orbital floor exploration may not be the best candidates, these represent only a minority. The use in most other patients will produce similar aesthetic and functional outcomes while minimizing the rate of complications and reducing operative times.

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