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Original Article

Design and manufacture of dental-supported surgical guide for genioplasty

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KEYWORDS
Genioplasty;
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Abstract *Background/purpose:* Genioplasty were used widely to correct chin deformities. The purpose of this study was to design and manufacture a dental-supported surgical guide for genioplasty surgery and assess for surgical accuracy.
Materials and methods: eleven patients with chin deformities were treated in this study. The computed tomography (CT) data of the patient's skull and the digital dental models of stone dental models were acquired preoperatively. For each patient, a virtual three-dimensional (3D) model of the skull was constructed and enhanced with digital dental models. A surgical simulation was then performed using computer-aided surgical simulation (CASS) technology based on clinical examination and 3D cephalometry. The surgery was simulated preoperatively which allowed the design of a cutting guide and a dental-supported repositioning guide for genioplasty, which was then 3D-printed and used during operation after disinfection. After surgery, the outcome was evaluated by superimposing the postoperative CT model onto the preoperative model, recording the linear and angular deviation of landmarks and plane, then measuring the differences between the planned and actual outcomes.
Results: The osteotomy and repositioning were successfully performed as planned using surgical guides. No inferior alveolar nerve damage was seen in this study. The dental-supported surgical guide showed excellent accuracy, with the largest differences between the planned and the postoperative chin segment being 0.9 mm and 3.2°.
Conclusion: The dental-supported surgical guide designed preoperatively provided a reliable method of transfer genioplasty planning. This can assist surgeons in accurately performing osteotomy and repositioning bone segments during a genioplasty.

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Introduction

Whether looking from the front or the side, the chin has an important influence on the whole face in terms of aesthetics. Genioplasty are used widely to correct chin deformities and these procedures are challenging because the chin deformity may exist in all three dimensions. In the past, a genioplasty mainly relied on the doctor's experience, and the preoperative two-dimensional plane measurement was limited. This process was often time-consuming and contained potential errors, making the postoperative effect difficult to predict.[1,2]

With the rapid development of computer-aided surgical simulation (CASS) technology, surgeons are now able to design a surgical guide preoperatively. The design can be precisely transferred to the patient in the operating room exactly as planned on the computer.[1,3] There were only a few reports with small sample sizes on the use of genioplasty surgical guides. Although it shows good surgical outcomes, the design of these surgical guides was often bulky, which made it difficult to be used intra-operatively.[1,4,5] In addition, the anatomical landmarks on the chin were not unclear and the surgical guide positioning was often inaccurate, which makes it difficult to improve the accuracy of genioplasty.

In order to eliminate the above-mentioned problems. The purpose of this study was to design and validate a new dental-supported surgical guide to perform horizontal osteotomy genioplasty. The surgical guides were designed in two pieces: a cutting guide that defines the cutting line and the screw locations, and a repositioning guide that precisely repositions the chin segment into the planned new position and orientation using the predefined screw locations. Teeth was used as anatomical landmarks to overcome unclear landmarks on the chin.

Materials and methods

Study design and sample

This was a prospective study of eleven patients undergoing genioplasty for deformity correction. The surgeries were performed in the Department of Oral and Maxillofacial Surgery of Affiliated Stomatological Hospital of Kunming Medical University between March 2017 and January 2020.

The inclusion criteria for the study were: One, patients who were scheduled to undergo genioplasty; Two, patients who agreed to participate in the study. Patients with cleft-lip-palate or craniofacial deformities, systemic or coagulative disorders, mandibular trauma or has undergone genioplasty, pregnancy, and patients requiring segmented genioplasty were excluded from the study. This study was approved by the ethics committee of the Kunming Medical University Affiliated Stomatological Hospital, and all patients signed informed consent forms.

Virtual planning

A computed tomography (CT) scan of the patient's entire skull with a 1.25-mm slice thickness was acquired preoperatively (Siemens AG, Munich, Germany). Patients were in a supine position during scanning and instructed to bite a wax to slightly separate the maxilla and mandible about 1 mm. The stone dental models of the maxilla and mandible were then scanned using a high-resolution laser surface scanner (Sirona Dental Systems GmbH, Bensheim, Germany) to obtain the digital dental models.

The preoperative simulation was performed using ProPlan CMF software (Materialise NV, Leuven, Belgium). First, the Digital Imaging and Communications in Medicine (DICOM) data of the CT scan was imported into the software, and a threshold range was set to acquire the skull and soft tissue masks. Then we performed Edit Object, Region Growing, Boolean Operations, etc, to segment the soft tissue, mandible, upper skull (skull minus mandible), and inferior alveolar neural tube. Second, the stereolithography (STL) files of the digital dental models were combined with the three-dimensional (3D) maxillary and mandibular models. This resulted in a composite skull model with accurate bone and dental information.[1,6–8] Third, the composite skull model was orientated according to the natural head position (NHP), which was defined by the Frankfort horizontal plane. After the patient's skull was oriented, the entire surgical procedure was simulated on the computer. A maxillary Le Fort I osteotomy, bilateral mandibular ramus sagittal split osteotomies (BSSRO), and a genioplasty were simulated on the computer based on clinical examination and 3D cephalometric analysis (some patients only needed genioplasty). The inferior nerve canal, as well as the range between the osteotomy line and the anterior teeth root apex were marked in order to protect the inferior alveolar nerves and roots of teeth (Fig. 1).[9,10] If the simulated outcomes were not satisfactory, the surgical plan could be modified, and the simulation was easily reset depending on the situation.

Once the surgical plan was finalized, a surgical guide was designed using Geomagic Studio software (Geomagic Inc, Morrisville, NC,USA). The 3D models included the osteotomy plane, the distal mandible, and the chin segment in the initial position and final position were imported into Geomagic Studio software (Geomagic Inc). The cutting guide and cutting line were designed based on the distal mandible, the osteotomy plane, and the chin segment in initial position model data, and the direction of osteotomy was determined with reference to the thickness of the cutting guide (Fig. 2B).The screw holes on both sides of the cutting line. Hole-5 and Holes-6 served as reference

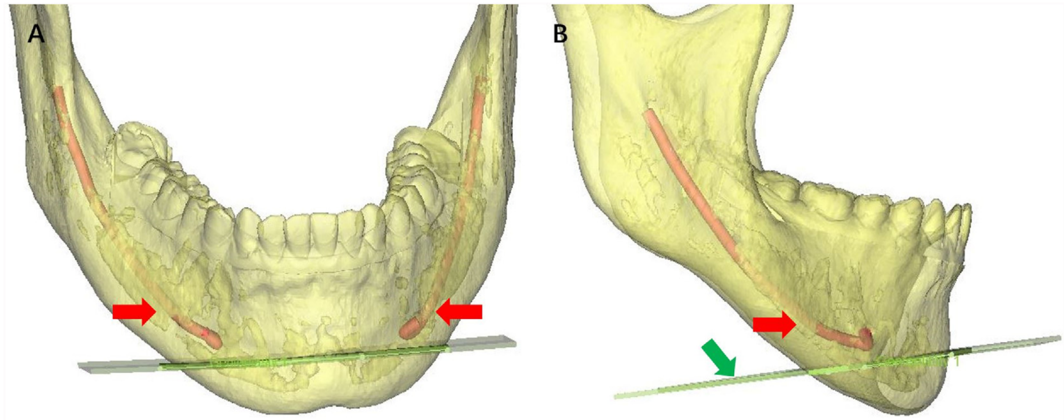

Figure 1 (A) Simulation of virtual osteotomy in order to protect the inferior alveolar nerves and teeth root. The inferior alveolar nerve (red arrow) was marked on the 3D model. (B) The final osteotomy plane was designed on the chin of the mandible (green arrow).

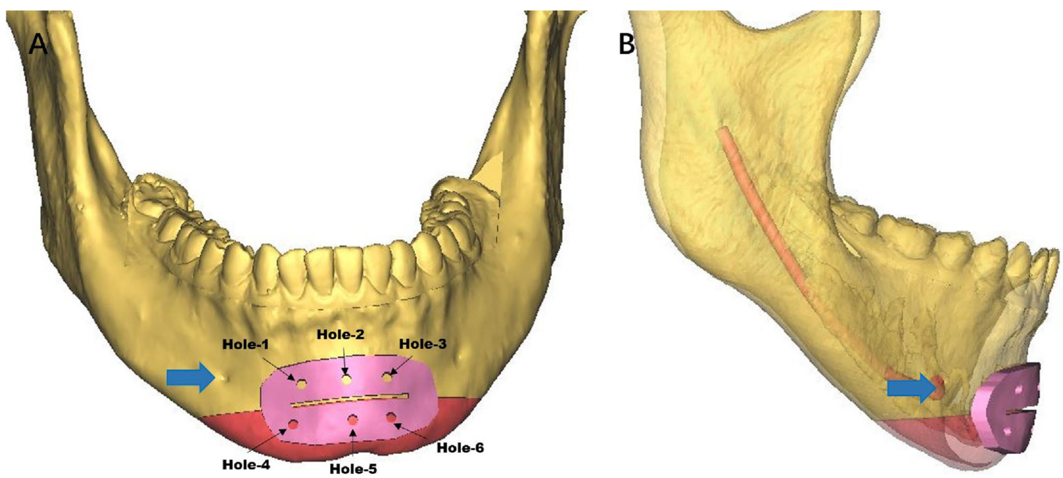

Figure 2 (A) Screw holes located on both sides of the cutting line. The cutting guide was not extended to the mental foramen area (blue arrow). (B) The cutting guide that defined the cutting line and indicated the direction of the osteotomy. The chin segment was marked in red.

landmarks on the bone for automatic repositioning of the chin segment. It is important to note that the cutting guide was not extended to the mental foramen area (Fig. 2A). During the design of the repositioning guide, the distal mandible and the chin segment in the final position were used. The repositioning guide contained two parts: The upper portion of the repositioning guide was designed like a dental splint, which served as a locking mechanism to firmly attach the whole repositioning guide onto the mandibular teeth (Fig. 3A). The lower portion of the guide was designed to reposition the chin segment into the planned position and orientation using the predefined screw holes (Hole-5 and Holes-6) (Fig. 3B). Furthermore, a vertical solid round bar was designed to rigidly connect the upper and lower portions (Fig. 3).[2,4,10] Both surgical guides were transferred to the slicing software for further repair, slicing, and refining. The models were produced using a biocompatible material (resin) by 3D printing machine (FlashForge Guider II, FlashForge, Jinghua,China). The surgical guide was disinfected for surgery after testing on the model.

Surgical technique

The surgeries were performed by a single chief surgeon who is experienced in orthognathic surgery. During surgery, all patients used occlusal surgical splints for the maxilla and mandible to be placed in the desired position (some patients only needed genioplasty). A genioplasty was performed by routine incision. The cutting guide was positioned as planned and attached firmly to the chin with six screws using the drilling holes (Fig. 4A). Once the osteotomy cutting lines were marked on the chin with a reciprocating saw, the screws and the cutting guide were removed, and the osteotomy continued. After the osteotomy was completed, the repositioning guide was repositioned on the mandibular dentition. The chin segment was moved and rotated until the two corresponding screw holes (Hole-5 and Holes-6) was aligned with the guide. With the screws screwed in, the chin segment was automatically moved into the final position. Simultaneously, the titanium plates were placed on the chin and fixed by the screws

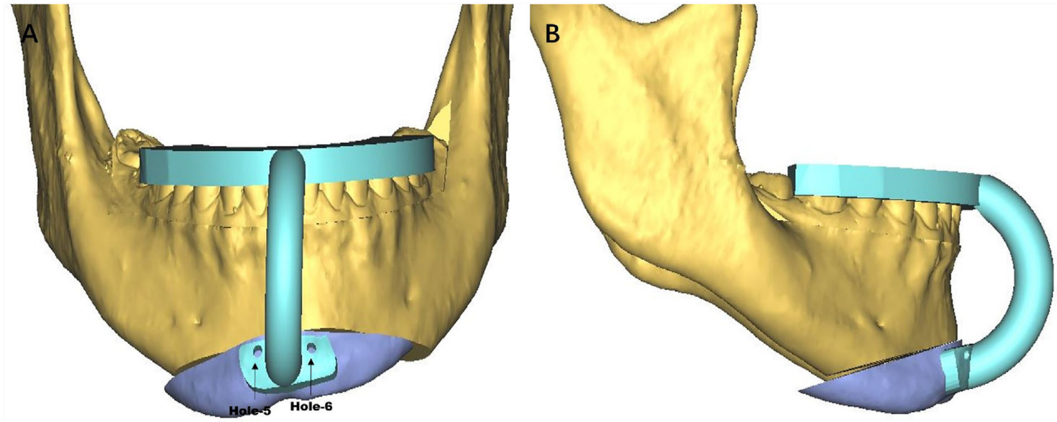

Figure 3 (A) The upper portion of the repositioning guide was designed like a dental splint. The lower portion of the guide repositioned the chin segment into the planned position and orientation using the predefined screw holes (Hole-5 and Holes-6). (B) Chin segment was marked in dark blue, and it will automatically be arranged into planned position as the screws were placed into the Hole-5 and Holes-6.

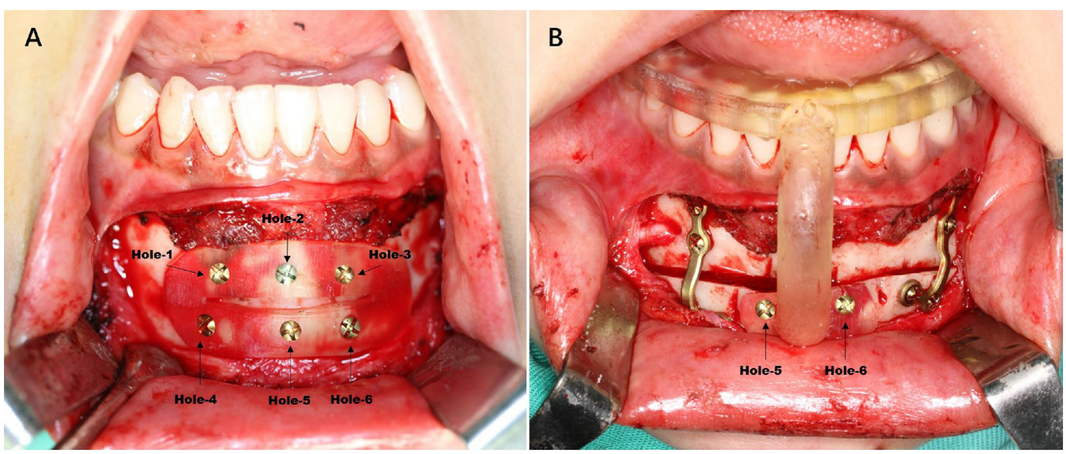

Figure 4 (A) The cutting guide was positioned as planned and attached firmly to the chin with six screws using the drilling holes. (B) The repositioning guide was positioned on the mandibular dentition. The chin segment was moved and rotated until the Hole-5 and Hole-6 on the chin segment and the lower portion of the guide were aligned. The chin segment was automatically moved into the final position when the screws were placed in. The titanium plates were placed on the chin and fixed with screws.

(Fig. 4B). Finally, the repositioning guide and associated screws were removed, and the surgical wound closed as usual.

Data analysis

A CT scan (parameters were the same as those during the preoperative scan) was obtained one month after the operation to evaluate the outcome of genioplasty. Postoperative 3D mandibular models were generated as the segments of the preoperative CT segmented models.

The accuracy of the chin segment position was reported using two methods. First, the segmented postoperative models were imported into Geomagic Studio (Geomagic Inc) that contained the preoperative planned models. The postoperative outcomes were compared with the planned outcomes by superimposing the postoperative models to the planned models. A color-coded discrepancy map was used to evaluate the overall difference between the postoperative contour and the planned contour of the chin (Fig. 5).[11,12] Besides, to evaluate whether the outcome of genioplasty was accurate, the theory where 3 points can be used to define an object in 3D space also was utilized.[1,13] To do this, landmarks on each planned and postoperative model were digitized, then the linear and angular differences between the models were compared.[14] Previous research done by Li et al.[2,10] and Xia et al.[13] was referenced to ensure the landmarks between the planned and the postoperative chin segments corresponded to each other.

Three landmarks were digitized on the chin segment model: the pogonion (Pog) and two points at the right and left lower borders of the chin segment (Chin left, Chin right). Three reference planes were digitized: the frankfort horizontal plane (FH); the sagittal plane (SP, based on clinical examination, mirroring techniques); and the coronal plane (CP). The three landmark points (Pog, Chin left, Chin

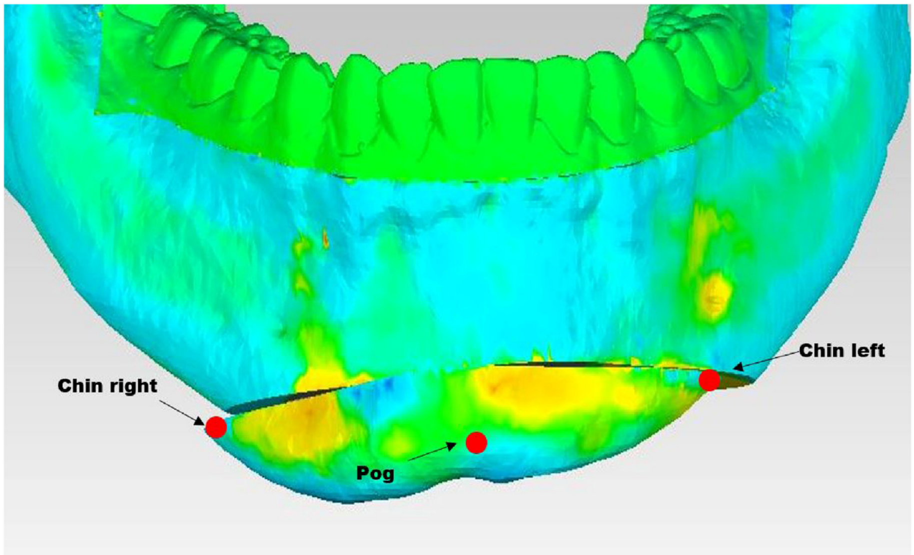

Figure 5 A color-coded discrepancy map was used to evaluate the overall difference between the postoperative contour and the planned contour of the chin. Three points were digitized on each chin segment while it was in the planned final position. The landmarks on the planned models were marked in red. Pog: Pogonion. Chin left point: The left lower borders of the chin segment. Chin right: The right lower borders of the chin segment.

right) (Fig. 5) were connected to form a triangle plane (TP).[2] The three landmarks and the triangle plane, which represented the position and orientation of the planned chin model to evaluate the surgical accuracy.

Descriptive statistics were calculated for all variables (distance, angle, etc.) similar to Bland and Li's method.[2,10] The distribution of the differences data was screened. Lack of agreement was estimated by the mean differences and standard deviations (SD) between planned and actual postoperative measurements. The lower and upper limits of the differences were termed the 95% limits of agreement.

In interpreting the results of the accuracy measurements for the chin segment, positional differences of less than 1 mm and orientational difference of less than 4° were considered to be clinically insignificant.[15]

Results

A total of 11 patients were enrolled in this study. Osteotomy and repositioning were successfully performed, as planned during a genioplasty using a dental-supported surgical guide. There were no difficulties during installing and using both cutting and repositioning guides. All patients healed uneventfully, and no inferior alveolar nerve damage was seen in this study. The postoperative patients were satisfied with the surgical outcomes.

The postoperative outcomes were compared with the planned outcomes by superimposing the postoperative models to the planned models. The results of the color-coded discrepancy map showed that the surgical plan was precisely performed. The contrasting results were shown by a color-coded discrepancy map (Fig. 5). The largest deviation was 3.20 mm (SD = 0.77 mm), with the most obvious area of deviation determined to be around the osteotomy line (orange area), and most of the area was blue or green, indicating that the postoperative contour was highly consistent with the planned contour.

The linear differences of the three landmarks to the three reference planes between the planned outcomes and the postoperative outcomes were shown in Table 1. The largest linear difference was 0.9 mm which was shown from the Chin right point to the Sagittal plane, with the standard deviation being 0.24 mm, and the largest 95% limits of agreement were between 0.54 mm and 0.71 mm (Table 1). The angular differences of the triangle plane with the three reference planes between the planned outcomes and the postoperative outcomes were also shown in Table 1. The largest angular difference was 3.2° and the largest 95% limits of agreement were between 1.42° and 2.16°(Table 1).

Discussion

The chin has distinct features and characteristics. Chin deformities can cause complex issues rather than singular issues such as overdevelopment or underdevelopment.

Robert A[16] mentioned that in 1942, Hofer was the first to use extraoral incision to perform a chin osteotomy to adjust the morphology in the sagittal and vertical directions, thus creating a new era of plastic surgery on the chin. However, the surgical design relied on the doctor's experience. It was impossible to perform accurate cephalometric analysis, virtual surgery, and postoperative evaluation based on experiences only. With the rapid development of computer technology, Hemmy[17] first reported the application of 3D reconstruction technology in craniomaxillofacial surgery in 1987, opening the precedent of digital technology in craniomaxillofacial application. Currently, there are some reports on the use of computer-aided design and computer-assisted manufacturing (CAD/CAM) surgical guides for

Table 1 Linear and angular differences between the planned and the postoperative chin segments.

Parameter	Mean	Range	SD	95% Limits of agreement	
				Lower	Upper
Distance from Frankfort horizontal plane (mm)					
Pog	0.37	0.20–0.60	0.14	0.28	0.47
Chin left	0.50	0.10–0.70	0.19	0.37	0.63
Chin right	0.60	0.50–0.70	0.09	0.54	0.66
Distance from Sagittal plane (mm)					
Pog	0.43	0.10–0.70	0.21	0.28	0.57
Chin left	0.59	0.30–0.80	0.18	0.47	0.71
Chin right	0.52	0.10–0.90	0.24	0.36	0.68
Distance from Coronal plane (mm)					
Pog	0.34	0.10–0.70	0.20	0.20	0.47
Chin left	0.53	0.30–0.80	0.14	0.43	0.62
Chin right	0.62	0.40–0.80	0.14	0.52	0.71
Plane angulation relative to the Frankfort horizontal plane (degree)					
TP	1.33	0.60–2.80	0.68	0.87	1.79
Plane angulation relative to Sagittal plane (degree)					
TP	1.53	0.04–3.20	0.90	0.93	2.13
Plane angulation relative to Coronal plane (degree)					
TP	1.79	0.90–2.70	0.55	1.42	2.16

SD: the standard deviations. Pog: Pogonion. Chin left point: The left lower borders of the chin segment. Chin right: The right lower borders of the chin segment.TP: Plane defined by point Pog, point Chin left and point Chin right.

orthognathic surgery, and the results demonstrate the high predictability of postoperative outcomes by CAD/CAM fabricated customized surgical guides and patient-specific osteosynthesis.[14,18,19] Some researchers have also designed surgical guides for genioplasty.[1,4,5,20] However, the surgical guides in previous research were cumbersomely designed, bulky, and difficult to use during operation.

In this study, 3D reconstruction, virtual surgery, cutting guide design, and repositioning guide for genioplasty was done using ProPlan CMF (Materialise NV) and Geomagic Studio software. The digital dental models of the patients were obtained for our treatment planning, not for the purposes of surgery but to obtain more precise details of their dental structures.[21,22] This step may well be eliminated in the future if new technologies enable more precise images of patients' teeth to be obtained either as a result of advances in CT itself, the development of intraoral scanners, or optical laser scanners.[23] The color-coded discrepancy map showed a high degree of accuracy (Fig. 5). The largest area of deviation was the osteotomy line area. This could be because the titanium plate was only implanted to the buccal side of the chin segment and the lingual side may result in an unexpected rotational movement of the chin segment due to lack of titanium plate supported. Another reason is that after moving the chin segment to the final position (secured with titanium plates and screws), the chin segment or distal mandible of the osteotomy site would be repeatedly polished using a ball drill that would result in further deformation. Besides, the result of the quantitative analysis showed that the largest differences between the planned and the postoperative chin segment were 0.9 mm and 3.2°, meaning that the accuracy of the genioplasty surgical guides was clinically acceptable.

The genioplasty surgical guide used in this study consists of two sets of surgical guides, a cutting guide, and a repositioning guide. This setup had multiple significant advantages. First, the shape and position of the osteotomy line could be adjusted in simulated, which allowed the osteotomy line to be preoperatively planned, minimizing possible damage of teeth and nerve. The cutting guide had a certain thickness, which allows the surgeon to adjust the depth and orientation during operation that lead to a minimally invasive and stable osteotomy. The osteotomy was also guided to avoid the lingual soft tissue injury and lingual hematoma. Second, the screw holes were marked by the cutting guide. This created reference landmarks for the chin segment repositioning in conjunction with the use of the repositioning guide. The repositioning guide automatically repositions the chin segment into the final planned position using these screw holes. The concept of the repositioning guide was similar to that reported previously by Li et al.[2,10] Third, in order to avoid excessive removal of soft tissue from the chin, the cutting guide and the lower portion of the repositioning guide were designed slimly. The lower portion of the repositioning guide only contains two screw holes for repositioning of the chin segment. It was much easier for surgeons to bend the titanium plates intraoperatively because there was more space. Fourth, this kind of surgical guide was small and easy to design, both time and cost was reduced with the use of a 3D printer for production of the guide. Fifth, the repeated intraoperative measurement and visual assessment were no longer needed, because the final planned position of the chin position was already planned preoperatively on the computer and the plan could be accurately transferred to the patient by the surgical guides during operation. Finally, with the development of 3D printing, the repositioning guide may be made of titanium material which would reduce operation time even more.

Although the surgical guides were advantageous, there were still unresolved problems. First, Precise details of patients' dental structures cannot be obtained by CT imaging, so digital dental models needed to replace the less-than-accurate CT imaging in order to generate a composite skull model with accurate information on both the bone structures and the teeth. There were potential errors during this process. Second, the potential errors of the software and hardware. The conversion of data in different software meant the loss of data and these errors were inevitable.[24] In the future, there will be better integration software to complete the reconstruction, simulation, and output of data more accurately. Third, the final planned position of the chin segment was planned preoperatively on the computer and it was difficult to adjust intraoperatively unless the surgical guides were discarded. Lastly, the simulation of soft tissue was inaccurate no matter what kind of software was used. The changes in soft tissue can only be qualitatively determined and not quantitatively. Ho et al.[25] found that the ratio of change in hard tissue to soft tissue was 1:0.35 in Me (menton). However, more research is still needed to improve the accuracy of the ratio. Despite everything, these shortcomings can be overcome the improvement of engineering software.

This study indicated that the surgeon could easily perform genioplasty under the aid of the surgical guides. In order to further validate this technology, more patients will be enrolled in future studies. Eventually, genioplasty could become more precise, safe, less time-consuming, and minimally invasive with the development of CASS technology.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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