Journal of Plastic, Reconstructive & Aesthetic Surgery (2020) 73, 337–343

JPRAS
An International Journal of Surgical Reconstruction
www.JPRASurg.com

Orbital floor symmetry after maxillectomy and orbital floor reconstruction with individual titanium mesh using computer-assisted navigation

Yi-Fan Kang, Jie Liang, Zheng He, Lei Zhang, Xiao-Feng Shan[1,*], Zhi-Gang Cai[1,*]

Department of Oral and Maxillofacial Surgery, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Peking University School and Hospital of Stomatology, #22 Zhongguancun Avenue South, Haidian District, Beijing 100081, PR China

Received 21 January 2019; accepted 27 July 2019

KEYWORDS
Orbital reconstruction;
Individual titanium mesh;
Computed-assisted navigation;
Symmetry;
Maxillary reconstruction

Summary *Purpose:* The present study aimed to evaluate the symmetry of the orbital floor after maxillectomy and orbital floor reconstruction with individual titanium mesh using a computer-assisted navigation system.
Patients and methods: Nineteen patients who underwent orbital floor reconstruction with individual titanium mesh were included in this study. Postoperative computed tomography scans recorded after three-dimensional (3D) reconstruction were used to evaluate the symmetry of the orbital floor, including orbital floor height, orbital floor eminence, globe projection, orbital volume, and surface deviation.
Results: The average orbital floor height of the reconstructed and the unaffected side was 37.7 ± 2.3 and 37.8 ± 2.7 mm, respectively ($P = .47$). The average orbital floor eminence of the reconstructed and the unaffected side was 40.1 ± 5.5 and 39.6 ± 5.3 mm, respectively ($P = .17$). The average globe projection of the reconstructed and the unaffected side was 15.5 ± 3.2 and 15.3 ± 3.0 mm, respectively ($P = .27$). The average orbital volume of the reconstructed and the unaffected side was 25.9 ± 4.4 and 26.3 ± 4.4 cm^3, respectively ($P = .29$). Repeatability between the reconstructed and the unaffected side was 88.3% ± 2.6% at within 1 mm and 98.6% ± 0.9% at within 2 mm. The average of maximum deviation was 2.4 ± 0.2 mm.

[1]Both authors equally contributed to this work.
* Corresponding authors.
E-mail addresses: kqsxf@263.net (X.-F. Shan), c2013xs@163.com (Z.-G. Cai).

https://doi.org/10.1016/j.bjps.2019.07.014

Conclusion: Individual titanium mesh is one of the best techniques for orbital floor reconstruction, as it can be placed precisely and helps achieve desirable esthetic outcomes through virtual surgical planning and using a computer-assisted navigation system.

Introduction

Defects of the maxilla combined with orbital floor resulting from tumor ablative surgery can severely affect patients' facial function and appearance.[1-3] It may cause enophthalmos, exophthalmos, diplopia, and impaired visual acuity, thus affecting quality of life.[4,5] Such defects lead to loss of support to the orbit, the zygomaticofacial complex, and the dental arch. In addition, patients may develop midface collapse and ophthalmic complications after reconstruction failure. The complicated shape and contour of the orbital floor makes it difficult to reconstruct the maxilla combined with an orbital floor defect using a single flap. Restoration of such defects, both esthetically and symmetrically, can be challenging for a surgeon.

The titanium mesh is used widely in orbital bone fractures to reconstruct the orbital floor.[6] It can be prebent to simulate orbital bone structure and the shape of the orbital floor. Currently, virtual surgical planning (VSP), computer-aided design/computer-aided manufacture (CAD/CAM), and computer-assisted navigation are well-developed tools that help improve the precision of the prebent titanium mesh.[7] Moreover, individual titanium mesh based on rapid prototyping is another good choice for reconstruction.[8] Preoperative VSP uses the mirroring technique to reconstruct orbital floor defects, which helps provide desirable esthetic outcomes. However, only few studies have reported outcomes of orbital floor reconstruction with individual titanium mesh after tumor ablation. The aim of the present study was to evaluate the symmetry of the orbital floor after maxillectomy and orbital floor reconstruction with individual titanium mesh using a computer-assisted navigation system.

Patients and methods

Patients

Patients who underwent orbital floor reconstruction by a single surgical team at the Department of Oral and Maxillofacial Surgery, Peking University School of Stomatology, Beijing, China, between January 2012 and September 2017 were enrolled in this study. Inclusion criteria were (i) defects of the maxilla and the orbital floor after tumor ablation, (ii) orbital floor reconstruction with individual titanium mesh, and (iii) surgery guided using a computer-assisted navigation system. Exclusion criteria were (i) bilateral orbital floor defects, (ii) defects involving the orbital wall, and (iii) obvious preoperative differences in visual acuity and eye globe movement between the unaffected and the affected side. In total, 19 patients were included in this retrospective study. This study adhered to principles of the Declaration of Helsinki in terms of medical protocols and ethics and was approved by the institutional ethics committee (PKUSSIRB – 201412028).

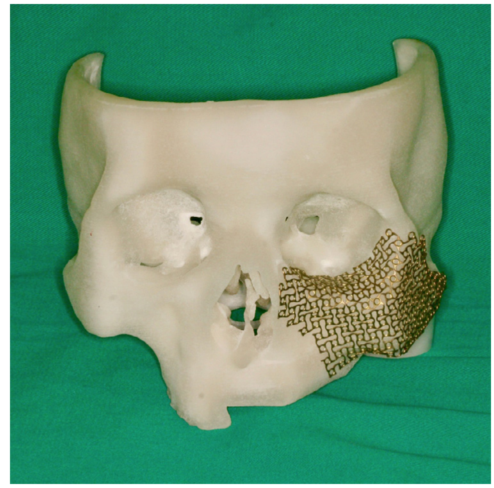

Figure 1 After virtual surgical planning, a resin stereo model was printed for prebending of the titanium mesh.

Surgical procedure

Patients' preoperative CT scans (120 kV, 25 mAs, SW = 1.25 mm) were used for VSP. Tumor resection and maxillectomy were simulated using Proplan CMF 1.4 (Materialize, Belgium) and iPlan CMF 3.0 (BrainLab, Germany). The orbital floor was reconstructed using the mirroring technique from the unaffected side, and a resin stereo model was printed for prebending of the titanium mesh (Figure 1). The entire surgery was conducted under the guidance of a navigation system of VectorVision workstation (BrainLab, Germany). After tumor resection and maxillectomy, the titanium mesh was guided into position using the navigation system. The maxillary defect was rehabilitated using a deep circumflex iliac artery bone flap (DCIA), free fibular flap (FFF), or anterolateral thigh flap (ALT). The mesh surface was completely covered by soft tissue. After mesh and flap fixation, location and contour of implants and bone grafts were confirmed using the navigation system, and adjustments were made according to preoperative VSP (Figure 2).

Symmetry evaluation

Computed tomography (CT) scans were obtained at 1 month after surgery, and cephalometric analysis was performed

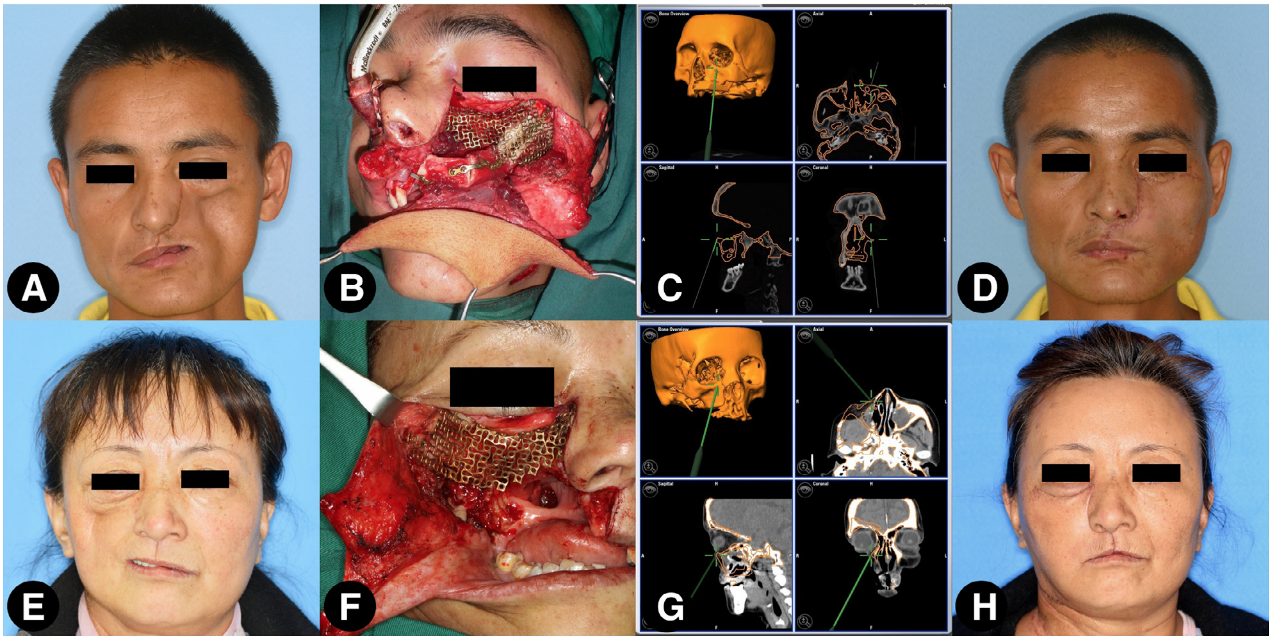

Figure 2 Surgical procedure. (A) A 21-year-old male patient with left maxillary defect due to gingival carcinoma was reconstructed with a fibular flap and a titanium mesh. (B) A three-segment fibular flap and a titanium mesh were fixed. Subcutaneous tissue of the skin island was used to cover the titanium mesh to increase the thickness of soft tissue over the titanium mesh, and skin of the skin island was removed. (C) A computer-assisted navigation system (CANS) was used to place the titanium mesh precisely. (D) Postoperative facial profile. (E) A 55-year-old female patient with right maxillary defect due to maxillary sinus carcinoma was reconstructed with the ALT flap and titanium mesh. (F) The titanium mesh was fixed. Subcutaneous tissue of the skin island was used to cover the titanium mesh to increase the thickness of soft tissue over titanium mesh, and part of the skin was removed. (G) Computer-assisted navigation system (CANS) was used to place the titanium mesh precisely. (H) Postoperative facial profile.

using Proplan CMF. Distance between the midpoint of the superior orbital rim (Om) and the orbitale (Or) was defined as the orbital floor height, which was measured to represent the vertical position of the orbital floor. On the other hand, distance from the optic foramen (Of) to Or was defined as the orbital floor eminence, which was measured to represent the sagittal position of the orbital floor (Figure 3(A)).

Globe projection and orbital volume were measured using iPlan CMF. Before measurement, the Frankfort horizontal plane was adjusted to be parallel to the horizontal plane and to divide the midsagittal plane equally into right and left parts. On an axial slice with the largest diameter of the eye globe, a baseline was drawn from the anterior point of the lateral orbital rim to the midsagittal line. Distance from the most prominent point of the cornea to the baseline was defined as the globe projection (Figure 3(B)). Orbital volume was measured by autosegmentation of the orbital cavity under the bony window and automatically calculated using a computer (Figure 3(C)).

The unaffected orbital cavity was mirrored on the reconstructed side using Geomagic Control 2014 (3D systems, USA) to assess surface deviation of the orbital floor. "Three-dimensional (3D) comparison" was applied to illustrate deviation from the mirrored unaffected side in a deviation spectrum. The resulting error grade color map represented the surface deviation between the reconstructed and the unaffected side (Figure 3(D)).

Statistical analysis

All statistical analyses were performed using SPSS 20 (SPSS Inc., USA). All measurements were performed by the same investigator twice. The time interval between each measurement was 2 weeks. Intraobserver reproducibility was evaluated using intraclass correlation coefficient (ICC). Paired *t*-test was used to investigate differences between the reconstructed and the unaffected side in terms of orbital floor height, orbital floor eminence, globe projection, and orbital volume.

Results

In total, 19 patients (11 men and 8 women) were included in this study (Table 1). All patients had unilateral orbital defects after tumor ablation, and the orbital floor was all reconstructed using individual titanium mesh, prebent upon the 3D resin model. The median patient age was 44 (range: 7-62) years. Intraobserver reproducibility was good (ICC $= 0.89$). All patients were followed up for >1 year (14-48 months). None of the patients experienced any disturbances in vision or eye globe movement dysfunction, and none of the patients had titanium mesh exposure.

At 1 month after surgery, the average orbital floor height of the reconstructed and unaffected sides was 37.7 ± 2.3

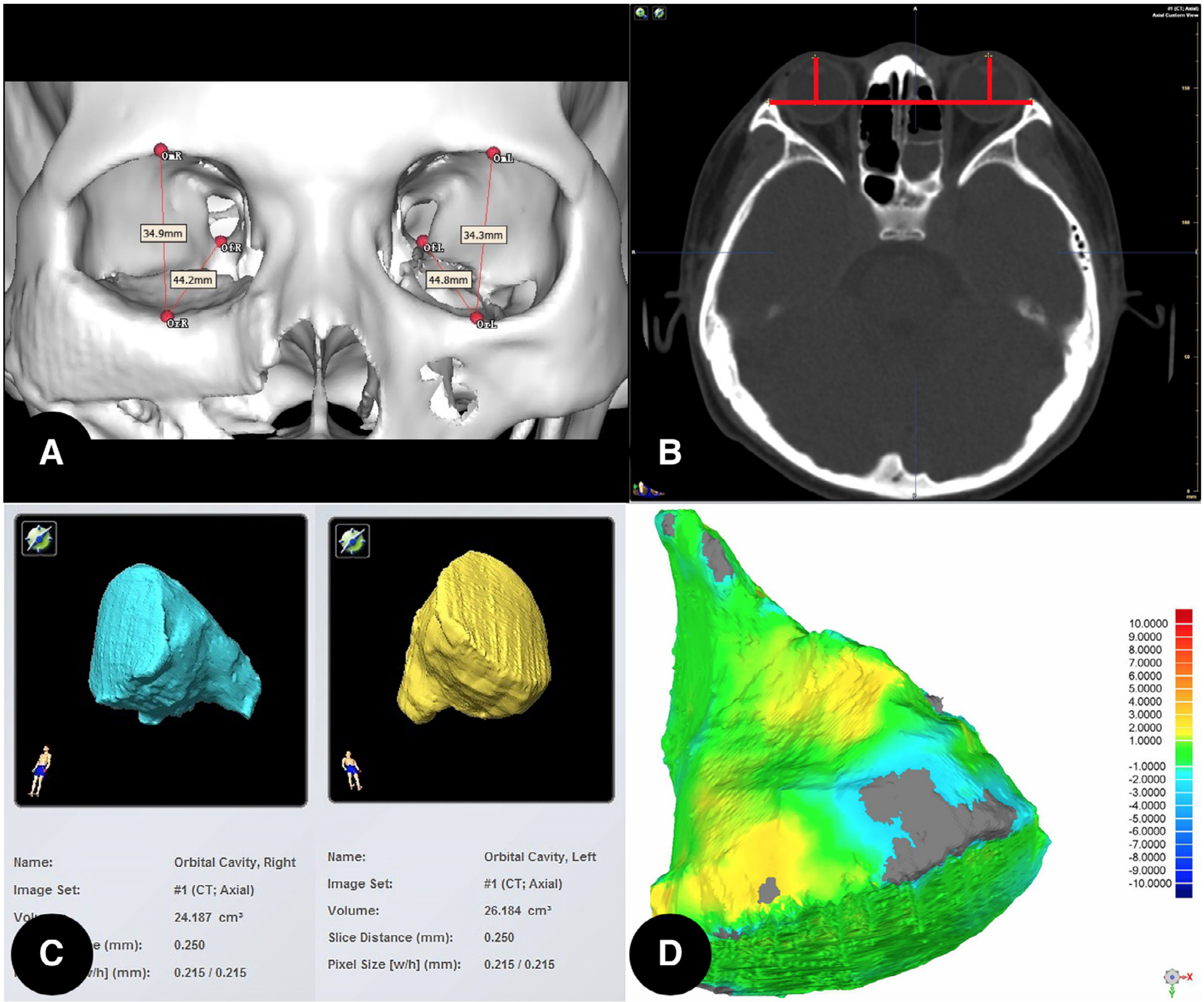

Figure 3 Symmetry evaluation. (A) Distance between the midpoint of the superior orbital rim (Om) and the orbitale (Or) was defined as orbital floor height, which was measured to represent the vertical position of the orbital floor; distance from the optic foramen (Of) to Or was defined as orbital floor eminence, which was measured to represent the sagittal position of the orbital floor. (B) On an axial slice with the largest diameter of the eye globe, a baseline was drawn from the anterior point of the lateral orbital rim to the midsagittal line; distance from the most prominent point of the cornea to the baseline was defined as globe projection. (C) Orbital volume was measured by autosegmentation of the orbital cavity under the bony window and calculated automatically using iPlan CMF software. (D) "3D comparison" was applied to illustrate deviation from the mirrored unaffected side in a deviation spectrum; the resulting error grade color map represented surface deviation between the reconstructed and the unaffected side.

and 37.8 $\pm$ 2.7 mm, respectively; no significant difference was noted between both sides ($P = .47$). The average orbital floor eminence of the reconstructed and unaffected sides was 40.1 $\pm$ 5.5 and 39.6 $\pm$ 5.3 mm, respectively; no significant difference was noted between both sides ($P = .17$). In addition, the average globe projection of reconstructive and unaffected sides was 15.5 $\pm$ 3.2 and 15.3 $\pm$ 3.0 mm, respectively, and the difference was not significant ($P = .27$). Moreover, the average orbital volume of the reconstructed and unaffected sides was 25.9 $\pm$ 4.4 and 26.3 $\pm$ 4.4 cm^3, respectively, and again, the difference was not significant ($P = .29$) (Figure 4).

Furthermore, repeatability between the reconstructed and the unaffected side was 88.3% $\pm$ 2.6% at within 1 mm and 98.6% $\pm$ 0.9% at within 2 mm. The average of maximum deviation was 2.4 $\pm$ 0.2 mm. These findings indicated good morphological symmetry on both sides (Table 2).

Discussion

Flaps raised using the Weber-Fergusson approach are usually too thin and thus pose risks of titanium mesh exposure and wound dehiscence. Nakayama reported a titanium mesh exposure rate of 27.8% and suggested reducing the proportion of titanium mesh and debridement to resolve this issue.[9] In our study, although inflammatory reactions were observed in the maxillary sinus region in follow-up CT scans without any complaints, no mesh exposure was observed during the follow-up period (14–48 months). Based on our

Table 1 Patient characteristics.

Variable	Clinical details
Number of patients	19
Sex	
Male	11
Female	8
Median age (year, range)	44 (7-62)
Disease	
Benign tumor	11
Malignant tumor	8
Reconstruction flaps	
ALT[a]	11
FFF[b]	7
DCIA[c]	1
Complications	
Disturbance of vision	None
Dysfunction of eye movement	None
Titanium mesh exposure	None

[a] Anterolateral thigh flap.
[b] Free fibular flap.
[c] Deep circumflex iliac artery bone flap.

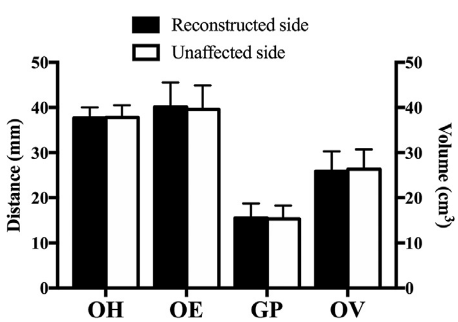

Figure 4 No significant differences were noted between the reconstructed and the unaffected side in terms of orbital floor height ($P = .47$), orbital floor eminence ($P = .17$), globe projection ($P = .27$), and orbital volume ($P = .29$). OH: orbital floor height (mm); OE: orbital floor eminence (mm); GP: globe projection (mm); and OV: orbital volume (cm^3).

experience, two factors might have contributed to this result: first, confirming sufficient soft tissue coverage, and second, establishing appropriate pathway for postoperative infection drainage. Our strategy was to leave the titanium mesh interconnected with the nasal cavity. In case of an infection, the exudate would be drained into the nasal cavity instead of accumulating in the facial region, thus avoiding exposure of the titanium mesh.

The midface can be divided into three zones: the malar region, the infraorbital rim, and the pyriform aperture. The infraorbital rim is an important part of the facial horizontal buttresses, which connects the nose and the zygoma. Moreover, the infraorbital rim supports the lower eyelids and soft tissues of the cheek.[10] When vertical and sagittal positions of the titanium mesh are not accurate, the face seems more senile and the lower eyelid may be malpositioned.[11] Thus, asymmetry of the orbital floor reconstructed using an individual titanium mesh may cause severe facial soft tissue asymmetry and esthetic issues.

Table 2 Deviation distribution and maximum deviation of orbital cavity.

Patient no.	Deviation distribution (%)		Maximum deviation (mm)
	≤±1 mm	≤±2 mm	
1	90.2	99.3	2.2
2	87.7	98.3	2.2
3	92.9	99.0	2.5
4	83.3	97.5	2.5
5	89.5	99.8	2.1
6	83.6	96.9	2.4
7	86.5	99.1	2.4
8	88.4	97.2	2.6
9	86.6	98.9	2.3
10	88.3	97.6	2.4
11	87.4	99.1	2.5
12	90.0	99.5	2.4
13	87.7	99.1	2.2
14	89.8	98.1	2.5
15	89.7	99.0	2.3
16	86.2	98.0	2.7
17	93.3	99.8	2.2
18	86.9	97.3	2.5
19	89.9	99.6	2.4
Mean ± SD	88.3 ± 2.6	98.6 ± 0.9	2.4 ± 0.2

Several studies have evaluated effects of orbital floor reconstruction after tumor ablation or fracture on eye function in terms of orbital volume, globe projection, and postoperative vision.[4,12] With the computer-assisted navigation system, orbital function can be well preserved. In the present study, no significant difference was noted in postoperative orbital volume and globe projection between the reconstructed and the unaffected side ($P > .05$). In addition, none of the patients experienced any disturbances in vision or eye globe movement dysfunction. Of note, few studies have assessed the symmetry of orbital floor reconstruction, and most of these studies were based on subjective evaluation by a doctor or the patient without a universally accepted standard.[12] Although change in orbital volume is one of the most important indicators of postoperative outcomes, shape and position of the titanium mesh cannot be determined by volume measurements alone. Accordingly, we proposed a new method to evaluate the symmetry of the orbital floor after reconstruction surgery by using 3D measurement. In a previous study, orbital height, orbital width, and orbital eminence were used to evaluate orbital development in children.[13] These three parameters were used to approximately describe orbital cavity in 3D; among these parameters, orbital height and eminence were most closely related to vertical and sagittal positions of the orbital floor. However, the extent of surgery did not include the midpoint of the superior orbital margin and the optic foramen. Thus, the position of Or on the reconstructed side represented the position of the orbital floor. This method can be used to objectively evaluate the 3D position of orbital floor reconstruction.

In our study, preoperative VSP was performed in 19 patients. For unilateral orbital defects after tumor ablation, we used the mirrored unaffected side as a reference; thus, the mirrored unaffected orbital cavity was used to evaluate surgical outcomes as well. Mirroring has been used as one of the best tools for reconstruction of defects in VSP and has been proven as a legitimate method to simulate anatomy.[14] Although asymmetry is a common finding in facial hard tissues, and the average difference between left and right measurements is typically <3 mm or 3%,[15] assessment of facial asymmetry is often inadequate in regions covered by soft tissues.[16] In our study, deviation between the reconstructed and the unaffected side was 88.3% $\pm$ 2.6% at within 1 mm and 98.6% $\pm$ 0.9% at within 2 mm. Moreover, the average of maximum deviation was 2.4 ± 0.2 mm. Collectively, these findings indicated good surgical outcomes for orbital floor morphology, which also proved mirroring as a reliable VSP technique for reconstruction of unilateral defects. However, it remained unclear whether a difference of >3 mm meant that the outcome was not symmetric. Gateno et al. indicated that people with larger faces will have higher values of facial asymmetry.[17] Zimmerer et al. proposed several factors that influence clinical parameters of orbital floor reconstruction from both patient's and medical viewpoints.[4] Thus, it remains uncertain how large of a difference can cause asymmetric surgical outcomes.

Several studies have reported use of an intraoperative navigation system for orbital floor reconstruction, some of which have shown that navigation-assisted orbital floor reconstruction is precise and safe.[7,8,18,19] A navigation system is an intraoperative tool used by surgeons to compare the actual location of an implant with the target location. It can significantly reduce implant translation and rotation errors.[20] Prebending of individual titanium mesh was used for orbital floor reconstruction to acquire favorable results.[21] It has various advantages such as convenience of fabrication, stability, flexibility, no donor site morbidity, and reduced operation time.[12] Currently, use of prebent titanium mesh with a navigation system is the best choice for orbital floor reconstruction in our hospital. Although satisfactory outcomes can be acquired in most situations, manual bending of the titanium mesh inevitably produces errors.[8] The rapid prototyping individual titanium mesh might be a solution to this issue. A multicenter study showed that CAD-based individual orbital implants were more precise for reconstruction.[4] However, this technique also has certain drawbacks: design and manufacture of rapid prototyping individual titanium meshes require more time than prebent titanium meshes, which might delay the surgery. Moreover, rapid prototyping might increase treatment costs as well, which results in increased financial burden on patients.[8] Thus, although use of individual titanium mesh based on rapid prototyping for reconstruction is a developing trend, we still need more time and practice to improve this technique before making it a standard clinical procedure.

In conclusion, the individual titanium mesh is one of the best choices for orbital floor reconstruction. It can be placed precisely and helps achieve desirable esthetic outcomes through VSP and computer-assisted navigation. Individual titanium mesh based on rapid prototyping is the future direction for orbital floor reconstruction.

Declaration of Competing Interest

None.

Acknowledgments

This work was supported by the National Key Research and Development Program of China (grant no. 2016YFC1102902) and Beijing Municipal Development Foundation of China (grant no. Z161100000516016 and Z171100001017129).

References

1. Muzaffar AR, Adams WP Jr, Hartog JM, Rohrich RJ, Byrd HS. Maxillary reconstruction: functional and aesthetic considerations. *Plast Reconstr Surg* 1999;**104**:2172–83 quiz 84.
2. Cordeiro PG, Chen CM. A 15-year review of midface reconstruction after total and subtotal maxillectomy: part I. Algorithm and outcomes. *Plast Reconstr Surg* 2012;**129**:124–36.
3. Futran ND, Mendez E. Developments in reconstruction of midface and maxilla. *Lancet Oncol* 2006;**7**:249–58.
4. Zimmerer RM, Ellis E 3rd, Aniceto GS, et al. A prospective multicenter study to compare the precision of posttraumatic internal orbital reconstruction with standard preformed and individualized orbital implants. *J Craniomaxillofac Surg* 2016;**44**:1485–97.
5. Wang S, Xiao J, Liu L, et al. Orbital floor reconstruction: a retrospective study of 21 cases. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008;**106**:324–30.
6. Dubois L, Steenen SA, Gooris PJ, Mourits MP, Becking AG. Controversies in orbital reconstruction I. Defect-driven orbital reconstruction: a systematic review. *Int J Oral Maxillofac Surg* 2015;**44**:308–15.
7. Novelli G, Tonellini G, Mazzoleni F, Bozzetti A, Sozzi D. Virtual surgery simulation in orbital wall reconstruction: integration of surgical navigation and stereolithographic models. *J Craniomaxillofac Surg* 2014;**42**:2025–34.
8. Rana M, Chui CH, Wagner M, et al. Increasing the accuracy of orbital reconstruction with selective laser-melted patient-specific implants combined with intraoperative navigation. *J Oral Maxillofac Surg* 2015;**73**:1113–18.
9. Nakayama B, Hasegawa Y, Hyodo I, et al. Reconstruction using a three-dimensional orbitozygomatic skeletal model of titanium mesh plate and soft-tissue free flap transfer following total maxillectomy. *Plast Reconstr Surg* 2004;**114**:631–9.
10. Neligan P. *Plastic surgery*. London: Elsevier saunders; 2013.
11. Yaremchuk MJ, Kahn DM. Periorbital skeletal augmentation to improve blepharoplasty and midfacial results. *Plast Reconstr Surg* 2009;**124**:2151–60.
12. Zhang WB, Mao C, Liu XJ, et al. Outcomes of orbital floor reconstruction after extensive maxillectomy using the computer-assisted fabricated individual titanium mesh technique. *J Oral Maxillofac Surg* 2015;**73**:2065.e1.
13. Hou Z, Xian J, Chang Q, Wei W, Li D. Digital evaluation of orbital development after self-inflating hydrogel expansion in chinese children with congenital microphthalmia. *J Plast Reconstr Aesthet Surg* 2016;**69**:706–14.
14. Jansen J, Dubois L, Schreurs R, et al. Should virtual mirroring be used in the preoperative planning of an orbital reconstruction? *J Oral Maxillofac Surg* 2018;**76**:380–7.
15. Farkas LG, Cheung G. Facial asymmetry in healthy North American Caucasians. An anthropometrical study. *Angle Orthod* 1981;**51**:70–7.

16. Ferrario VF, Sforza C, Ciusa V, Dellavia C, Tartaglia GM. The effect of sex and age on facial asymmetry in healthy subjects: a cross-sectional study from adolescence to mid-adulthood. *J Oral Maxillofac Surg* 2001;**59**:382–8.
17. Gateno J, Jones TL, Shen SGF, et al. Fluctuating asymmetry of the normal facial skeleton. *Int J Oral Maxillofac Surg* 2017.
18. Yu H, Shen SG, Wang X, Zhang L, Zhang S. The indication and application of computer-assisted navigation in oral and maxillofacial surgery – Shanghai's experience based on 104 cases. *J Craniomaxillofac Surg* 2013;**41**:770–4.
19. Markiewicz MR, Dierks EJ, Bell RB. Does intraoperative navigation restore orbital dimensions in traumatic and post-ablative defects. *J Cranio-Maxillofac Surg* 2012;**40**:142–8.
20. Dubois L, Schreurs R, Jansen J, et al. Predictability in orbital reconstruction: a human cadaver study. Part II: navigation-assisted orbital reconstruction. *J Craniomaxillofac Surg* 2015;**43**:2042–9.
21. Metzger MC, Schon R, Schmelzeisen R. Preformed titanium meshes: a new standard? *Skull Base* 2007;**17**:269–72.