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Original Article

Three-dimensional printing automatic registration navigational template for mandibular angle osteotomy surgery

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Abstract: The prominent mandibular angle is considered as unattractive in Asians because it gives the face a square, coarse, and muscular appearance. Mandibular angle osteotomy (MAO) is commonly used to correct prominent mandibular angles through an intraoral approach. This study aims to improve the accuracy and safety of surgery for MAO through optimized design of 3D printing navigational template. Computed tomographic (CT) data were imported into Mimics 14.0 software and surgical simulations were performed. An automatic registration navigational template was designed and fabricated. The osteotomy operations were performed on ten fresh head specimens with individualized navigational templates. Measurements and statistical analysis of three-dimensional models were performed on virtual and actual post-operations. The results were evaluated using paired *t*-test. No significant differences ($P > 0.05$) were observed between the virtual and actual post-operations. In conclusion, the MAO can be performed accurately and safely using the 3D printing automatic registration navigational template.

Keywords: Three-dimensional printing, mandibular angle osteotomy, automatic registration, navigational surgical template

Introduction

A prominent mandibular angle is considered to be unattractive in Asians because it gives the face a square, coarse, and muscular appearance [1]. Mandibular angle osteotomy (MAO) is commonly used to correct prominent mandibular angles through the intraoral approach. Especially in the south of China, it has become popular and considered as the facial bone contouring surgery, which reduces the lower facial width. However, limited vision in the operative site may lead to difficulties or complications, such as condylar fracture, inferior alveolar nerve injury, over-correction/under-correction, facial asymmetry, and formation of a second mandibular angle during surgery [2].

With the development of computer-aided design and three-dimensional printing technology, the navigational templates have been applicable for the MAO in the past two years [3, 4]. The use of navigational templates mainly aims to make the actual operation identical to the pre-surgical planning from the computer-assisted design. In the present study, we modified the navigational template and evaluate its advantage in accuracy based on ten fresh head specimens.

Materials and methods

The ten fresh head specimens were provided by the Invasive Surgical Anatomy Department of Southern Medical University and Department of Neurosurgery of Nanfang Hospital of Southern Medical University. The instruments used in the analysis included general surgical instruments, maxillofacial plastic instruments (ZXQ-1; Xia Long Medical Instrument Manufacturing Co., Ltd.; Shao shan; People's Republic of China) and a digital camera (Canon 50D; Canon, Inc., Tokyo, Japan).

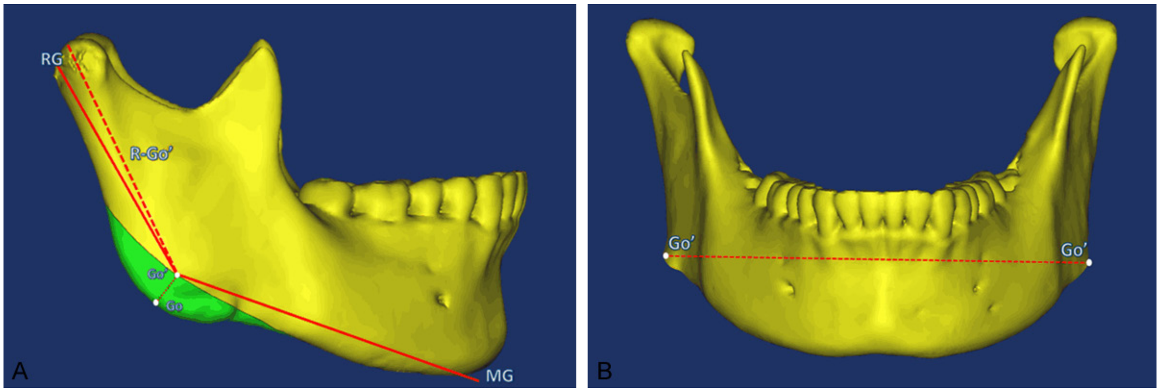

Figure 1. Observation of mandibular ramus and mandibular width by using Mimics software. A. Bilateral gonial angle, bilateral gonion displacement distance, bilateral length of mandibular ramus were measured in Mimics software. B. The mandibular width was measured in Mimics software.

3D models, surgical simulation and virtual postoperative measurements

All the specimens were analyzed by using the CT imaging (SOMATOM Definition CT, Siemens Medical Systems, Germany) with 0.6 mm slice thickness. The CT images were stored as the digital imaging and communicated in medicine (DICOM) format files. All the images were then imported into Mimics software (version 14.0; Materialise, Leuven, Belgium) for 3D reconstruction. The mandibular angle on one side was performed via the osteotomy operation using the software according to the designed osteotomy line. Next the facial midline is set as the axis of symmetry and the other side line was obtained in reference to the mirror image of the cut side. After the virtual MAO, seven sets of data, including bilateral gonion displacement distance (Go-Go'), bilateral gonial angle (RG-Go'-MG), bilateral length of mandibular ramus (R-Go') and the mandibular width (Go'-Go'), which were analyzed by using the Mimics software (**Figure 1A**, **1B**).

Production of navigational templates

The complete mandibular 3D models were exported in the format of ".STL" and imported into the 3-matic format (version 6.0; Materialise, Leuven, Belgium) for the template design. The whole design procedure included marking, thickening, boolean union, and local smoothing. The marked template includes two parts, including the first part (which covers the mandibular angle) and the second part (which covers the second premolar and the first molar for template registration). Then the two parts of the templates were thickened to 3 mm and 2 mm, respectively. Then, the thicked first and second parts were combined by boolean union. Finally, the local smoothing was performed on the lateral side of the template.

The original templates were exported in the format of ".STL" and imported into Mimics software for the same osteotomy operation. A square window (2 mm of side length) is opened in the template to check whether registration is good when the first molar operation was performed. The designed navigational template was produced by a 3D printer with the printing precision of 0.1 mm (MakerBot Replicator 2X, USA).

Surgical procedures

For the ten fresh head specimens, bilateral MAO was performed through the intraoral approach. The registration parts of templates were attached with the second premolar and first molar. The masseter was then stripped from the mandibular ramus to the body, and the inferior border was freed from the attached muscle [5]. Naturally, the remaining parts of templates were positioned on the outer surface of the mandibular angle. Then, the bilateral MAO was easily performed along the lower edge of the navigational template with an oscillating saw following the same registration procedure above (**Figure 2A-C**).

Postoperative measurements

All of the specimens received CT scans post operation and the images were imported into

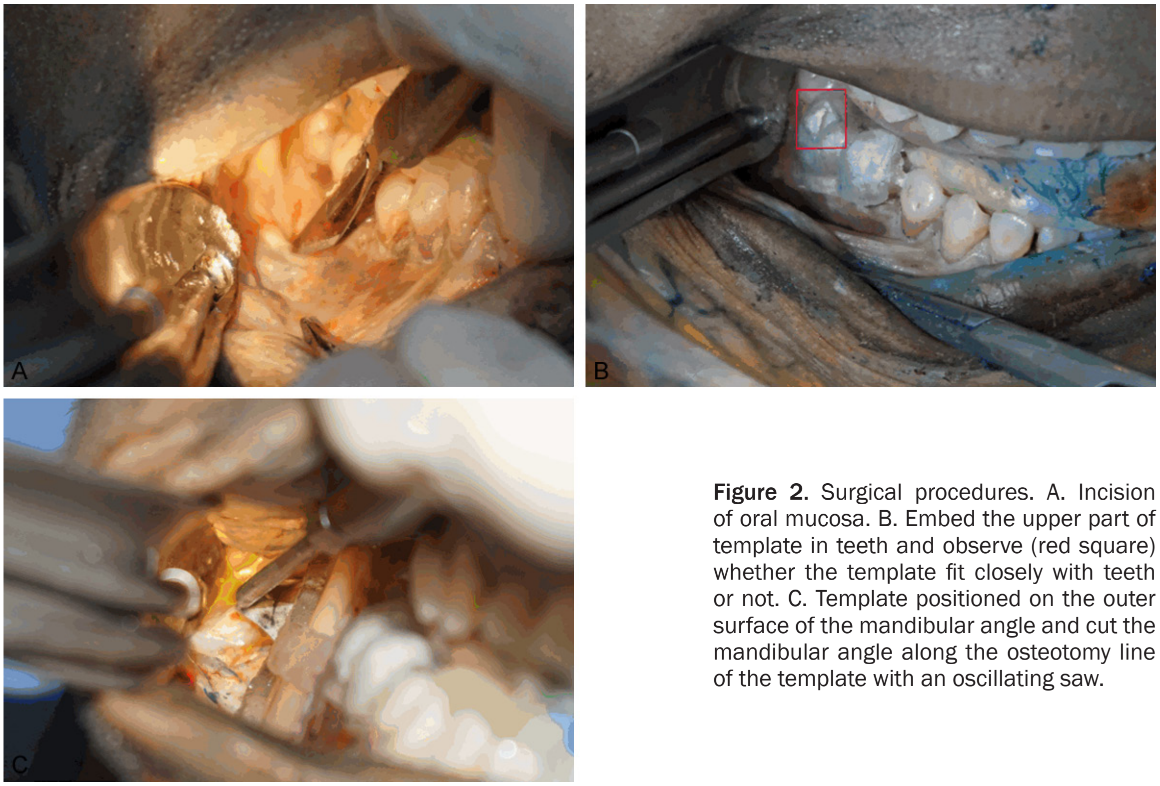

Figure 2. Surgical procedures. A. Incision of oral mucosa. B. Embed the upper part of template in teeth and observe (red square) whether the template fit closely with teeth or not. C. Template positioned on the outer surface of the mandibular angle and cut the mandibular angle along the osteotomy line of the template with an oscillating saw.

Mimics software for 3D reconstruction. Then, the bilateral gonial angle, bilateral gonion displacement distance, bilateral length of mandibular ramus and the mandibular width were analyzed by using the Mimics software.

Statistical analysis

The paired *t*-test was used to determine statistical differences in seven sets of data between the virtual post-operation and actual post-operation for the ten fresh head specimens. Data were reported as mean ± SD. All the data were analyzed by using SPSS 20.0 software (SPSS, Chicago, IL, USA).

Results

No significant differences (**Table 1**, $P > 0.05$) were observed between the virtual post-operation and actual post-operation in seven sets of data for the ten fresh head specimens.

The mean deviations in gonial angle on the left and right sides were 0.16 ± 0.57 and 0.59 ± 0.98°, respectively (**Table 1**). The maximum deviation was no more than 1.03° and 2.86°, respectively (**Table 1**). The mean deviations in gonial displacement distance on the left and right sides were 0.27 ± 0.48 and 0.25 ± 0.40 mm, respectively (**Table 1**). The maximum deviation was no more than 0.81 and 0.83 mm, respectively (**Table 1**). The mean deviations in length of mandibular ramus on the left and right sides were 0.04 ± 0.54 and 0.22 ± 0.45 mm, respectively (**Table 1**). The maximum deviation was no more than 0.87 and 1.00 mm, respectively (**Table 1**). The mean deviation in mandibular width was 0.26 ± 0.70 mm (**Table 1**). The maximum deviation was no more than 0.95 mm (**Table 1**).

Discussion

Comparisons for the Orientals and Westerners, there are differences in cultural backgrounds and esthetic views. A square face contour gives a strong, masculine, and unattractive impression, which generally is regarded as an aesthetic problem for women and even for some men in Oriental culture. Also the over-growth of the mandibular angle is more common in Asians. Therefore, more and more people would prefer their face to be slender and oval-shaped with smooth curves and outlines.

The MAO for prominent mandibular angle was firstly reported by Adams in 1949. He resected hyperostotic bone and the medial portion of

Table 1. The differences, mean ± SD, maximum, *P* value of seven sets of data

	L-Vir-A versus L-Act-A	R-Vir-A versus R-Act-A	L-Vir-D versus L-Act-D	R-Vir-D versus R-Act-D	L-Vir-L* versus L-Act-L*	R-Vir-L* versus R-Act-L*	Vir-W versus Act-W
1	0.52	0.86	0.65	0.38	0.55	0.01	0.75
2	0.26	0.68	0.81	0.35	0.26	0.24	0.95
3	1.03	0.38	0.41	0.46	0.87	0.39	0.77
4	0.72	2.86	0.58	0.63	0.54	0.48	0.32
5	0.42	0.74	0.78	0.83	0.33	0.11	0.82
6	0.39	0.57	0.37	0.17	0.30	0.26	0.36
7	0.22	0.53	0.27	0.35	0.83	0.67	0.38
8	0.33	1.04	0.11	0.39	0.24	1.00	0.65
9	0.39	0.31	0.55	0.37	0.33	0.17	0.91
10	0.78	0.44	0.31	0.21	0.44	0.52	0.89
Mean ± SD (absolute values)	0.16 ± 0.57	0.59 ± 0.98	0.27 ± 0.48	0.25 ± 0.40	0.04 ± 0.54	0.22 ± 0.45	0.26 ± 0.70
Maximum (absolute values)	1.03	2.86	0.81	0.83	0.87	1.00	0.95
P value	0.409	0.090	0.116	0.081	0.843	0.163	0.270

"Vir" = "Virtual Post-operation", "Act" = "Actual Post-operation", "L" = "Left", "R" = "Right", "A" = "Gonial angle", "D" = "Gonion displacement distance", "L*" = "Length of mandibular ramus", "W" = "Mandibular width".

masseter muscle under direct vision through an external approach [6]. Later, many researchers have improved or modified the operative techniques for better correction [7-10].

The main problem of MAO is the limitation of the apparatus, limited vision and the individual variation during the surgery, which makes it extremely difficult for the surgeon to cut the mandibular angle as computer-aided design in pre-operation, Therefore, we have decided to apply a low-cost navigational template to solve this problem.

In the recent years, the 3D-print technology has been developed rapidly, especially in the clinical. Although the navigational template fabricated by 3D-print technology has been applied frequently to other surgery, the application in MAO is relatively less common. Uncertain registration is the biggest problem. Only the templates are in right location, the surgical accuracy could be guaranteed. But the obvious bony anatomical marks ware not in this region, therefore, when the templates are used in the operation, surgeons can't ensure that the templates ware in the right location. The surgeons generally believe that the templates are in the right location when the templates can't move. But the cause of this result may be soft tissue blocking, rather than bony landmarks.

In this study, we designed osteotomy lines based on 3D-reconstructed images of the patients' mandible. In 3D-images of the mandible, inferior alveolar nerve canal were displayed clearly. The osteotomy lines could be designed to avoid nerve canal, and make it safe. We confirmed the osteotomy line based on the surgeon's knowledge of the mandibular anatomy, clinical examination and cognition of aesthetics. Subsequently, we designed automatic registration navigational templates with the same osteotomy lines. In the process of actual operation, due to narrow surgical vision and space, the templates may be unable to be embedded preoperative designed position and be in displacement, therefore, we designed the part of automatic registration. It is integrated with part of osteotomy and this design will ensure that when its location is right, other parts of the templates are right. The two parts are thickened to 3 mm and 2 mm, respectively, based on their better hardness, stability and wider vision. In order to ensure that the template fit closely with teeth, we opened a window in the automatic registration part of template to observe the position of the template. After the mandibular angle exposed fully in the surgery, the upper part of template is embed in teeth and lower part of it is attached to the surface of mandible. At the end, the mandibular angle is cut along the osteotomy line of the template with an oscillating saw.

For the accuracy of surgery, the results were satisfied. Certainly, bone abrasion occurred when perform osteotomy with saw. And adequate exposure of soft tissues must be performed for fitting of the template. Through reference to the mirror image on the contralateral mandible, we designed the contralateral cutting line. This approach may guarantee the symmetry of bilateral mandibular angles.

The surgeons can easily determine the cut line at the surgical site and perform MAO with precision. Our results showed that the 3D models of the virtual post-operation and actual post-operation were almost consistent. It can be guaranteed that ostectomy will be performed well as the pre-operative design. In the software the mandibular canal can be visualized, which is helpful in the design of an osteotomy line that avoids injury to the inferior alveolar nerve.

The 3D printing-navigational template can also meet the needs of the individual operation. Subsequently, it provides a visualized method for patients to easily understand the operation and helps young plastic surgeons to make MAO safer, more convenient and efficient.

This study described an optimized design to manufacture a navigational template for MAO. The results of this study also suggest that the automatic registration 3D navigational template further improved the accuracy and safety of MAO, according to the optimal preoperative planning. This technology realizes the personalized MAO with improved surgical results and can be further explored for improving clinical applications.

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Disclosure of conflict of interest

None.

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