Three-Dimensional Planes of Reference for Orbital Fractures

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Introduction: Three-dimensional planes of reference for orbital fractures (3D-PROF) is a technique for isolating segments of the orbital cavity for 3D analyses.

Method: Using 3D-PROF, the orbital floor, and medial wall were isolated on Meshlab (National Research Council, Pisa, Italy).(1)Hemi-facial segmentation: Removal of contralateral skull using the mid-sagittal plane(2)Caudal-facial segmentation: Removal of facial bones below the plane across the infraorbital foramen and external acoustic meatus(3)Superolateral segmentation: Removal of orbital roof and lateral wall using a plane across the inferior orbital fissure, external acoustic meatus, and posterior clinoid process(4)Posterior skull segmentation: Removal of skull segment posterior to the orbital cavity using the orbital apex as reference point

A pilot study was conducted to evaluate the interobserver variability of 3D-PROF. Facial computed tomography scans of 20 patients with normal unilateral orbit were randomly selected. Four observers performed 3D-PROF to isolate the orbital floor.

The isolated orbital segments are evaluated for:(1)Total surface area(2)Preservation of 3 critical landmarks (infraorbital rim, posteromedial bulge, inferior orbital fissure)

Results: The intraclass correlation coefficient for the total surface area of the resultant bony segment was excellent (0.85, confidence interval 0.707–0.934, $P < 0.01$). All landmarks achieved a rate of preservation of at least 90% (18/20) for the observers, except for the infra-orbital rim where 1 observer achieved 85% (17/20).

Conclusion: Three-dimensional planes of reference for orbital fractures, is an easy and reproducible technique for isolating regions of interest of the orbital cavity for preoperative planning.

Key Words: Blow-out, facial fracture, maxillofacial, orbit, orbital fracture

(*J Craniofac Surg* 2021;32: 1464–1466)

Three-dimensional (3D) analysis of the orbital cavity is used in surgical planning and research.[1,2]

In 3D analysis, the first step is to isolate the region of interest (ROI) from the rest of the skull. ROI are often manually isolated by tracing the boundaries of the obit. Due to the complex anatomy of the orbit, this process is challenging, time-consuming, and prone to operator errors.[3] Excessive isolation of the ROI leads to deletion of critical structures. Incomplete isolation results in an obstructed view. The obtained ROI can be used for subsequent analysis of its contour, shape, and thickness.

An algorithm planes of reference for orbital fractures (PROF) was developed for two-dimensional (2D) analysis of the orbital cavity using Osirix Lite Digital Imaging and Communications in Medicine Viewer version 7.0.1 (Geneva, Switzerland).[4] Three dimensional (3D)-PROF builds on a similar concept. It is a platform that utilizes fixed landmarks and reference planes to isolate ROI of the orbital cavity in 3D.

Three-dimensional planes of reference for orbital fractures was developed to allow surgeons to systematically isolate any part of the orbit for analysis. A reproducible segment of the orbit can be obtained for accurate analysis of the ROI. This study describes the method of 3D-PROF to isolate the orbital floor and medial wall.

MATERIALS AND METHODS

From our database of patients with Digital Imaging and Communications in Medicine data, facial computed tomography (CT) scans of 210 consecutive patients admitted under the Division of Plastic, Reconstructive and Aesthetic Surgery, Department of Surgery, National University Health System, Singapore from January 2012 to December 2015 were accessed. Approval was sought from the National Healthcare Group Institutional Review Board, Singapore (DSRB No. 2019/00628) to conduct the study. Patients with CT scans in accordance with image-guided surgery protocol (1 mm fine-cuts, 0-degree gantry, facial CT scans) were selected.

Exclusion criteria includes:

(1) Patients below 21 years old
(2) Patients with bilateral orbital fractures

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Received October 28, 2020.

Accepted for publication November 16, 2020.

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The authors report no conflicts of interest.

Supplemental digital contents are available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.jcraniofacialsurgery.com).

ISSN: 1049-2275

DOI: 10.1097/SCS.0000000000007380

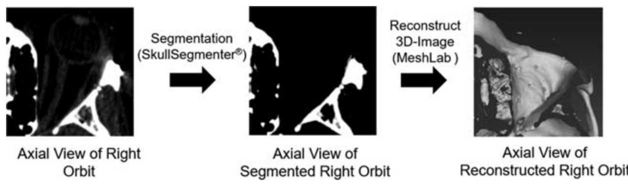

FIGURE 1. Axial view of right orbit after segmentation and 3D image reconstruction. 3D, three dimensional.

(3) Patients with a history of congenital malformation, tumors, or trauma to the orbit

Forty-five patients had facial CT scans that met our study criteria. Skull Segmenter (School of Computing, National University of Singapore, Singapore) was used to separate the skull from the soft tissue by altering the intensity threshold. The skull was then recreated into a 3D image with Meshlab (National Research Council, Pisa, Italy) (Fig. 1).

Three-dimensional planes of reference for orbital fractures was performed using the recreated 3D images on Meshlab (National Research Council, Pisa, Italy). The steps involved in 3D-PROF can be modified to isolate any part of the orbit of interest. It is not restricted to the floor and medial wall. As an example, these are the steps to isolate the orbital floor and caudal segment of the medial wall: (Fig. 2)

(1) Hemi-facial segmentation: removal of contralateral skull using the mid-sagittal plane
(2) Caudal-facial segmentation: removal of facial bones below the plane across the infraorbital foramen and external acoustic meatus
(3) Superolateral segmentation: removal of orbital roof and lateral wall using a plane across the inferior orbital fissure, external acoustic meatus, and posterior clinoid process
(4) Posterior skull segmentation: removal of skull segment posterior to the orbital cavity using the orbital apex as reference point

PILOT STUDY

A pilot study was performed to evaluate the reproducibility of 3D-PROF with 4 naïve observers who had no prior experience in reading CT scans. A single instructor trained the observers to perform 3D-PROF using 1 CT scan, before allowing them to practice on 2 different CT scans. The observers proceeded to isolate the orbital floor and medial wall of 10 unfractured left orbit and 10 unfractured right orbit, using 3D-PROF. The resultant bony segment (Fig. 3) was then evaluated for its:

(1) Total surface area using Meshlab (National Research Council, Pisa, Italy)
(2) Rate of preservation of 3 critical landmarks:

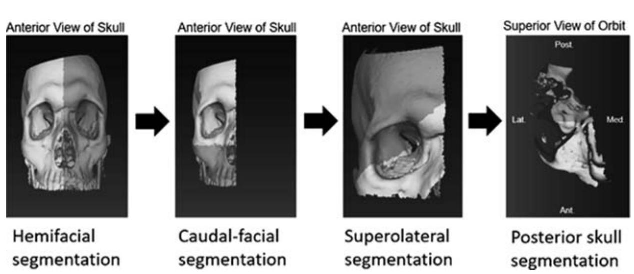

FIGURE 2. 3D-PROF algorithm applied to images from *Meshlab*. 3D-PROF, three-dimensional planes of reference for orbital fractures.

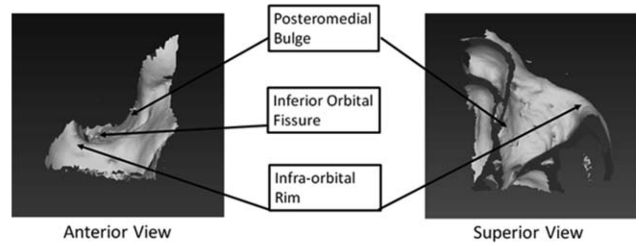

FIGURE 3. Resultant bony segments by 3D-PROF. 3D-PROF, three-dimensional planes of reference for orbital fractures.

- Posteromedial bulge
- Inferior orbital fissure
- Infraorbital rim

RESULTS

Surface Area

Bland–Altman analysis was performed to determine the inter-observer variability amongst the observers. The intraclass correlation coefficient was 0.85 (confidence interval 0.707–0.934, $P < 0.01$) for the total surface area of the resultant bony segment. This result shows that 3D-PROF has an excellent consistency in isolating the orbital floor and part of the medial wall as the ROI.

Preservation of Landmarks

The rate of preservation of all landmarks achieved a minimum of 90% (18/20) for each observer, except for the infra-orbital rim where 1 observer achieved 85% (17/20) as shown in Supplemental Table 1, http://links.lww.com/SCS/C254.

DISCUSSION

Reconstruction of the craniofacial region using 3D imaging is superior to traditional 2D imaging in terms of practicality and accuracy.[5,6] Three-dimensional reconstructed images in severe facial trauma provides a more comprehensive evaluation of morphology compared to traditional 2D radiographs. In conventional 2D radiography, the depth and thickness of structures cannot be measured.[7] A reasonable amount of estimation is required by surgeons. Patients' outcomes are highly dependent on variables such as surgeon's experience and the severity of injury.[8] Computed tomography images utilize fine-cut CT scans. Surgeons can use 3D imaging from the CT scan to circumvent these issues.[7] Three-dimensional images can be used to isolate the orbit to increase accuracy in preoperative planning.[3,9–11] The use of accurately reconstructed 3D images reduces the time and effort spent on interpreting the images when compared to going through a laborious set of cross-sectional CT.[12]

Jansen et al emphasized the importance of achieving a reproducible segment of the orbit in presurgical assessment.[13] Owing to its complex anatomy, a standardized and reproducible technique for isolating 3D reconstructed images of the orbit is lacking.[14,15] To ensure that an ROI is easily reproducibly, well-defined anatomical landmarks are crucial in order to achieve a high level of accuracy.[16–18] This echoes the findings of Cavalcanti et al and Baysai et al which states that a high level of landmark reproducibility is possible despite using different landmarks.[11,19]

The accuracy of a proposed protocol using anatomical landmarks on 3D CT scans for isolating a segment of the orbit has been evaluated in this study.[20] We have focused on the isolation of the orbital floor and medial wall because they are commonly fractured.[21] Despite being performed by naïve observers with no prior experience in reading CT scans, a high level of agreement was found in our study. There are 2 reasons for this. Results from 3D-PROF are easily reproduced as it employs identifiable anatomical landmarks during isolation of the orbit. The proposed protocol in 3D-PROF is simple and objective, yielding a high level of accuracy. Similar findings were obtained by Titiz et al where the observer's level of experience did not affect the accuracy of various landmarks placement.[22]

Based on the requirements of researchers and surgeons, the proposed technique in 3D-PROF can be modified to allow users to isolate reproducible ROIs to perform further analysis on. In skulls with extensive fractures where anatomical landmarks are lost, this protocol cannot be employed to consistently isolate the orbits. Further development of this protocol with identification of bilateral fractures and reconstruction of the skull can surmount this limitation.[23–25]

Three-dimensional planes of reference for orbital fractures can be made more efficient through automation, by incorporating a set of automated script function that allows users to define a series of steps to isolate the orbit based on predefined landmarks. Automation, such as identification of the planes for hemi-facial and caudal-facial segmentation, has already been rendered into the protocol.[24,26]

Three-dimensional planes of reference for orbital fractures is a versatile platform that can be used to isolate any part of the orbital cavity for further analysis. The protocol proposed in 3D-PROF allows for a reproducible method to isolate the orbital floor and medial wall on 3D CT scans. This allows for better preoperative planning, clinical research, and anatomical studies of the orbit.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Dr. Chan Yiong Huak (Biostatistics Unit, Yong Loo Lin School of Medicine, National University Health Systems, Singapore) for assisting with the statistical analysis of this paper.

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