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Computer-assisted osteotomy guides and pre-bent titanium plates improve the planning for correction of facial asymmetry

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Abstract. This study investigated the surgical outcomes and accuracy of computer-assisted osteotomy guides and pre-bent titanium plates in the treatment of patients with facial asymmetry. Thirteen patients with facial asymmetry undergoing bimaxillary orthognathic surgery were included. Virtual simulation of Le Fort I osteotomy, sagittal split ramus osteotomy, and genioplasty, if needed, was conducted on the preoperative three-dimensional model. Computer-assisted osteotomy guides and pre-bent titanium plates were produced and used in the actual operation. The postoperative outcome was assessed for facial symmetry and surgical accuracy. All patients were followed up for at least 18 months and their level of satisfaction was investigated. Use of the computer-assisted osteotomy guides and pre-bent titanium plates was successful in all patients. Maxillary canting, mandibular ramus inclination, and mandibular length were corrected on both sides postoperatively. Superimposition of the surgical simulation and postoperative images demonstrated favourable accuracy. Quantitative analysis revealed a mean linear difference of <0.60 mm in the maxilla and 1.57 mm in the mandible. All patients were satisfied with the surgical outcome; there were no complications or cases of relapse during follow-up. The application of computer-assisted osteotomy guides and pre-bent titanium plates achieved favourable outcomes and accuracy, improving planning for the correction of facial asymmetry.

Key words: facial asymmetry; computer-assisted osteotomy guides; pre-bent titanium plates; orthognathic surgery.

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Facial asymmetry is one of the most complicated conditions to treat in the field of oral and maxillofacial surgery and it is difficult to achieve good therapeutic outcomes. Patients with facial asymmetry requiring orthognathic surgery have a higher demand for facial symmetry. The aetiology in such cases includes congenital disorders, acquired diseases (such as condylar hyperplasia, osteochondroma, and absorption), and traumatic and developmental deformities[1–3]. Facial asymmetry is characterized by occlusal plane canting, chin deviation away from the midline, discrepancy between the upper and lower dental

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midline, and cheek irregularity. Although new procedures are being used to improve the surgical outcome, the majority of published studies have demonstrated the difficulty in achieving absolute symmetry[4,5].

The traditional methods for orthognathic surgery planning include cephalometric analysis and model surgery. However, these methods present limitations, especially for patients with facial asymmetry, since errors may be introduced during transfer of the face bow and use of the semi-adjustable articulators, and the movement measurements of the plaster cast may be imprecise. In addition, the manual intermediate and final splints are not accurate[6–8]. Three-dimensional (3D) imaging is now also used in orthognathic surgical planning. Compared with traditional planning, the 3D model can better demonstrate the rotation of maxilla and mandible, occlusal plane canting, and different lengths of the mandibular body or ramus. More accurate anatomical information and precise quantitative measurements can be performed on a 3D model.

More recently, computer-aided design and computer-aided manufacturing (CAD/CAM) techniques have been applied in the planning of orthognathic surgery for the correction of facial deformities[9,10]. De Riu et al.[11] performed a randomized controlled clinical trial and demonstrated that computer-assisted orthognathic operations for facial asymmetry allowed better control and accuracy in repositioning and alignment of the maxilla and mandible compared with the classical method of planning. A number of studies have demonstrated the use of CAD/CAM cutting templates and splints for the correction of facial asymmetry, achieving a good appearance[12–19]. However, most of these studies focused on virtual surgical simulation and osteotomy guides and ignored the importance of the placement of titanium plates. In addition, few studies have performed a quantitative assessment of the deviated side and non-deviated side.

In this study, virtual surgical simulation combined with osteotomy guides and pre-bent titanium plates was performed for patients with facial asymmetry. The purpose of this study was to evaluate the clinical outcomes with the use of this method and to perform a quantitative assessment of the deviated side and non-deviated side. All patients were followed up for at least 18 months and the patients' level of satisfaction was investigated.

Materials and methods

The study procedure was divided into six stages: (1) acquisition of the skull data from spiral computed tomography (CT) and the dentition from laser scanning, (2) creation of a skull–dental composite 3D model by integration of the CT bone model and digital dental model, (3) virtual surgical simulation including Le Fort I osteotomy and sagittal split ramus osteotomy (SSRO), with or without genioplasty, (4) fabrication of computer-assisted osteotomy guides and pre-bent titanium plates, (5) transfer of the virtual planning to the actual operation, and (6) comparison of the postoperative outcome and the virtual planning.

Study population

This study included 13 consecutive patients (seven female and six male) with class I or class III malocclusion and facial asymmetry, who underwent corrective two-jaw orthognathic surgery between June 2014 and October 2017 in the West China Hospital of Stomatology of Sichuan University. The mean age of these patients was 25.5 years (range 18–29 years). The inclusion criteria were (1) clinical facial asymmetry, (2) occlusal plane canting of more than 4° or chin deviation away from the facial midline of more than 4 mm radiologically; (3) asymmetry corrected by bimaxillary surgery, with or without genioplasty. Patients with facial trauma or infection, cleft lip/palate, condylar osteochondroma, condylar absorption, previous temporomandibular joint (TMJ) surgery, hemifacial microsomia, or congenital muscular torticollis were excluded.

Image acquisition

Three-dimensional maxillofacial images were acquired using a spiral CT scanner (Philips Brilliance 16; Philips, Best, Netherlands) and the plaster dental casts were scanned by a laser scanner (3Shape, Copenhagen, Denmark). The images were stored in DICOM format and processed with Geomagic Studio software (3D Systems, Rock Hill, SC, USA). Using the segmentation function, the maxilla and mandible were separated and merged with the digital dental model. A skull–dental composite 3D model was created for surgical simulation.

3D surgical simulation

The maxilla and mandible were imported into Geomagic Freeform Plus modelling software (3D Systems) and the 3D reference planes were established. The Frankfort horizontal (FH) plane was defined as the plane passing through the bilateral orbitale and the right porion. The midsagittal plane (MSP) was defined as the plane perpendicular to the FH plane and passing through nasion and basion. The coronal plane (CoP) was defined as the plane passing through right porion and perpendicular to the FH plane and MSP. The FH, MSP, and CoP were created for 3D surgical simulation (Fig. 1).

Landmarks on the surface of the skull that were used in this study are defined in Table 1. The deviated side was defined as the side including the menton, while the non−deviated side was the side contralateral to the chin deviation[18]. Surgical simulations including Le Fort I osteotomy, SSRO, and genioplasty, if necessary, were performed. The bony segments were then mobilized to the optimal position to correct the facial asymmetry. Virtual titanium plate models of actual commercial plates were imported into the Geomagic Freeform software, placed on the edge of the piriform aperture and the area of the zygomatic alveolar crest, and bent exactly to attach to the maxillary bone surface in a manner similar to the actual operation. For the mandible, the virtual titanium plates were placed and bent on the mandibular surface. The drilling screw holes were marked on the surface of the bone model according to the locations of the holes in the bent titanium plates. Next, the cavity blocks for the bent virtual titanium plates, the templates with osteotomy guides and drilling screw holes, the first splint, the final splint, and the bridges were constructed. The bridges were used to connect the first splint and the templates. All of these pieces were produced by a 3D printer (Objet Eden260VS Dental Advantage; Stratasys, Eden Prairie, MN, USA), using polymer materials. The commercial titanium plates were pre−bent according to the cavity blocks before surgery.

Surgical implementation

The surgery was executed according to the virtual surgical simulation by a senior surgeon. The maxilla and mandible were mobilized after Le Fort I osteotomy and SSRO according to the osteotomy guides on the templates. The drilling screw holes on the templates were designed as the holes that the titanium plates would subsequently be fixed to. The maxillary and mandibular segments were placed in the planned positions with the pre−bent titanium plates fixed to the designed holes. The pre−bent titanium plates and the drilling screw holes provided a precise system for positioning and fixation.

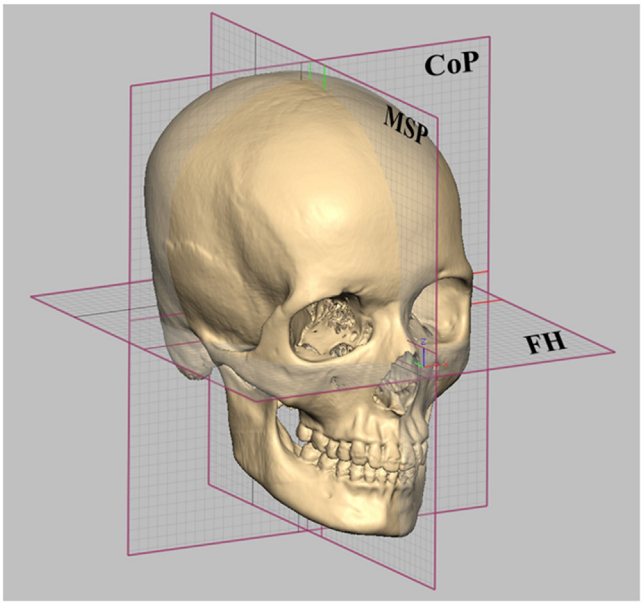

Fig. 1. Reference planes for 3D measurements. The Frankfort horizontal (FH) plane was defined as the plane passing through the bilateral orbitale and the right porion. The midsagittal plane (MSP) was defined as the plane perpendicular to the FH plane and passing through nasion and basion. The coronal plane (CoP) was defined as the plane passing through right porion and perpendicular to the FH plane and MSP.

Table 1. Definitions of the selected landmarks in the maxilla and mandible.

Landmark	Definition
U3	Cusp of the maxillary canine
U6	Mesiobuccal cusp of the first maxillary molar
L3	Cusp of the mandibular canine
L6	Mesiobuccal cusp of the first mandibular molar
CC	Condylar centre, defined as the midpoint between the medial pole (MP) and lateral pole (LP) of the condylar head
Go	Most posterior and inferior point on the mandibular angle
Me	Most inferior midpoint of the chin on the outline of the mandibular symphysis

Postoperative validation

Spiral CT images were captured 1 month after surgery. To evaluate the extent of the asymmetry correction in the postoperative CT images, the distances from U6 to FH, Go to FH, and Go to Me were calculated; the difference between the left and right sides represented the maxillary canting, mandibular ramus inclination, and mandibular length, respectively. To evaluate the accuracy of the virtual surgical simulation with respect to the actual outcome, the virtual surgical simulation and the postoperative CT images were registered using the surface registration of the cranial base. Surface superimposition was performed to evaluate the difference between the images, while the accuracy was calculated in terms of the root−mean−square deviation (RMSD). To quantitatively evaluate the linear difference, the distances between the landmarks and FH, MSP, and CoP on the deviated and non−deviated sides were calculated on the simulated models and postoperative images. Each 3D measurement was performed by two operators.

Postoperative follow−up

Postoperative symptoms including infection, recovery of the oral incisions, change in terms of facial symmetry, and temporomandibular joint disorder (TMD) were assessed during follow-up of at least 18 months. The presence of clinical symptoms of TMD was mainly determined on the basis of clicking sounds in the TMJ. In addition, the patients' degree of satisfaction with their dental alignment and facial appearance was investigated.

Statistical analysis

The statistical analysis was conducted using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). Intra-observer reproducibility and reliability of the measurements was evaluated by calculation of the intra-class correlation coefficient (ICC) of the errors. The *F*-test was used to evaluate the significance of the differences between the left and right sides. The paired *t*-test was used to evaluate the significance of the differences in linear measurements on the deviated and non-deviated sides. A *P*-value of < 0.05 was considered significant.

Results

Clinical outcome

The osteotomy guides, first splint, final splint, bridges, and cavity blocks for the bent virtual titanium plates were fabricated, and the commercial titanium plates were then pre−bent before surgery (Fig. 2). Every step of the actual surgery in the maxilla and mandible was done according to the preoperative virtual simulation (Fig. 3). Frontal facial profile views, the occlusion, and radiographs of a representative patient before surgery and at 1 month and 18 months after surgery are shown in Fig. 4, demonstrating a noticeable improvement.

Extent of the correction of asymmetry

The measurements of the left and right sides (preoperative and postoperative) are listed in Table 2. The distances U6– FH, Go–FH, and Go–Me were corrected on both sides postoperatively, representing good correction of facial asymmetry.

Evaluation of maxillary and mandibular displacement using superimposition

Superimposition of the surgical simulation and postoperative images was performed by surface registration on the cranial base, which was stable and unaffected by the orthognathic surgery (Fig. 5). Based on the colour scale, the differences between the two surfaces were more obvious for the mandible than for the maxilla. The maxilla had a lower RMSD (0.64 ± 1.12 mm) than the mandible (1.54 ± 1.88 mm). Overall, the precision of the surgical execution achieved a satisfactory outcome regarding the positioning of the maxilla and mandible for the correction of facial asymmetry.

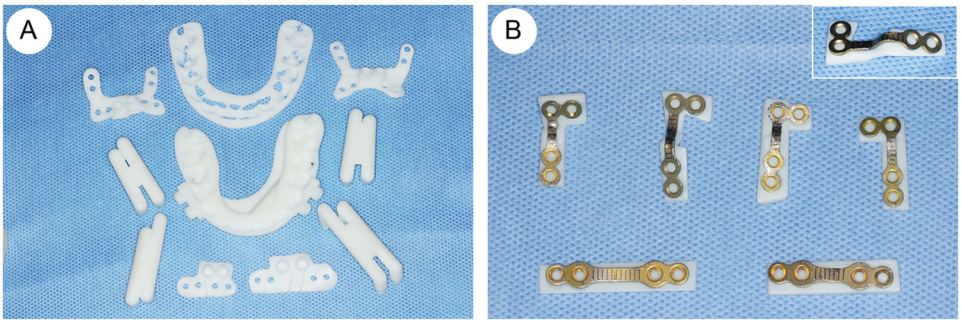

Fig. 2. The osteotomy guides and pre-bent titanium plates system. (A) The templates with osteotomy guides and drilling screw holes, the first splint, the final splint, and the bridges. (B) The titanium plates, pre-bent according to the cavity blocks. The profile of one pre-bent titanium plate is demonstrated in the upper right box.

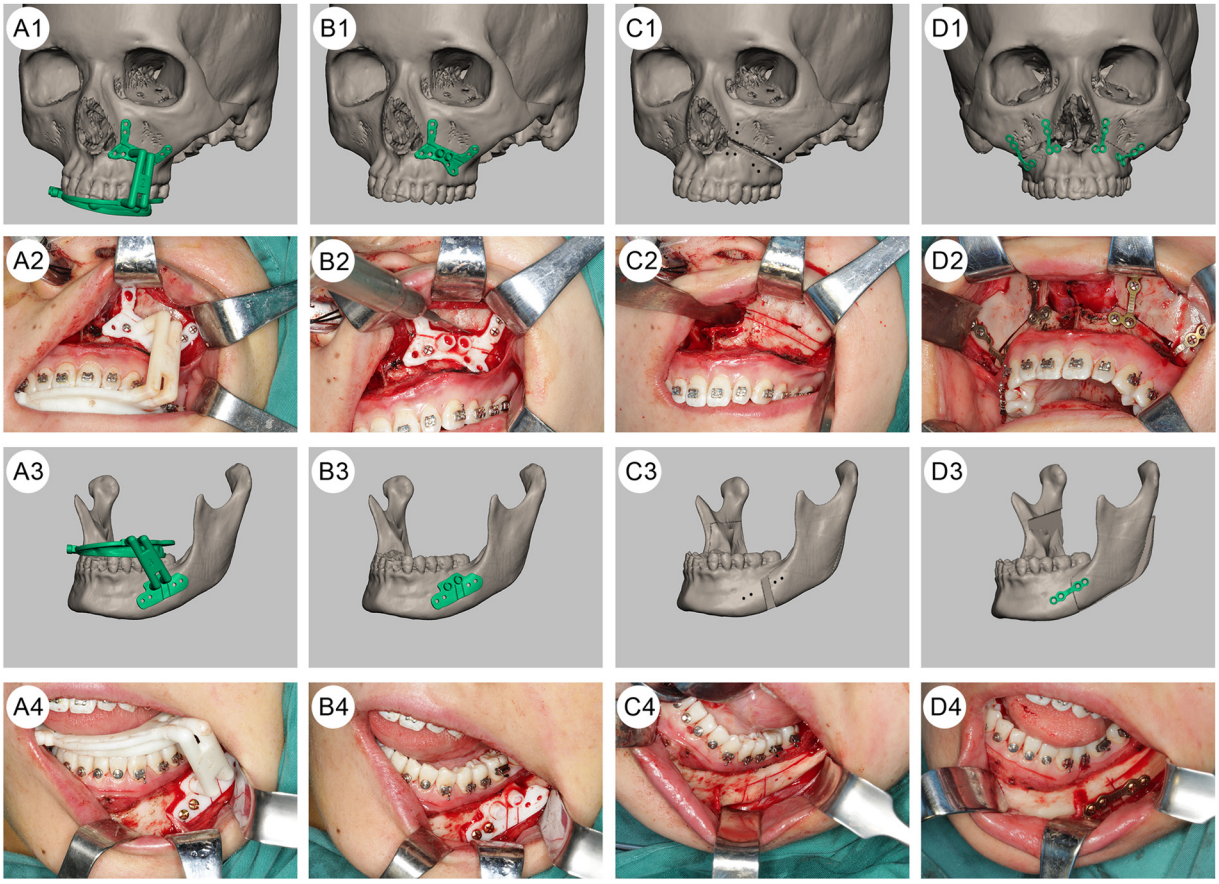

Fig. 3. The procedure of virtual surgical simulation and corresponding actual operation on the non-deviated side of the maxilla (A1–D1 and A2–D2) and mandible (A3–D3 and A4–D4). (A) The templates with osteotomy guides and drilling screw holes were positioned using the first splint and bridges. (B) The templates were fixed to the surfaces of the maxilla and mandible according to the drilling screw holes. (C) The maxillary and mandibular osteotomies were conducted according to the osteotomy guides and the templates were unloaded. (D) The maxillary and mandibular segments were placed in the planned positions and the pre-bent titanium plates were fixed according to the locations of the drilled screw holes.

Evaluation of maxillary and mandibular displacement using quantitative analysis

The ICC was 0.92 for displacements of the landmark locations, indicating acceptable intra-observer reproducibility and reliability. Linear differences in the landmarks (U3, U6, L3, L6, CC, and Go) between the surgical simulation and postoperative outcome on the deviated and non-deviated sides are listed in Tables 3 and 4. Overall, the mean linear differences were all less than 1.57 mm, and no significant difference between the surgical simulation and postoperative outcome was found. Regardless of the side (deviated or non-deviated), all patients showed mean linear differences of the maxilla of less than 0.60 mm, indicating excellent success in maxillary repositioning. For the mandible, some landmarks on the deviated side (from L3, L6, CC, and Go to CoP) and on the non-deviated side (from CC and Go to MSP; from L3, L6, CC, and Go to CoP) showed more than 1.00 mm difference. This indicated that anteroposterior displacement on the deviated side and anteroposterior and mediolateral displacement

Fig. 4. Frontal facial profile views, the occlusion, and radiographs of a representative patient before surgery, 1 month after surgery, and 18 months after surgery.

Table 2. Comparison between the left and right sides for the evaluation of the extent of asymmetry correction.

Patient	Sex	Deviated side	Maxillary canting (mm)		Ramus inclination (mm)		Mandibular length (mm)	
			Preop.	Postop.	Preop.	Postop.	Preop.	Postop.
			Left; Right	Left; Right	Left; Right	Left; Right	Left; Right	Left; Right
1	F	Right	51.62; 46.31	48.18; 48.31	63.54; 59.13	63.62; 62.91	85.18; 79.53	88.45; 88.90
2	F	Right	52.66; 46.81	48.87; 49.23	63.52; 56.83	65.15; 65.93	91.77; 83.82	84.91; 84.85
3	M	Right	54.26; 47.54	47.35; 47.43	64.83; 58.91	65.07; 65.32	92.83; 85.45	87.15; 86.72
4	F	Left	41.36; 47.62	42.21; 42.82	50.76; 59.22	57.24; 58.01	77.16; 84.85	76.82; 76.48
5	M	Right	54.57; 50.10	49.43; 49.04	64.21; 59.54	64.73; 64.28	88.43; 82.65	83.78; 83.93
6	M	Left	46.12; 51.35	48.23; 48.53	58.96; 63.28	62.73; 63.60	79.38; 85.25	78.12; 75.59
7	F	Right	52.86; 47.42	49.57; 49.84	64.35; 59.41	65.21; 64.71	86.27; 80.41	88.93; 89.21
8	F	Right	50.91; 45.68	47.39; 47.64	62.36; 56.74	64.52; 64.09	84.36; 77.21	76.88; 77.12
9	M	Left	45.23; 49.38	46.53; 46.82	57.26; 63.18	63.19; 63.32	80.23; 85.65	79.67; 80.42
10	F	Left	44.25; 48.12	44.18; 44.53	55.37; 61.58	59.83; 60.71	78.64; 83.39	86.13; 86.62
11	F	Right	52.05; 47.42	49.15; 49.02	62.53; 58.75	63.23; 62.98	89.27; 85.13	87.16; 86.68
12	M	Right	54.62; 46.96	47.81; 47.68	64.73; 57.42	65.55; 64.38	92.73; 85.84	86.73; 87.38
13	M	Right	53.77; 49.21	49.32; 49.19	64.21; 58.32	64.67; 64.92	85.67; 79.52	82.42; 81.17
P-value			0.09	0.86	0.17	0.97	0.14	0.93

F, female; M, male; Preop., preoperative; Postop., postoperative.

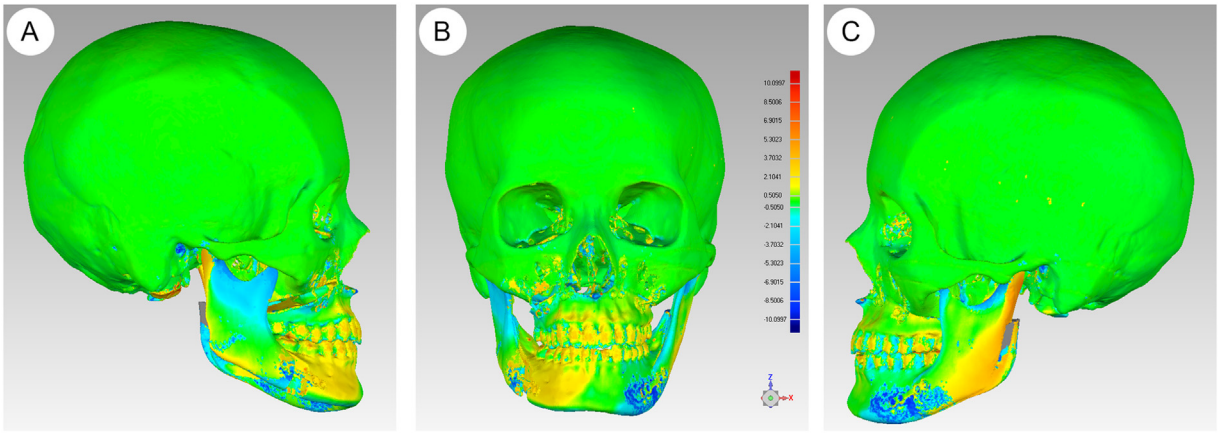

Fig. 5. Superimposed images of the virtual surgical simulation and the postoperative outcome for the representative patient.

Table 3. Quantitative comparison between the virtual simulation and the postoperative outcome on the deviated side.

Parameters	Virtual simulation	Postoperative outcome	Difference	*P*-value
To FH				
U3	49.68 ± 3.48	49.21 ± 3.17	0.47 ± 1.06	0.38
U6	47.58 ± 2.18	48.06 ± 2.33	0.48 ± 1.86	0.37
L3	48.80 ± 3.04	48.28 ± 3.34	0.53 ± 1.48	0.43
L6	46.91 ± 3.28	47.50 ± 3.43	0.59 ± 1.01	0.21
CC	2.38 ± 1.01	3.09 ± 0.72	0.71 ± 1.31	0.25
Go	63.27 ± 2.37	63.73 ± 2.75	0.46 ± 1.24	0.21
To MSP				
U3	15.81 ± 0.93	15.66 ± 0.97	0.15 ± 0.78	0.66
U6	24.44 ± 0.85	24.01 ± 1.29	0.43 ± 0.98	0.34
L3	13.24 ± 0.61	13.62 ± 0.66	0.38 ± 0.48	0.41
L6	21.67 ± 1.92	21.28 ± 1.60	0.39 ± 1.08	0.42
CC	48.95 ± 1.43	49.45 ± 1.71	0.50 ± 0.71	0.15
Go	47.07 ± 1.84	47.52 ± 1.87	0.45 ± 1.10	0.36
To CoP				
U3	82.02 ± 2.27	82.62 ± 1.79	0.60 ± 0.86	0.27
U6	64.45 ± 0.46	64.98 ± 0.40	0.53 ± 0.56	0.21
L3	82.58 ± 0.98	81.52 ± 1.08	1.06 ± 1.21	0.11
L6	66.72 ± 2.82	65.63 ± 2.31	1.09 ± 1.47	0.15
CC	14.38 ± 1.61	13.14 ± 1.56	1.24 ± 0.49	0.18
Go	17.56 ± 1.91	16.24 ± 2.34	1.32 ± 0.62	0.29

FH, Frankfort horizontal; MSP, midsagittal plane; CoP, coronal plane. Data are expressed as the mean ± standard deviation.

on the non-deviated side were evident in the mandible.

Postoperative follow–up

No symptoms of infection were observed among the patients and the oral incisions recovered well postoperatively. All patients maintained a good facial symmetry outcome without relapse. Three of the 13 patients had clicking sounds in the deviated TMJ, which were present in only one patient at 18 months after surgery. One of the 13 patients had clicking sounds in the non–deviated TMJ, but these were no longer evident at 18 months after surgery. All patients were satisfied with their dental alignment and facial appearance and none underwent any secondary correction for facial deformity.

Discussion

Facial asymmetry is one of the most complicated conditions to treat and requires highly accurate planning preoperatively. However, traditional planning methods for orthognathic surgery have limitations, especially for patients with facial asymmetry. Fortunately, advances in computer–aided surgical planning have improved surgical simulation. Templates with positioning guides have been fabricated by computer–aided methods for more accurate correction of craniomaxillofacial deformities, in particular for facial asymmetry[20].

De Riu et al.[11] reported that surgical outcomes for the correction of facial asymmetry were better with the use of computer-assisted orthognathic operations than with the classical method of planning. Wong et al.[15] introduced the matching optimal symmetry plane method, reducing postoperative mandibular deviation in the correction of facial asymmetry. Ying et al.[16] combined orthognathic surgery and guiding templates and splints for the correction of facial asymmetry associated with vertical maxillary excess and mandibular prognathism, and this offered improvements in accuracy, complexity, and duration over traditional procedures. Shaheen et al.[21] presented a protocol for designing and printing the final digital occlusal splints by means of 3D virtual surgical planning. They reported that the condition of all patients with facial asymmetry was improved, with satisfactory outcomes, and the protocol had an acceptable clinical error margin, although it was stated that the method could be improved in the future. Ho et al.[20] assessed surgical plan modification after 3D simulation and demonstrated that 3D computer-assisted surgical simulation could improve the planning for patients with facial prognathism and asymmetry. The authors of the present study agree with these previous reports. The present study was performed to assess a computer-aided technique for correcting facial asymmetry and the outcomes obtained. Most of the previous studies focused on virtual surgical simulation and guiding osteotomy, but few emphasized the importance of the placement of the titanium plates or performed a quantitative assessment of the deviated side and non-deviated side.

Previous research conducted at the West China Hospital of Stomatology of Sichuan University demonstrated that

Table 4. Quantitative comparison between the virtual simulation and the postoperative outcome on the non-deviated side.

Parameters	Virtual simulation	Postoperative outcome	Difference	*P*-value
To FH				
U3	49.93 ± 2.57	49.51 ± 2.31	0.42 ± 1.18	0.42
U6	47.67 ± 2.01	48.27 ± 2.12	0.60 ± 1.48	0.32
L3	48.78 ± 3.31	48.23 ± 3.24	0.55 ± 1.76	0.38
L6	46.53 ± 2.87	47.12 ± 2.73	0.59 ± 1.47	0.29
CC	2.24 ± 0.89	2.96 ± 1.04	0.72 ± 0.86	0.31
Go	63.65 ± 2.12	64.27 ± 2.25	0.62 ± 1.47	0.22
To MSP				
U3	15.60 ± 1.22	15.92 ± 1.04	0.32 ± 0.98	0.57
U6	24.67 ± 0.95	24.32 ± 1.43	0.35 ± 1.08	0.29
L3	13.62 ± 0.79	13.04 ± 0.94	0.58 ± 0.66	0.34
L6	21.73 ± 2.13	21.24 ± 1.84	0.49 ± 1.42	0.46
CC	49.11 ± 1.34	50.23 ± 1.61	1.12 ± 0.69	0.22
Go	47.21 ± 2.11	48.64 ± 2.03	1.43 ± 1.47	0.41
To CoP				
U3	82.15 ± 2.17	82.68 ± 2.05	0.53 ± 1.06	0.35
U6	64.13 ± 0.68	64.61 ± 0.70	0.48 ± 0.61	0.19
L3	82.43 ± 1.34	81.22 ± 1.52	1.21 ± 1.08	0.21
L6	66.90 ± 2.56	65.72 ± 2.23	1.18 ± 1.32	0.17
CC	15.19 ± 1.74	13.63 ± 1.48	1.56 ± 1.01	0.16
Go	17.88 ± 2.01	16.31 ± 2.25	1.57 ± 0.83	0.32

FH, Frankfort horizontal; MSP, midsagittal plane; CoP, coronal plane. Data are expressed as the mean ± standard deviation.

CAD/CAM osteotomy and pre-bent titanium plates were feasible and effective in the treatment of patients with a skeletal open bite[22]. In the present study, the templates with osteotomy guides and drilling screw holes were used to direct the maxillary and mandibular osteotomies. The amount of bone removed during surgery could be more easily and accurately determined. The drilling screw holes and the pre-bent titanium plates were combined as a system for repositioning the bone segments and guiding the rigid internal fixation. This system was very accurate for positioning, especially for localization of the condyles. With this method, the extent of bone cutting and rotation of the maxilla and mandible could be well planned, which is vital to correct facial asymmetry. In addition, the drilling screw holes and the pre-bent titanium plates provided accurate transfer of the virtual surgical simulation to the actual operation. As the titanium plates were pre-bent before surgery, the time and the error of bending the titanium plates during the operation were reduced.

The results of this study showed that the distances U6–FH, Go–FH, and Go–Me on the left and right sides were corrected postoperatively, leading to good correction of the maxillary canting, mandibular ramus inclination, and mandibular length. This shows the feasibility of the computer-assisted osteotomy guides and pre-bent titanium plates. Accurate repositioning of the maxilla and mandible is essential for achieving optimal aesthetic features. Superimposition of the surgical simulation and postoperative images showed a satisfactory outcome in the positioning of the maxilla and mandible for the correction of facial asymmetry, with greater accuracy for the maxilla.

Few studies reporting new methods for the treatment of facial asymmetry have analyzed the difference between the deviated and non-deviated sides quantitatively. According to the published literature, linear differences of <2 mm may be considered a criterion of success[23–26]. This study found a mean linear difference of less than 0.60 mm for the maxilla on the deviated side and the non-deviated side, which was in agreement with the results of the superimposition. For the mandible, some landmarks on the deviated side (from L3, L6, CC, and Go to CoP) and landmarks on the non-deviated side (from CC and Go to MSP; from L3, L6, CC, and Go to CoP) showed more than 1.00 mm difference. This indicates that anteroposterior displacement on the deviated side and anteroposterior and mediolateral displacement on the non-deviated side were evident in the mandible. This may be related to the differences in muscle strength on the deviated and non-deviated sides of patients with facial asymmetry, which takes time to recover postoperatively and deserves further study. During follow-up visits for at least 18 months after surgery, no complications occurred in any of the patients and they were all satisfied with their dental alignment and facial appearance.

In conclusion, the 3D computer-aided osteotomy guides and pre-bent titanium plates helped to improve the surgical planning for patients with facial asymmetry. The results of this study revealed good correction of the maxillary canting, mandibular ramus inclination, and mandibular length through the use of this method. The maxilla exhibited highly accurate positioning, while the mandible showed different displacement on the deviated and non-deviated sides. The outcomes of this study could be used to improve the clinical planning and surgical execution for facial asymmetry patients requiring orthognathic surgery.

Funding

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Competing interests

None declared.

Ethical approval

The study protocol was approved by the Ethics Committee of West China Hospital of Stomatology (judgement reference number WCHSIRB-ST-2014-149).

Patient consent

Patient consent was obtained to publish the clinical photographs.

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