Expert Consensus on Navigation-guided Unilateral Delayed Zygomatic Fracture Reconstruction Techniques

Yang HE[1], Yi ZHANG[1], Guang Yan YU[1], Chuan Bin GUO[1], Guo Fang SHEN[2], Xin PENG[1], Xiao Jing LIU[1], Jing WANG[1], Wen Bo ZHANG[1], Yan Pu LIU[3], Xiao Ming GU[4], Wei Dong TIAN[5], Li LU[6], Zu Bing LI[7], Shi Lei ZHANG[2]; Society of Oral and Maxillofacial Surgery, Chinese Stomatological Association

The zygoma is located in the medial and lateral parts of the face, supporting the midfacial contour. The forward projection of the zygoma and the zygomatic arch often expose them to injury. Fractures of the zygoma can lead to the displacement of the zygoma and the zygomatic arch, causing facial collapse deformity. For delayed zygomatic fractures, the loss of normal anatomical landmarks caused by the malunion of the fracture lines and remodelling of the bony contour makes it difficult to determine the correct positions of the zygomatic bones. In such cases, ideal and steady outcomes with satisfactory midface symmetry have been difficult to obtain using traditional surgical methods. Nowadays, the application of digital surgical software and surgical navigation helps surgeons to perform accurate preoperative simulations to obtain ideal three-dimensional virtual surgical plans and achieve accurate reduction by intraoperative navigation systems, which increase the accuracy and predictability of fracture reduction outcomes. Experts from the Society of Oral and Maxillofacial Surgery, Chinese Stomatological Association have fully discussed and formulated an expert consensus on navigation-guided unilateral delayed zygomatic fracture reconstruction techniques to standardise the clinical operation procedures and promote the application.

Key words: *delayed zygomatic fractures, digital navigation, unilateral*

Chin J Dent Res 2020;23(1):45–50; doi: 10.3290/j.cjdr.a44335

1 Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, P.R. China.
2 Department of Oral and Craniomaxillofacial Surgery, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, P.R. China.
3 Department of Oral and Maxillofacial Surgery, School of Stomatology, Air Force Military Medical University, Xi'an, P.R. China.
4 Department of Oral & Maxillofacial Surgery, The Third Medical Centre of Chinese PLA General Hospital, Beijing, P.R. China.
5 Department of Oral & Maxillofacial Surgery, West China Stomatology Hospital, Sichuan University, Chengdu, P.R. China.
6 Department of Oromaxillofacial-Head and Neck Surgery, School of Stomatology, China Medical University, Shenyang, P.R. China.
7 Department of Oral and Maxillofacial Surgery, School of Stomatology, Wuhan University, Wuhan, P.R. China.

Corresponding author: Prof. Yi ZHANG, Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, 22# Zhongguancun South Avenue, Haidian District, Beijing 100081, P.R. China. Tel: 86-10-82195158; Fax: 86-10-82195158. Email: zhangyi2000@263.net

The zygoma is located in the medial and lateral parts of the face, supporting the midfacial contour. The forward projection of the zygoma and the zygomatic arch expose them often to injury. Fractures of the zygoma can lead to the displacement of the zygoma and the zygomatic arch, causing facial collapse deformity. For mild zygoma fracture or zygoma fracture occurring within 3 weeks, anatomical reduction and fixation of the fractured bone segments can usually be achieved successfully by proper treatment or surgery. However, for delayed zygomatic fractures, the loss of normal anatomical landmarks, caused by the malunion of the frac-

This article was first published in the Zhonghua Kou Qiang Yi Xue Za Zhi (Chinese Journal of Stomatology) 2019;54(6):363–367 (in Chinese), and this is the second publication using the same contents as the original publication.

ture lines and remodelling of the bony contour, makes it difficult to determine the correct positions of the zygomatic bones. In such cases, ideal and steady outcomes with satisfactory midface symmetry have been difficult to obtain using traditional surgical methods.

Nowadays, the application of digital surgical software and surgical navigation helps surgeons to perform accurate preoperative simulations to obtain ideal three-dimensional (3D) virtual surgical plans and achieve accurate reduction by intraoperative navigation systems, which increases the accuracy and predictability of fracture reduction outcomes[1-5].

Experts from the Society of Oral and Maxillofacial Surgery, Chinese Stomatological Association have fully discussed and formulated an expert consensus on 'Navigation-guided unilateral delayed zygomatic fracture reconstruction techniques', to standardise the clinical operation procedures and promote the application.

Indications for the technique

- Unilateral delayed zygomatic fracture[6];
- No severe craniofacial asymmetry or large bone defects.

Equipment for the technique

Data acquisition equipment

Data from computed tomography (CT) scans can be commonly used in bone surgeries; helix slices of a thickness less than 1.25 mm can meet the accuracy requirements for maxillofacial surgery.

Digital surgical software

Digital surgical software can mainly be used for the preoperative surgical planning and postoperative evaluation of navigation-guided surgery. Navigation-related digital surgical software should have the following features[7]:

- 3D reconstruction and measurements (including length, angle and volume) of the data;
- Surgical planning, including modules such as segmentation, merging, repositioning and mirroring;
- Evaluation of the postoperative accuracy of the surgery and surgical outcome. To evaluate the accuracy of navigation-guided surgery, the symmetry measurements and the 3D colour map analyses are often used to compare the bone location between the preoperative design and the actual surgical results[8].

Surgical navigation system

The surgical navigation system is the key part of the navigation operation, and many surgical navigation systems have emerged, both in China and internationally[9,10]. Passive infrared positioning methods are convenient and flexible, and are the most commonly used location methods at present.

The spatial registration methods are the fiducial-based paired-point transformation (i.e. coordinate registration), surface contour matching (i.e. non-coordinate registration), and a combination of the two. All these methods meet the requirements for maxillofacial navigation surgery.

Preoperative data acquisition and surgical planning

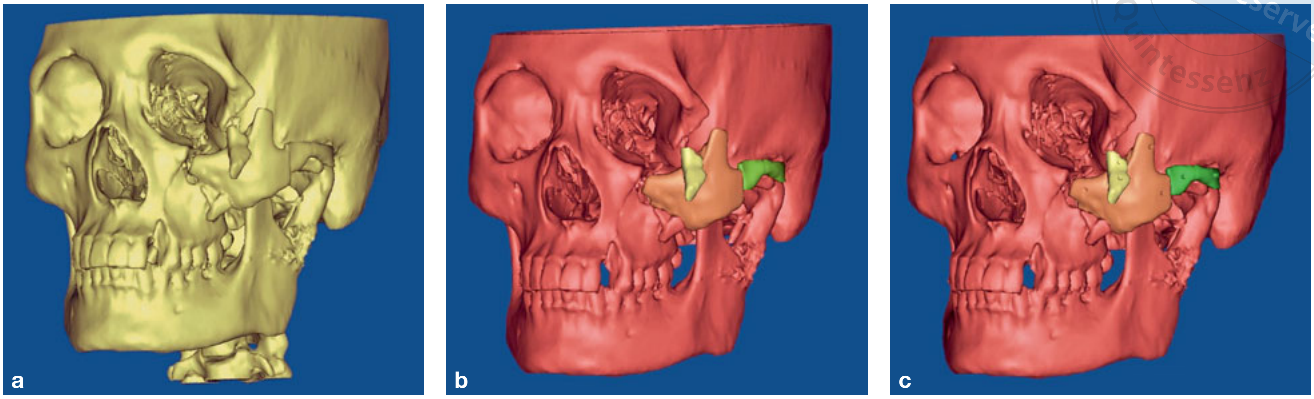
Preoperative data acquisition

All patients should undergo preoperative spiral CT scans. The CT data should be exported as Digital Imaging and Communications in Medicine (DICOM) files.

According to different registration methods, the following aspects need to be noted during data acquisition[10-12]: (1) For the surface contour matching method, the data acquisition time should be as close as possible to the operation time, and the scanning range (usually from the cranial dome to the hyoid bone) must include the registration area; (2) For the fiducial-based paired-point transformation method, the registration point must be marked before the CT examination. The pre-implanted metal screws, the maxillary occlusal plate with metal markers, the metal markers attached to the skin surface, and landmarks of maxillofacial bone tissue should usually be used. The range of registration points should be as close as possible to the surgical area.

Preoperative surgical planning

After importing the preoperative CT data into the digital surgical software, the surgical planning may begin. The surgical planning consists of three steps: (1) The 3D-based image construction of the affected side and segmentation of the zygoma and zygomatic arch fractured segments; (2) The 3D object should be mirrored on the normal side to the affected side; and (3) Virtually repositioning the fractured segments to match the contour of the mirrored normal object, and then generating the reduction navigation plans.



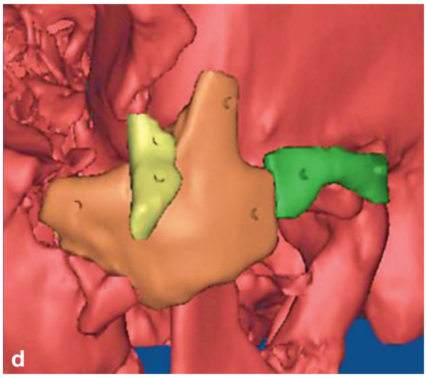


Fig 1 Three-dimensional (3D) reconstruction and segmentation: **(a)** 3D reconstruction; **(b)** Segmentation of the fractured fragments; **(c)** Artificial marker creation and location on the bony fragments surface; **(d)** Local amplification of surface marker creation and location.

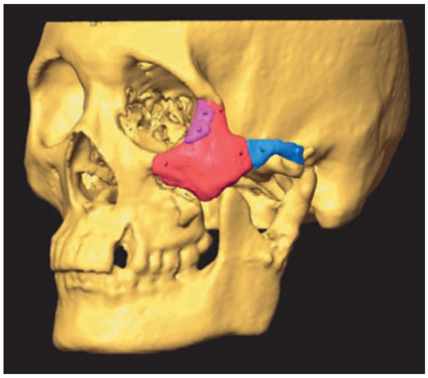


Fig 2 Virtual reduction of the fractured segments.

1. Dimensional reconstruction and segmentation

The CT imaging threshold should be adjusted to the range of the bone window to complete the 3D reconstruction of the maxillofacial region. Using segmentation, the main fractured bony segments that had become separated should be coloured and individually named. To increase the accuracy and efficiency of navigation surgery, artificial markers can be created on the surface of displaced bony segments.

2. Mirroring

The patient's head position should be adjusted, and then the median sagittal plane should be set according to the plane that passes through the nasion, the centre of the sella and the centre of the line that joins the left and right external acoustic foramens. The mirror module of the software should be used to mirror the 3D object on the normal side to the affected side, and the mirrored 3D object should be adjusted to match the non-displaced bony segments of the affected side.

3. Virtual segment reduction

The fractured zygoma and zygomatic arch segments (with markers if artificial markers are used to assist the reduction) must be repositioned to match the contour of the mirrored normal zygoma and zygomatic arch object. Subsequently, the reduction navigation plans can be generated.

Navigation surgery

Registration

First, the navigation data should be imported into the navigation system before surgery. After the induction of general anaesthesia, an incision of approximately 1 cm should be performed on the parietal bone, and the reference frame fixed with reflecting balls to the patient's skull to identify the patient's position. The reference frame needs to be fixed rigidly to avoid intraoperative loosening, and the fixing location should be away from thenatural bone suture. The infrared detection device

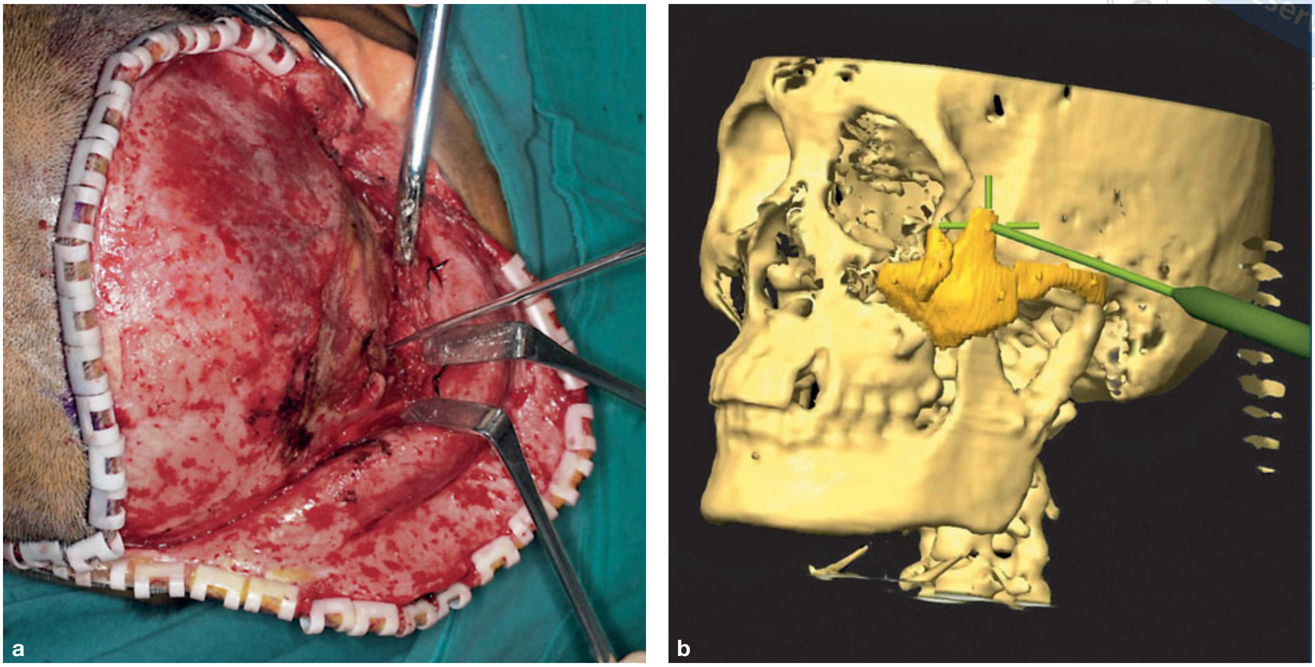


Fig 3 Navigation-guided locations of the artificial surface markers: Confirm the real-time intraoperative location **(a)** to the preoperatively planned position in the navigation system **(b)** , and then drill holes for marking.

should then be directed at the surgical field, and the detection area should manifest the reference frame and the surgical area simultaneously. The registration operation can then begin via fiducial-based paired-point transformation (i.e. coordinate registration) or surface contour matching (i.e. non-coordinate registration).

Marker positioning

The fractured zygoma and zygomatic arch should be exposed. If the artificial markers were created, navigation probes should be used to test for displacement of the fractured bones, and all reduction markers can be produced by drilling holes on the fractured segments.

Navigation-guided bony segments reduction

The fractured segments should be released and reduced. The navigation probes can then be used to test the fractured segment surface and the position should be adjusted to the preoperative planned positions, according to a given sequence of height, projection and width. If artificial markers of the zygoma surface were created, surgeons can reduce each bone segment under the guidance of artificial marker positions from superior to inferior parts and from the anterior to posterior parts. After confirming the final position, the bony segments should be fixed.

Evaluation

Postoperative CT scans should be obtained. Two methods can be used to evaluate the surgical outcome, including navigation accuracy and zygomatic symmetry measurements[13-16]. The accuracy of the navigation surgery can be evaluated by the navigation accuracy, and the bilateral symmetry of the zygoma and zygomatic arch bone can be evaluated using the CT measurements.

Evaluation of navigation accuracy

The postoperative and preoperative planned 3D images of zygomatic and orbital areas should be created as STL files. The preoperative and postoperative data should be imported into the digital surgical software. The 3D coordinates must be aligned after the postoperative data are superimposed. Then, the distance between the corresponding points should be compared to evaluate the accuracy of surgical navigation.

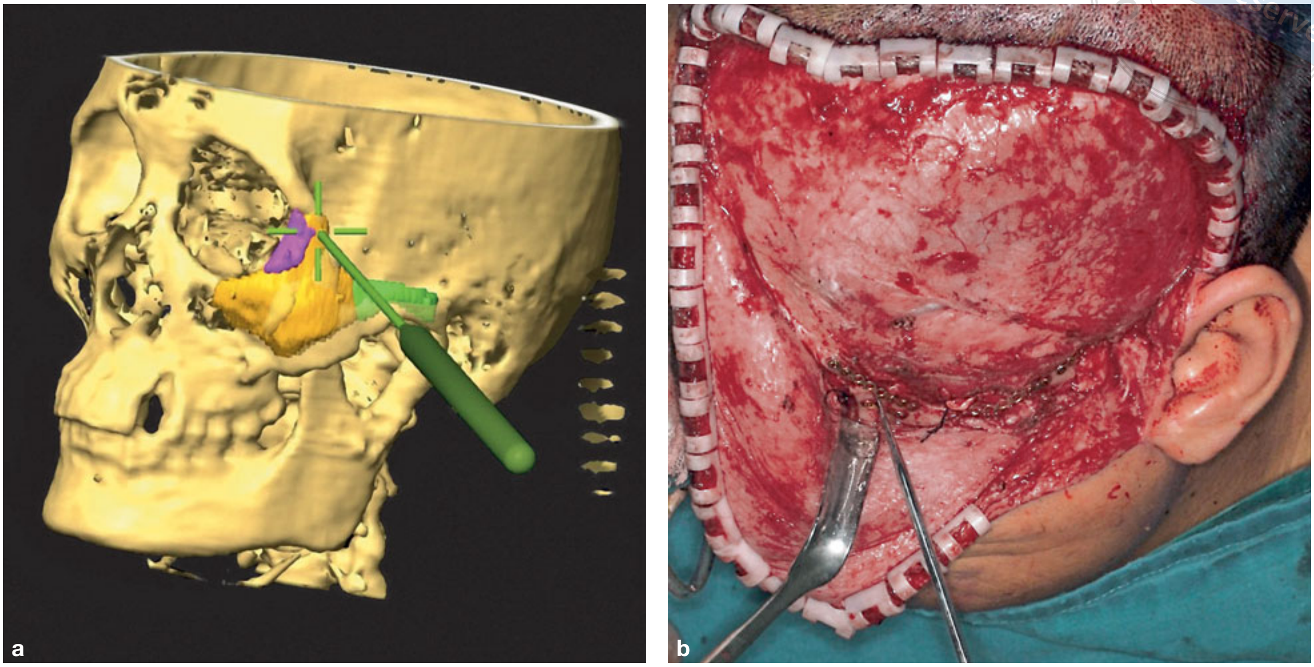


Fig 4 Navigation-guided zygoma reduction using artificial markers: **(a)** the preoperative virtual position; **(b)** superimpose the real-time intraoperative position.

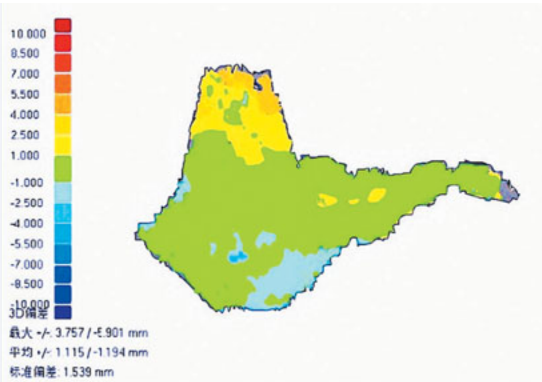


Fig 5 Colour map analysis: Evaluation of the accuracy of postoperative zygoma and zygomatic arch position and the preoperative plan. The blue part indicates that the deviation of the corresponding area is less than 1 mm.

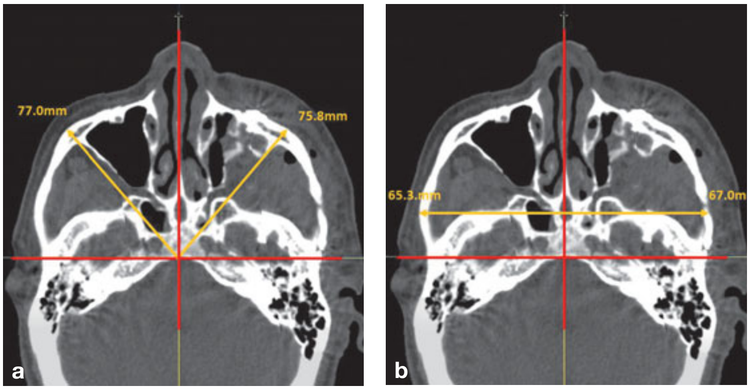


Fig 6 **(a)** and **(b)** Symmetry evaluation of bilateral zygoma eminence and width deviation using axial computed tomography (CT) scans.

Zygoma symmetry CT measurements

The postoperative CT data should be imported into the digital surgical software and the Frankfort plane and the median sagittal plane should be set as reference planes. The midline sagittal line must be set as the Y-axis and the intersection point between the median sagittal plane and the anterior border of the skull base should be set as the coordinate origin. Subsequently, the coordinate system should be established. The vertical distances from the widest point of the zygomatic arch of each side to the Y-axis and distances from the overall high points of the zygomatic contours to the coordinate origin should be measured to evaluate the symmetry of the zygomatic arch after surgery.

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