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The Precise Repositioning Instrument for Genioplasty and a Three-Dimensional Printing Technique for Treatment of Complex Facial Asymmetry

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Abstract
Background Facial asymmetry is very common in maxillofacial deformities. It is difficult to achieve accurate reconstruction. With the help of 3D printing models and surgical templates, the osteotomy line and the amount of bone grinding can be accurate. Also, by means of the precise repositioning instrument, the repositioning of genioplasty can be accurate and quick. In this study, we present a three-dimensional printing technique and the precise repositioning instrument to guide the osteotomy and repositioning, and illustrate their feasibility and validity.
Methods Eight patients with complex facial asymmetries were studied. A precise 3D printing model was obtained. We made the preoperative design and surgical templates according to it. The surgical templates and precise repositioning instrument were used to obtain an accurate osteotomy and repositioning during the operation. Postoperative measurements were made based on computed tomographic data, including chin point deviation as well as the symmetry of the mandible evaluated by 3D curve functions.
Results All patients obtained satisfactory esthetic results, and no recurrences occurred during follow-up. The results showed that we achieved clinically acceptable precision for the mandible and chin. The mean and SD of ICC between R-Post and L-Post were 0.973 ± 0.007. The mean and SD of chin point deviation 6 months after the operation were 0.63 ± 0.19 mm.
Conclusion The results of this study suggest that the three-dimensional printing technique and the precise repositioning instrument could aid in making better operation designs and more accurate manipulation in orthognathic surgery for complex facial asymmetry.
Level of Evidence IV This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine ratings, please refer to the Table of Contents or the online Instructions to Authors www.springer.com/00266.

Keywords Orthognathic surgery · Facial deformity · Three-dimensional printing technique · Surgical template · Precise repositioning instrument

Lin Wang and Dan Tian made the equal contribution to this study.

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Introduction

Serious maxillofacial deformities always incorporate facial asymmetry, especially the mandible and chin. Orthognathic surgery is regarded as an effective treatment. But it is difficult to achieve accurate reconstruction just based on the traditional techniques. Inaccurate preoperative analysis and surgical procedures lack of guidance can lead to unintentional faults, such as overcorrection/undercorrection, inferior alveolar nerve injury and facial asymmetry

[1–3]. So, it is necessary to find an effective way to perform surgery precisely.

Nowadays, precise technique in orthognathic surgery is more and more important with the development of digital technology, 3D printing techniques, navigation technology and special surgical instruments for orthognathic surgery [4–8]. The reliability and precision of computer-assisted orthognathic surgery have been widely reported [9]. However, reports concerning treatment especially for extreme asymmetry of the mandible and chin are limited [10]. In this study, we report a novel protocol whereby a patented instrument, named the precise repositioning instrument for genioplasty, and a three-dimensional printing technique together are used in the treatment of complex facial asymmetry, and illustrate their feasibility and validity.

Patients and Methods

From 2014 to 2016, eight adult patients (four females and four males, age range 20–24 years) with complex facial asymmetry were treated at our hospital. All patients had surgery during which 3D printing models, a variety of surgical templates and the precise repositioning instrument were used. The follow-up of each patient was at least 6 months. Photographic and radiographic examinations were performed preoperatively and 6 months after the operation, including frontal and lateral photographs of the patients at rest, posteroanterior and lateral radiographs, as well as CT. All patients were informed of the new method and traditional options preoperatively, and the patients gave consent for participation. The ethics committee of the hospital approved the study.

The Precise Repositioning Instrument for Genioplasty

We developed and patented (Patent No. 201410032051. 2, China) a special instrument for genioplasty, named the precise repositioning instrument for genioplasty. The instrument has two parts, and each part includes an intermediate rod, which has a semicylindrical plane (Fig. 1a, b). Firstly, the two parts of the instrument were, respectively, fixed at both sides of the chin osteotomy line with screws during genioplasty (Fig. 2a). The intermediate rod of the upper half is consistent with the middle sagittal plane of the face. The intermediate rod of the lower half is consistent with the sagittal mid-plane of the chin. After the osteotomy is performed, the lower half with the chin bone is moved to coincide with the intermediate rod at the upper half (Fig. 2b). So the chin mid-plane is located at the middle sagittal plane of the face. The procedure for use has been

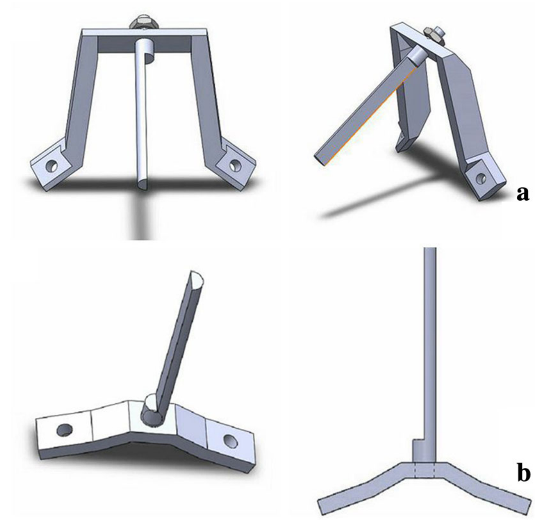

Fig. 1 The two parts of the precise repositioning instrument for genioplasty. **a** The part to be located on the upper chin bone, aligned to the middle sagittal plane of the face. **b** The part to be located on the truncated chin bone segment, aligned to the chin mid-plane

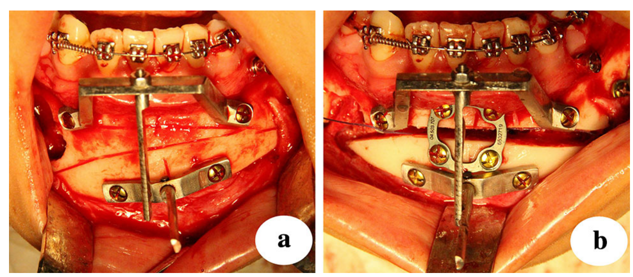

Fig. 2 **a** Placement of the precise repositioning instrument. **b** The truncated chin bone segment is located according to the precise repositioning instrument and fixed by one square titanium plate

explained in detail in a previous article [11]. This instrument allows for accurate and quick reposition of the chin bone with multidirectional translation and rotation.

Accurate Diagnosis and Preoperative Plan According to the 3D Printing Model

The patient received conventional clinical examination and preoperative CBCT scans. The scanning data were exported as DICOM format files and were imported into Mimics software (Version 8.01, Belgium) to generate virtual models. Then, the virtual model of the mandible was segmented and was exported to a 3D printer (Objet Eden 250, Israel) for a 3D printing model.

The diagnosis and plan were made based on clinical examination and virtual models. The surgery for complex asymmetry of the mandible and chin was precisely planned on the 3D printing model. The osteotomy lines were designed according to the mirror image on the mandible, with the facial midline as the axis of symmetry on the 3D printing model (Fig. 3a, b).

Design and Manufacture of the Templates

The templates were used to mark the osteotomy lines on 3D printing models. Firstly, the operative region of the 3D printing model was covered with wax. Secondly, the wax on the segment to be cut off was removed according the planned osteotomy lines. Then, the templates were made of self-curing plastics (Fig. 3c, d). In this way, the borders of the templates were easy to be formed. Finally, one hole or an extended edge was placed on the templates for fixation. Before the operation, the templates were immersed in povidone–iodine solution for 45 min.

Application of Templates and the Precise Repositioning Instrument in Surgery

All the patients were operated on under general anesthesia using nasotracheal intubation. The maxilla and mandible were exposed, and the templates were fixed on the bone through pre-drilled holes or an extended edge. The resection margins guided the saw blade to make the osteotomy as planned (Fig. 4a, b). The precise repositioning instrument was used to locate the segment truncated, and it was fixed by one titanium plate (Fig. 4c, d).

Evaluation of Postoperative Outcome

The postoperative analyses were done with CBCT data to compare the clinical results. For the analysis of postoperative symmetry, the postoperative three-dimensional coordinate values (x, y, z) regarding mandibular margins were obtained in Freeform software (version 12.0; Geomagic, Morrisville, NC, USA). We chose six points on the mandibular margins of each side in the lateral view. The goodness of fit between the left and right side was then calculated through the intraclass correlation coefficient (ICC) via SPSS 17.0 (SPSS, Chi-cago, IL, USA). The chin point deviation was also used for postoperative evaluation criteria in the frontal view.

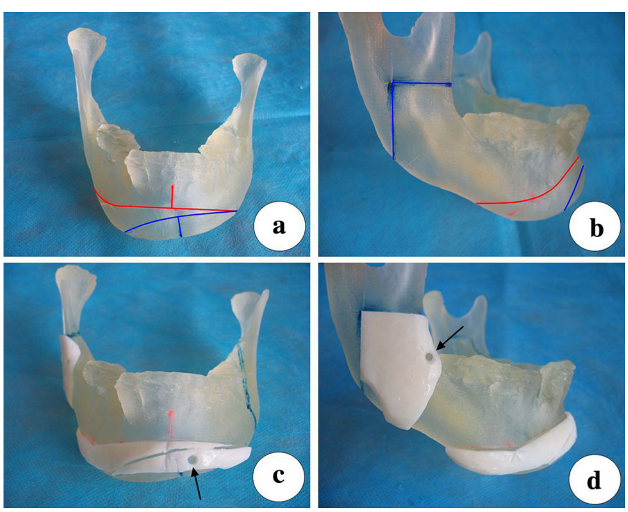

Fig. 3 3D printing model analysis. **a**, **b** The osteotomy lines designed according to the mirror image on mandible, with the facial midline as the axis of symmetry on the 3D printing models. **c**, **d** The templates made of self-curing plastics marked the osteotomy lines on 3D printing models. *Arrows* indicate the hole for fixation

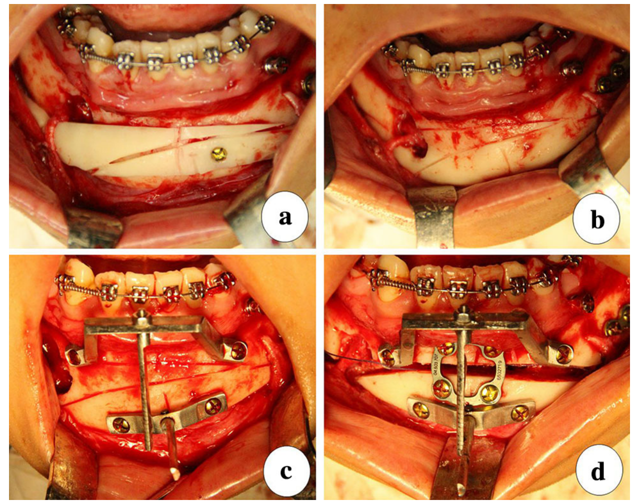

Fig. 4 **a** Dissected the right inferior alveolar nerve and placement of the surgical template. **b** Osteotomy lines made according to the surgical template. **c** Placement of the precise repositioning instrument. **d** Truncated chin bone segment located according to the precise repositioning instrument and fixed by one square titanium plate

Case Series

Patient 1

A 22-year-old female came to the hospital with a complaint of facial asymmetry. She had no previous orthognathic operation, craniofacial syndrome, or jaw bone trauma or tumor. Clinical examination revealed that the chin deviated to the left for about 13 mm and hyperevolutism of the TMJ, ramus and body on the right side. The maxilla had compensated changes with a canting to the right side for about 9 mm, and she had relatively normal occlusion (Fig. 5). The radiographic examination further confirmed the diagnosis of hemimandibular hypertrophy (Fig. 6a, b).

Bimaxillary orthognathic surgery was planned. The difficult points of this case were the badly deviated chin and the hyperevolutism of the right mandible body. So, the osteotomy lines on the chin were designed in reference to the mirror image of the left side, with the facial midline as the axis of symmetry on the 3D printing model (Fig. 7a, b). The template was made to mark the two planned osteotomy

Fig. 5 Preoperative photographs showed facial deformities of the patient

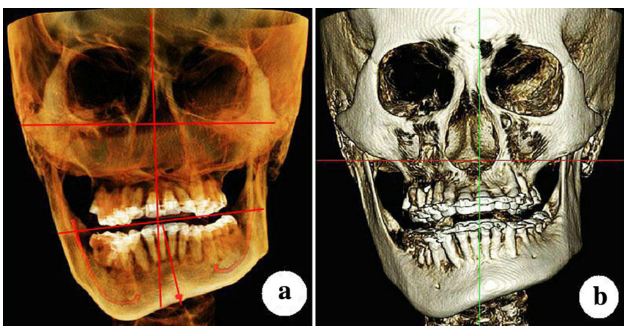

Fig. 6 CT scan reconstruction of the patient before surgery. **a** Reconstruction of the inferior alveolar nerve canal. **b** Upper and lower jaw reconstruction

lines and was formed on the chin with a screw (Fig. 7c, d). The osteotomy lines of the inverted-L osteotomy of the ramus on the right side were designed on the model (Fig. 7b). The template was made commensurate with the planned osteotomy line with a screw for fixation (Fig. 7d). The surgical simulation was done on the model (Fig. 7e, f). Pre- and postoperative orthodontic treatments were performed to level and align the dental arches.

Under general anesthesia, intraoral surgical approaches were used to completely expose the upper and lower jaw. Firstly, a conventional Le Fort I osteotomy was performed at the maxilla. About 9-mm-thick bone was removed at the right side of the maxilla. An intermediate splint was used with intermaxillary fixation to help locate the maxilla position. Four L-shaped titanium plates were put on for fixation. Secondly, an inverted-L osteotomy of the ramus on the right side and a sagittal split ramus osteotomy on the left side were applied. The template for the right ramus was formed on the surface of the bone with a screw. Osteotomy with a reciprocating saw was easily performed along the

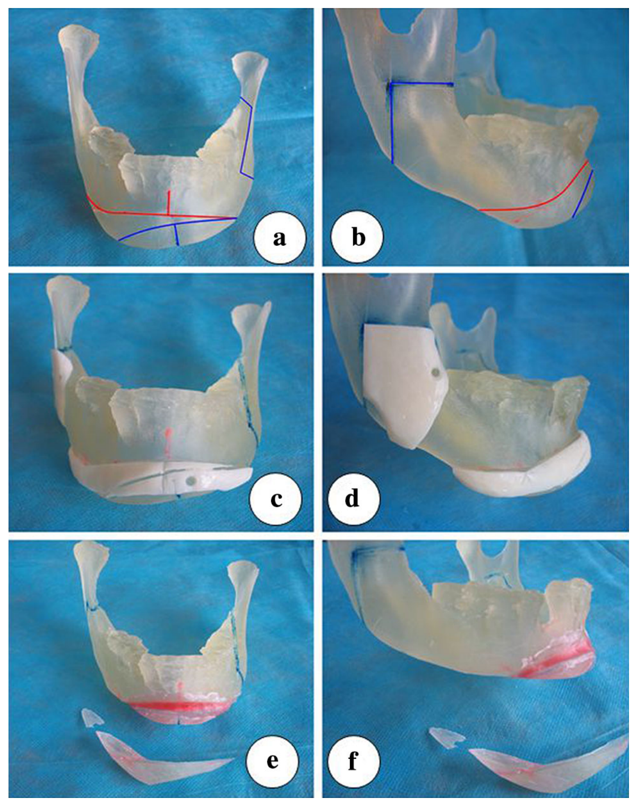

Fig. 7 3D printing model analysis. **a** Measurement, analysis and osteotomy lines designed (front view). **b** Measurement, analysis and osteotomy lines designed (lateral view). **c** Making the surgical template (front view). **d** Making the surgical template (lateral view). **e** Surgical simulation (front view). **f** Surgical simulation (lateral view)

edge of the surgical template. A final occlusal splint was used with intermaxillary fixation to help locate the mandible position. Finally, genioplasty was applied at the chin. The mental nerve of the right side was dissected for protection and preparation for the template. The template was formed on the chin with a screw (Fig. 8a). Osteotomy with a reciprocating saw was easily performed along the edge of the surgical template (Fig. 8b). According to the preoperative design, excess bone was removed at the chin (Fig. 8c, d). The precise repositioning instrument was used to locate the segment which was fixed by one square titanium plate (Fig. 8e, f). The intermediate rods of the two parts made sure that the chin mid-plane was consistent with the middle sagittal plane of the face.

After 3 weeks of postoperative elastic traction, the patient gained good occlusion and TMJ function. The patient showed good facial symmetry (Fig. 9) and good jaw bone symmetry by CT scan after 6 months of follow-up (Fig. 10).

Patient 2

A 22-year-old female came to the hospital. She had no previous orthognathic operation, craniofacial syndrome, or jaw bone trauma or tumors. Clinical examination revealed a square mandible and a deviated chin toward the right side as well as a retro position (Fig. 11). The radiographic examination further confirmed an asymmetrical face and the hyperevolutism of bilateral mandibular angles (Fig. 12).

The difficult points of this case were that the mandibular angle osteotomy and mandibular outer plate osteotomy needed to be performed simultaneously. Two of the templates were made commensurate with the planned osteotomy lines on both mandibular reduced gonial angles according to the 3D printing model (Fig. 13a–c). The others were made to mark the range of osteotomy on both mandibular outer plates (Fig. 13e–g). To position the templates on the mandible accurately, some parts of the templates were extended to the inferior border of the mandible for mechanical fixation of the template (Fig. 13d). No pre- or postsurgical orthodontic treatments were performed, as she had normal occlusion.

Under general anesthesia, intraoral surgical approaches were used to completely expose the bone of the lower jaw. After exposure of the mandibular, the surgical template for mandibular angle osteotomy was positioned on the outer surface of the mandibular angle and the mark with a reciprocating saw was easily performed along the edge of the surgical template (Fig. 14a, b). Then, the surgical template for the mandibular outer plate osteotomy was positioned on the outer surface of the mandibular angle and the mark with a reciprocating saw was easily performed along the edge of the surgical template (Fig. 14d, e). Mandibular angle osteotomy and mandibular outer plate osteotomy were performed along the marks. The outline of the excised mandibular angles was almost the same as that of the templates (Fig. 14c, f). Finally, genioplasty was applied at the chin using the precise repositioning instrument (Fig. 15a, b). The scale on the intermediate rods helped us to reposition the segment forward. Finally, the free bone mass was implanted into the bone gap which appeared when the segment moved as planned (Fig. 15c).

The patient showed good facial symmetry (Fig. 16) and good jaw bone symmetry by CT scan after 6 months of follow-up (Fig. 17).

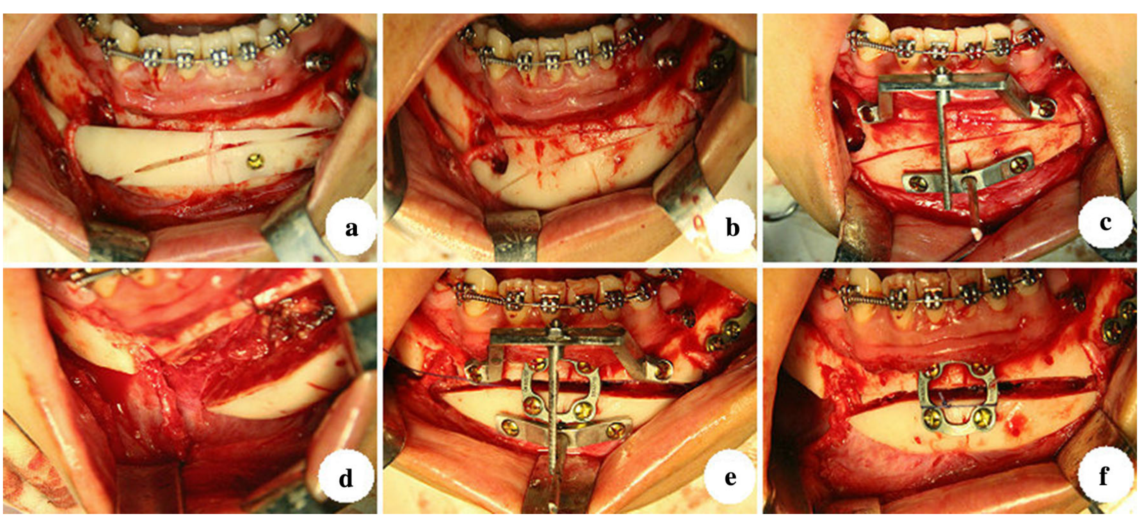

Fig. 8 **a** Dissected the right inferior alveolar nerve and placed surgical template. **b** Osteotomy lines made according to the surgical template. **c** Placement of the precise repositioning instrument. **d** Removed excess bone of the chin and reserved the inferior alveolar nerve. **e** Truncated chin bone segment located according to the precise repositioning instrument and fixed by one square titanium plate. **f** Removal of the precise repositioning instrument

Fig. 9 Postoperative photographs showed facial symmetry of the patient

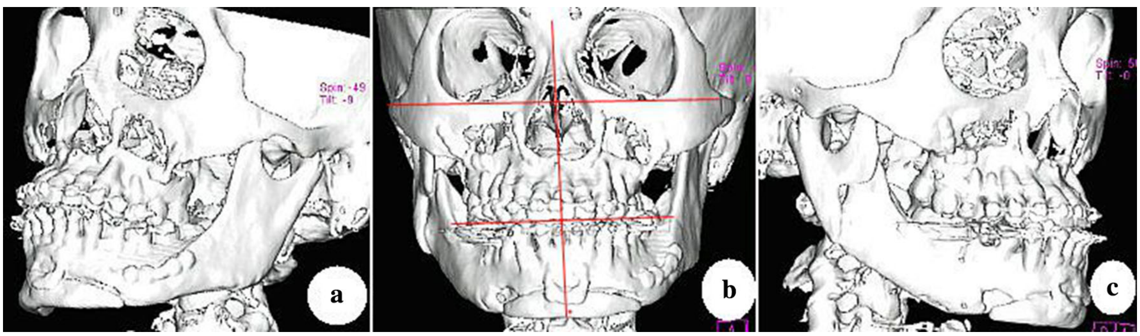

Fig. 10 CT scan reconstruction of the patient after operation, and bone healed well and the lower edge of the mandible appeared as a normal transition. **a** Sagittal split ramus osteotomy on the left side. **b** Basic symmetry in the frontal view. **c** Inverted-L osteotomy of the ramus on the right side

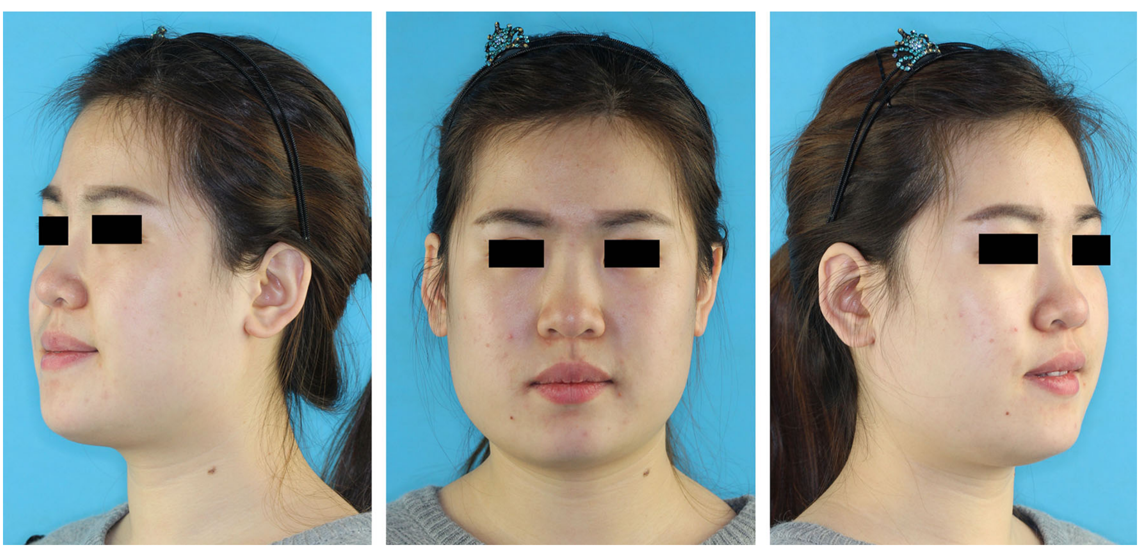

Fig. 11 Preoperative photographs showed facial deformities of the patient

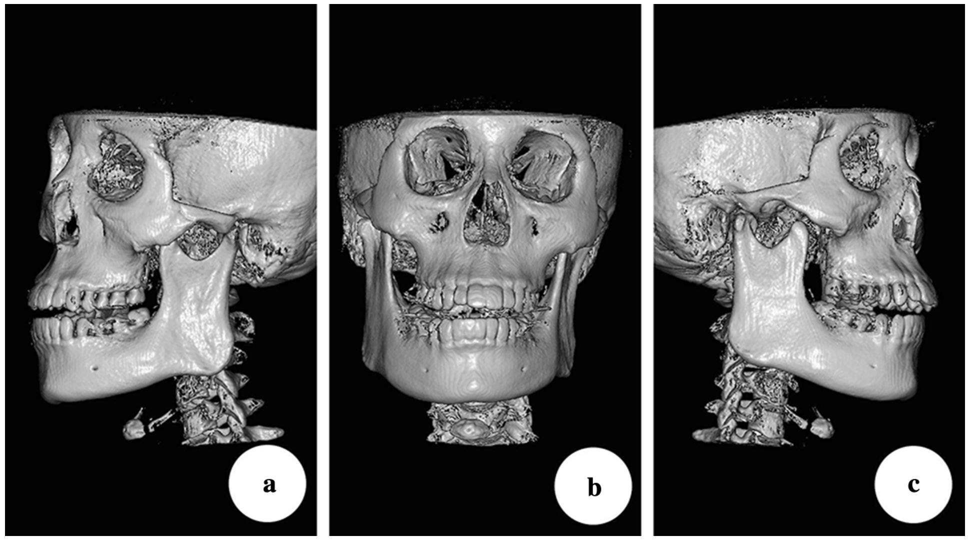

Fig. 12 CT scan reconstruction of the patient before operation. **a** Lateral view of the left side. **b** Front view. **c** Lateral view of the right side

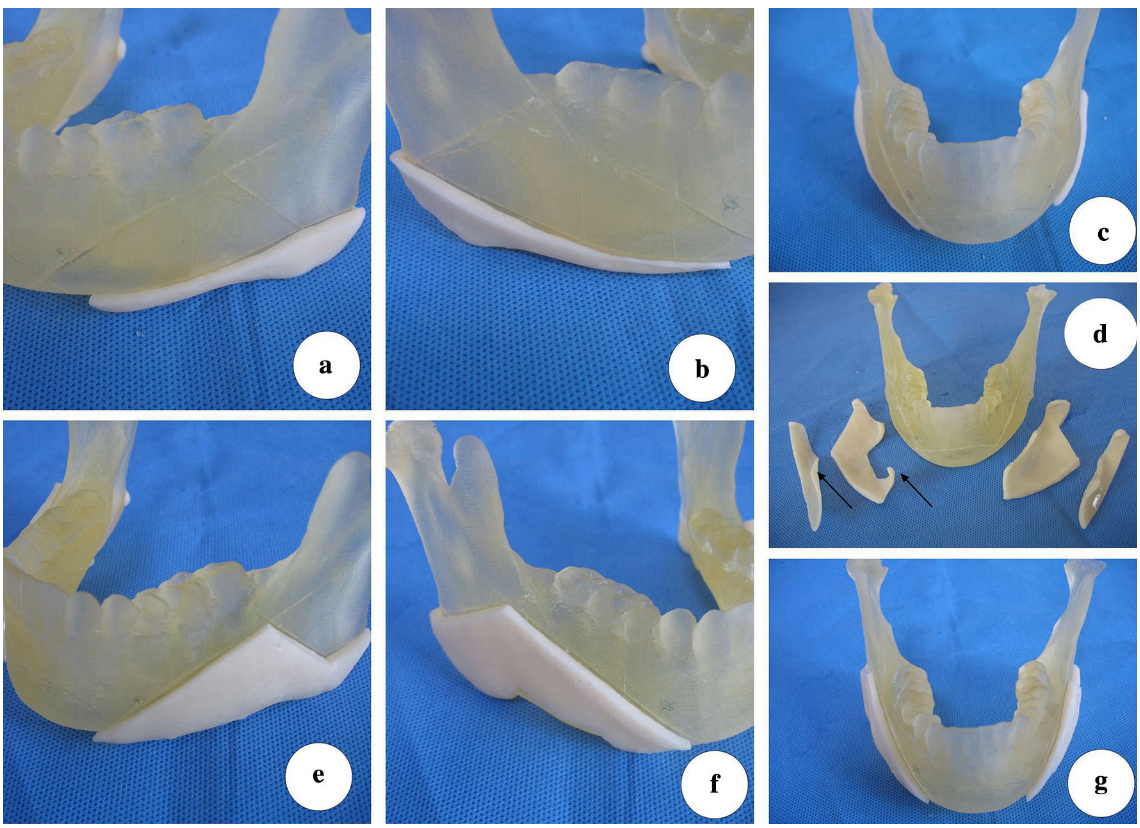

Fig. 13 Design of templates aided by 3D printing model. **a** Template on the left mandibular angle. **b** Template on the right mandibular angle. **c** Template on both mandibular angles in front view. **d** *Arrows* indicate the extended parts of the templates for fixation. **e** Template on the left mandibular outer plate. **f** Template on the right mandibular outer plate. **g** Template on both mandibular outer plates in front view

Results

All orthognathic operations were successful with the new method. No patient experienced severe complications, and bone healing was uneventful. There were no difficulties in using the templates and the precise repositioning instrument. All patients showed good facial symmetry and good jaw bone symmetry by CT scan after 6 months of follow-up. However, all cases showed temporary lower lip paresis at both sides, but all recovered after 3–6 months postoperatively.

The mean and SD of ICC between the right postoperative inferior border of the mandible (R-Post) and the left

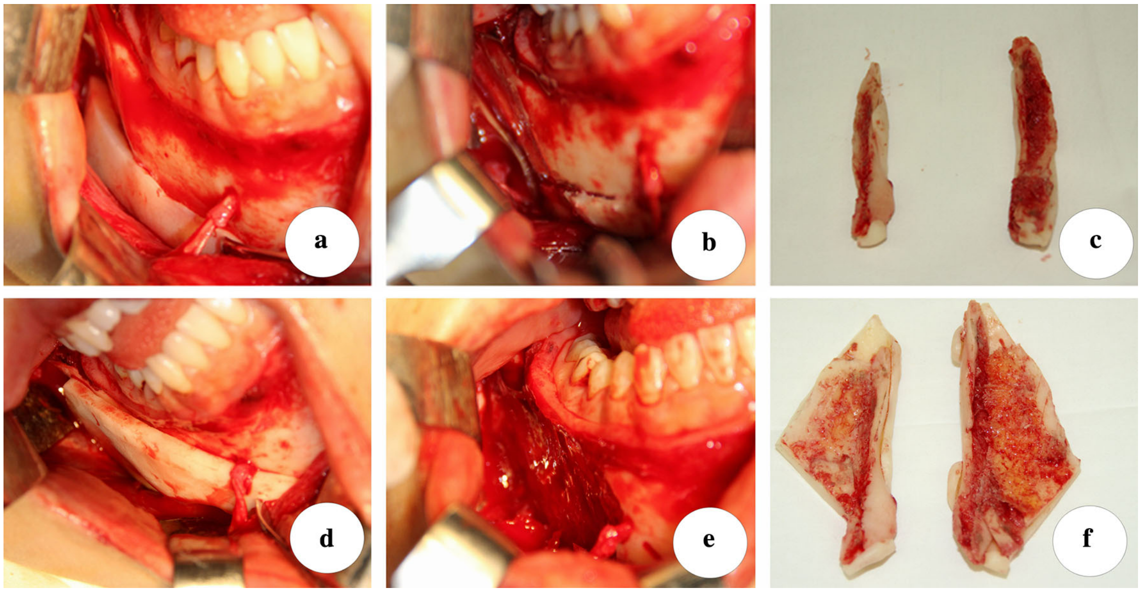

Fig. 14 **a.** Dissected the right inferior alveolar nerve and placed surgical template on the right mandibular angle. **b** Made osteotomy line according to surgical template on the right mandibular angle. **c** The outline of the excised mandibular angles was almost the same as that of the templates. **d** Placed surgical template on the right mandibular outer plate. **e** Made osteotomy line according to surgical template on the right mandibular outer plate. **f** The outline of the excised mandibular outer plates was almost the same as that of the templates

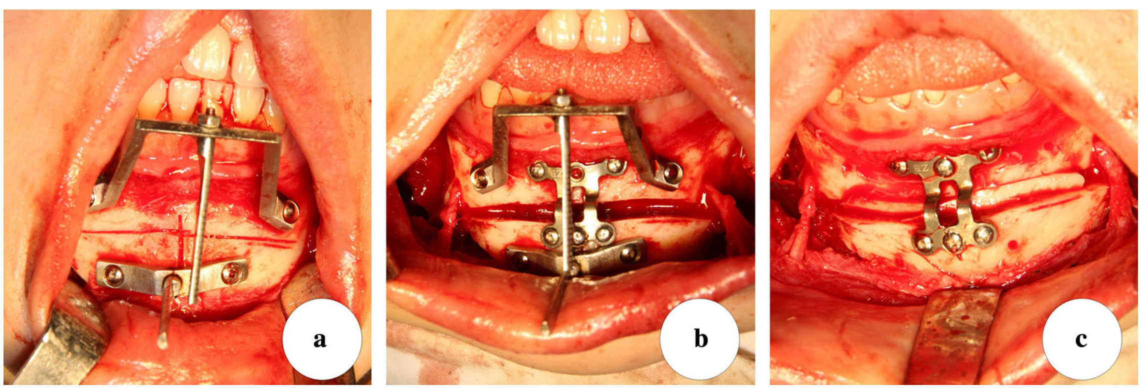

Fig. 15 **a** Truncated chin bone segment located according to the precise repositioning instrument. **b** Fixed chin bone by one titanium plate. **c** Removed the precise repositioning instrument and implanted the free bone mass into the bone gap

postoperative inferior border of the mandible (L-Post) were 0.973 ± 0.007. The mean and SD of chin point deviation 6 months after the operation were 0.63 ± 0.19 mm (Table 1).

Conclusion

The results of this study suggest that the three-dimensional printing technique and the precise repositioning instrument could help in making better operation designs and more accurate manipulation in orthognathic surgery for complex facial asymmetry.

Discussion

Serious facial asymmetry has very bad impact on patients both physically and spiritually. Orthognathic surgery is an effective treatment. But it is not precise to make the preoperative plan according to the two-dimensional cephalometry. Besides, there is no guidance to transfer the planned movements to the real operation [12, 13]. In recent years, computer-assisted design and 3D printing techniques have been widely used in maxillofacial surgery. They make the surgical procedure more precise [14, 15]. However, information about computer-assisted treatment for extreme asymmetry of the mandible and chin is limited. As the

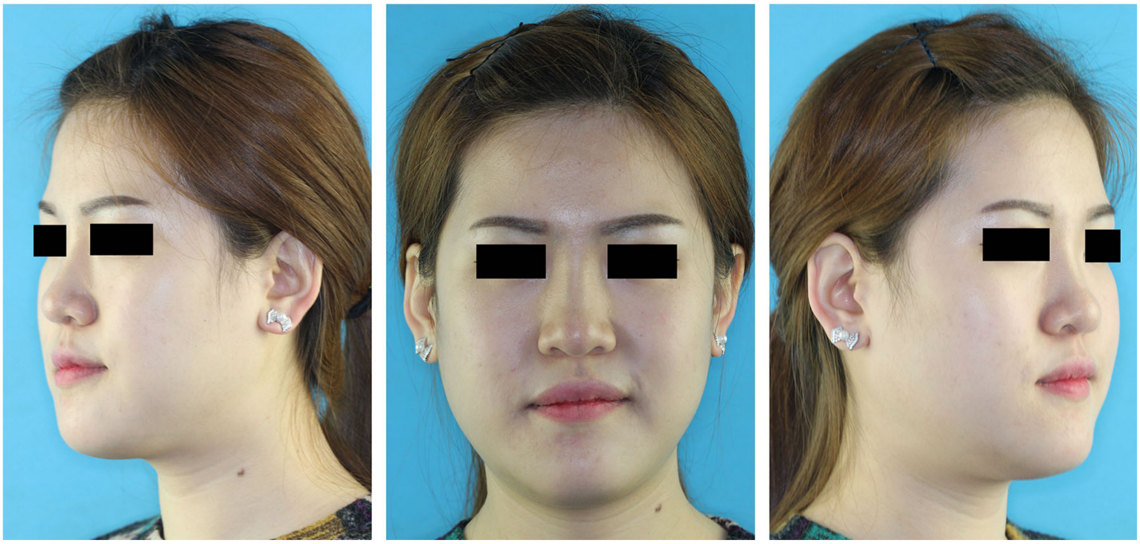

Fig. 16 Postoperative photographs showed facial symmetry of the patient

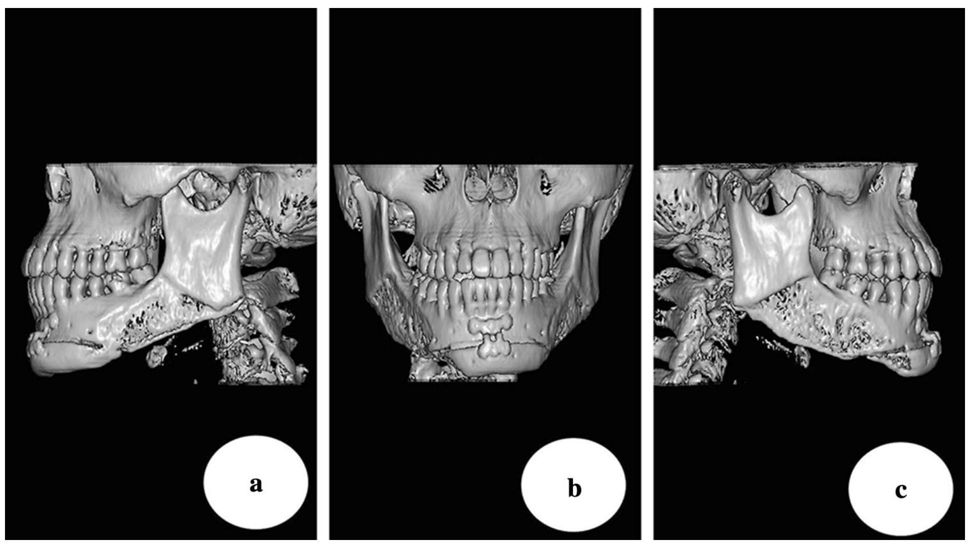

Fig. 17 CT scan reconstruction of the patient after operation. **a**. Lateral view of the left side. **b** Front view. **c** Lateral view of the right side

Table 1 The mean and SD of ICC (R-Post vs. L-Post) and chin point deviation 6 months after operation

Patient	R-Post versus L-Post	Chin point deviation (mm) (pre/post 6 months)
1	0.967	13.0/1.0
2	0.978	5.5/0.5
3	0.972	6.0/0.6
4	0.980	5.5/0.6
5	0.965	7.5/0.8
6	0.963	9.0/0.6
7	0.974	6.5/0.5
8	0.982	7.0/0.4
Mean ± SD	0.973 ± 0.007	0.63 ± 0.19 (post)

osteotomy line and the amount of bone grinding are complex, accurate preoperative planning and surgical guidance during the operation are badly needed. Our study presented a novel protocol whereby a patented instrument named the precise repositioning instrument for genioplasty and a three-dimensional printing technique together are used in the treatment for complex facial asymmetry.

In this study, a precise 3D printing model was obtained. We made the preoperative design and surgical templates according to it. With the help of these surgical templates, the surgeon could easily determine the osteotomy line and the amount of bone grinding without overcorrection or undercorrection. The preliminary results have shown that the ICCs between the right and the left postoperative inferior border of the mandible were almost consistent. This protocol made the surgery more precise and quicker.

It only took 5 min to install and remove the precise repositioning instrument and only 3 min to install and remove each template. Notably, the cost of operating time was reduced about 30–60 min. However, the preoperative preparation time was increased about 2–3 h, including the three-dimensional planning, the design and manufacture time for the templates. Unlike others [16] who have performed virtual surgical planning by computer software and fabricated surgical templates by 3D printing technique, our method was flexible, simple and feasible without any extra equipment, software and expense.

Patients with hemimandibular hypertrophy suffer an extremely asymmetric face. It is traditional to resect the excess bone of the affected mandible according to the unaffected side. In this way, the natural contour of the chin is destroyed and the artificial contour is straight, lacking of natural radians. Besides, the muscle attached to the lingual side of the chin is detached widely for osteotomy, which will be flabby after the operation. In our study, the osteotomy line was designed to maintain the natural contour of the chin. The asymmetric mandible was fixed by resecting bone above the chin bone segment. As the osteotomy line was complex, the 3D printing technique played an important role in the accurate design of osteotomy lines and creation of surgical templates making. This method was used with the patient reported above. Good clinical outcomes were achieved. In this way, the natural contour and muscle attachments of the chin were maintained and genioplasty could be performed without any extra osteotomy lines.

As a square face is unattractive for an East Asian woman, orthognathic surgery is more and more popular in China. But reports concerning simultaneous performance of mandibular angle osteotomy and mandibular outer plate osteotomy are limited [17, 18]. In our study, the patient reported above suffered a square and asymmetrical face. Her square face was caused by both the reduced gonial angles and the lateral protrusion. Besides, the bone must be resected differently on both sides of the mandible to achieve new facial symmetry. It was difficult to resect bone accurately and achieve the symmetry of bilateral mandibular angles. So we developed a preoperative design and made surgical templates on the 3D printing model. In this way, we performed the mandibular angle osteotomy and mandibular outer plate osteotomy simultaneously and precisely. Good clinical outcomes were achieved.

The position and proportion of the chin play an important role in lower facial contour and harmony [19]. Genioplasty is an effective treatment for facial deformities.

However, the truncated segment needs multidimensional movement for complex asymmetric deformity, which makes it difficult to achieve accurate repositioning. Surgeons used to reposition the segment according to their clinical experience. Nowadays, 3D virtual planning, prebending plates and surgical templates have been widely used. But it has been reported that 3D virtual planning has the least precision in the chin compared with the maxilla and mandible [20]. The prebending plates and surgical templates are complicated and time-consuming. Besides, they could not ensure the accuracy because of inaccurate reference points. To solve this problem, we have developed the precise repositioning instrument for genioplasty. The patent application is already submitted (Patent No. 201410032051. 2, China). In our study, its feasibility and validity were illustrated. Our results showed that the mean of chin point deviation 6 months after operation was 0.63 mm, which indicated that this instrument could provide clinically acceptable precision in repositioning the chin. Our instrument enabled quick and accurate repositioning of the segment. It only took 5 min to install and remove the instrument, while the cost of operating time was reduced about 10–15 min. It could be used for all patients without complicated preoperative design and preparation. The two parts of the instrument were located aligned to the mid-plane of the face and the chin, respectively, rather than special reference points. Besides, the half cylinder rods with scales could help to determine the sagittal movement. Genioplasty was as easy as installing a chin implant with our instrument. However, genioplasty had important advantages over the installation of a chin implant, including stability of movement, no tissue rejection and the management of patients with sleep apnea. In summary, our instrument is accurate, convenient and time saving.

We believe that this technique is not only a precision technique, but also provides an effective way to train young plastic surgeons and to communicate with the patients.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the hospital research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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