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Original Article

The application of digital model surgery in the treatment of dento-maxillofacial deformities

Minjiao Wang, Hongliang Li, Jiawen Si, Xudong Wang, Steve Guofang Shen, Hongbo Yu

Shanghai Key Laboratory of Stomatology, Department of Oral and Craniomaxillofacial Surgery, Ninth People's Hospital, College of Stomatology, Shanghai Jiao Tong University School of Medicine, Shanghai 200011, China

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Abstract: A retrospective study was conducted to explore the application of digital model surgery in the treatment of dento-maxillofacial deformities. Fifteen patients with dento-maxillofacial deformities were enrolled in this study. A digital craniomaxillofacial-dentition model was established by combining three-dimensional (3D) computed tomography (CT) and laser-scanned dentition models. Based on this composite model, surgical planning, simulations, and postoperative predictions were performed. Under the guidance of a 3D printed splint and guide, orthognathic surgeries and asymmetry corrections were performed. Clinical examinations were performed 3 months after surgery. Surgical accuracy was evaluated by comparing the postoperative CT 3D model with preoperative surgical planning. All patients successfully underwent virtual surgical planning, splint and guide 3D printing, and orthognathic surgery. Facial symmetry was greatly improved after surgery. The mean deviation between the preoperative design and actual surgical results was less than 2 mm. With preoperative planning, surgical simulation, and postoperative prediction, digital model surgery demonstrates great value in improving the accuracy of orthognathic surgery and restoring facial symmetry. It is regarded as a valuable technique to improve the results and execution of this potentially complicated procedure.

Keywords: Digital model surgery, dento-maxillofacial deformities, virtual surgical planning, orthognathic surgery, 3D printing

Introduction

Dento-maxillofacial deformities include abnormal jaw morphologies and/or volumes and anomalies in the upper and lower jaw and other craniofacial bones, which occurs as a result of dysplasia. Such deformities are also associated with occlusal relationships, stomatognathic-system abnormalities, and facial morphology deformities. Treatment for such deformities is often complex, requiring combined orthognathic and orthodontic treatments. Orthognathic surgery is universally inseparable from model surgery, requiring careful planning and modeling prior to surgical intervention. Dento-maxillofacial deformities are usually located in a three-dimensional space and present as structural abnormities of the jaw, while the traditional craniofacial modeling tends to focus on dental occlusions and does not directly reflect the movement of the jaw, which is especially problematic for patients with facial asymmetry [1, 2]. Therefore, we sought to improve upon this technique to enhance pre-surgical modeling for application to a wider range of dento-maxillofacial deformities.

Digital medicine represents a significant developmental advance in modern medicine; with the use of digital technology, surgeries can be designed in a virtual environment to improve surgical precision and planning. Due to its unique advantages and salient features, digital modeling has developed rapidly and has been increasingly applied to orthognathic surgery in recent years [2-9]. However, with digital model surgery, the accuracy of CT reconstruction is often poor, as the dentition and appliances can create artifacts, thus limiting its clinical application. Therefore, we combined 3D CT and laser-scanning of the dentition model to establish a digital craniomaxillofacial dentition model.

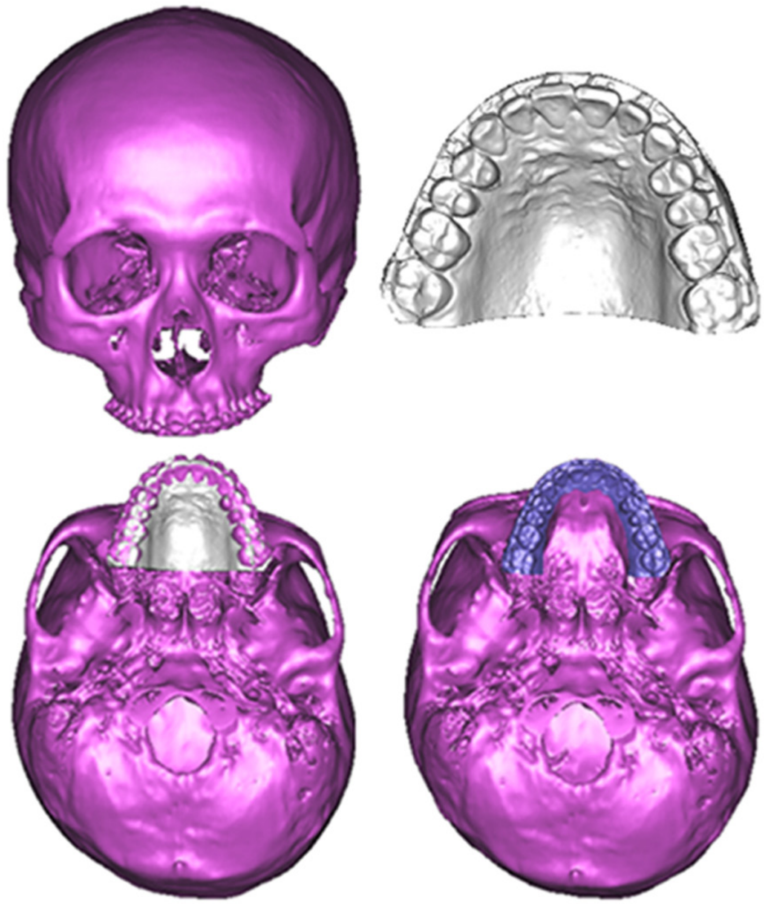

Figure 1. Establishment of a digital craniomaxillofacial dentition model.

Preoperative thin-cut (1.25 mm) spiral CT (Light speed 16, GE, Gloucestershire, UN) scan data was obtained for all patients, while patients were in a supine position. The Frankfurt plane was perpendicular to the horizontal (floor) scan field. The full skull pixel matrix was 512 × 512 with a tube voltage of 120 kV and a tube current of 120 mA.

Plaster dentition models of upper and lower jaws were fabricated using elastic impression materials, and records of the bite were made using wax forms. Die stone was required to avoid occlusion abrasions in the subsequent dentition model composite. Bite records were used to confirm the position of the maxilla and mandible to identify the initial occlusion before surgery, which were used to check the register in the following steps.

Based on this model, surgical planning, simulations, and postoperative predictions were performed. Under the guidance of a 3D printed splint and guide, orthognathic surgery and asymmetry corrections were completed with success. Our results indicate that this approach results in a preferable therapeutic effect, as reported here.

Patients and methods

Fifteen consecutive patients diagnosed with dento-maxillofacial deformities were admitted to the Department of Oral and Craniomaxillofacial Surgery, Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, from January 2014 to August 2014. All patients completed pre-surgical orthodontics,they (5 males and 10 females) had a median age of 24 years (range 22-27). Patients were classified into three grades as follows: 7 cases of skeletal class III malocclusions, 4 cases of skeletal class II malocclusions, and 4 cases of laterognathism of the mandible.

Then, a planned terminal occlusion plaster model, single maxillary plaster model, and single mandibular plaster model were scanned separately by a high-accuracy (±15 mm) laser scanner (Activity 880, Germany), which was used to visualize the 3D model with surface rendering and to store stereo lithography (STL) files.

For 3D image acquisition, the CT images stored in DICOM formats were imported into Proplan software (Edition 1.4, Materialise, Leuven, Belgium). A 3D model, including the patient's craniofacial skeleton, teeth, and soft tissue was converted. After segmentation of the maxilla and mandible using region growing and a Boolean operation, a high-quality 3D CT model was reconstructed.

For image fusions, the laser-scanned dentition model was aligned to the 3D CT model using the point registration function based on 5-10 notable and dispersive anatomic mark points in

Table 1. Definition and representation of skeletal landmarks

landmark	definition
S (sella)	middle point of the sellaturcica
N (nasion)	the intersection of the internasal and frontonasal sutures in the midsagittal plane
Po (porion)	the most upper point on bony external auditory meatus
Or (orbitale)	lowest point on infraorbital margin of each orbit
ANS (anterior nasal spine)	tip of Anterior Nasal Spine
A (subspinale)	Most posterior midline point on the premaxilla
UI (upper incisior)	Inter-dental papilla of the upper incisors at the junction of the crown and gingiva
U6(upper first molar)	Buccal tip of upper first molar
U3(upper canine)	tip of upper canine
B (supramental)	Most posterior midline point on the mandible
LI (lower incisior)	Inter-dental papilla of the lower incisors at the junction of the crown and gingiva
L6 (lower first molar)	Buccal tip of lower first molar
Pog (pogonion)	Most anterior midpoint of symphysis of mandible
Me (menton)	most inferior point on symphysis of mandible
Co (condylion)	exact tip of condyle
Go (gonion)	midpoint of posterior border of mandibular angle

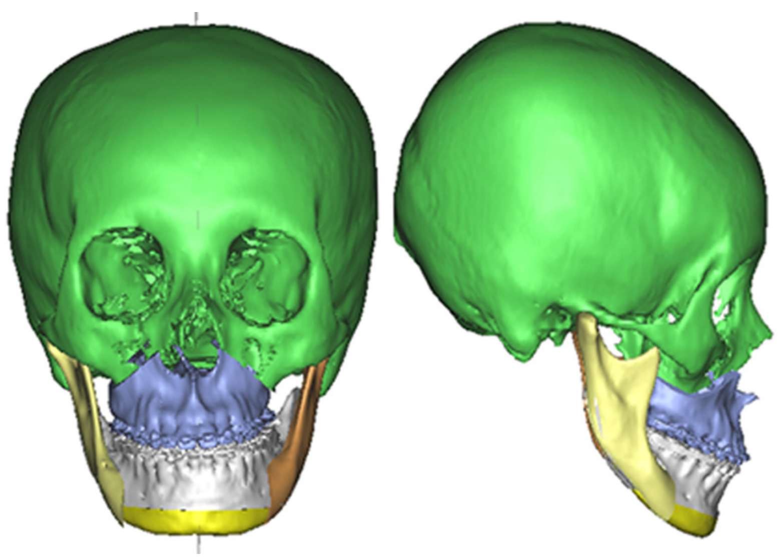

Figure 2. Virtual design of digital model surgery (Le Fort I osteotomy, mandible BBSRO, genioplasty).

the teeth. The teeth in the 3D CT model were replaced by a more-refined dentition model; a digital craniomaxillofacial dentition model that represents the anatomy of jaw and the dental occlusion was established (**Figure 1**).

For 3D cephalometrics, a series of anatomical landmarks were defined on the digital craniomaxillofacial dentition model (**Table 1**). Frankfort horizontal plane, three-dimensional reference planes, facial midlines, and metrical data sets were generated automatically according to the program settings. In some cases, the bony facial midline was not consistent with clinical examination and some adjustments were needed.

Osteotomies, which may include maxillary Le Fort I osteotomy, bilateral sagittal splint ramus osteotomy (BSSRO), genioplasty, and facial contouring, were performed based on the digital craniomaxillofacial dentition model. Osteotomized bony structures were repositioned in accordance with the surgery plan, and three-dimensional symmetries were checked by mirroring technology. Three-dimensional changes, premature contacts, and overlaps could be detected. In addition, the necessity for genioplasty and/or facial contouring surgery could be predicted (**Figure 2**).

The STL files of intermediate occlusions, final occlusions, and contouring bony structures were imported into Geomagic studio and Genmagic spark (North Carolina, USA) for the virtual design of surgical splints and guides, which would be manufactured by a 3D printer (**Figure 3**).

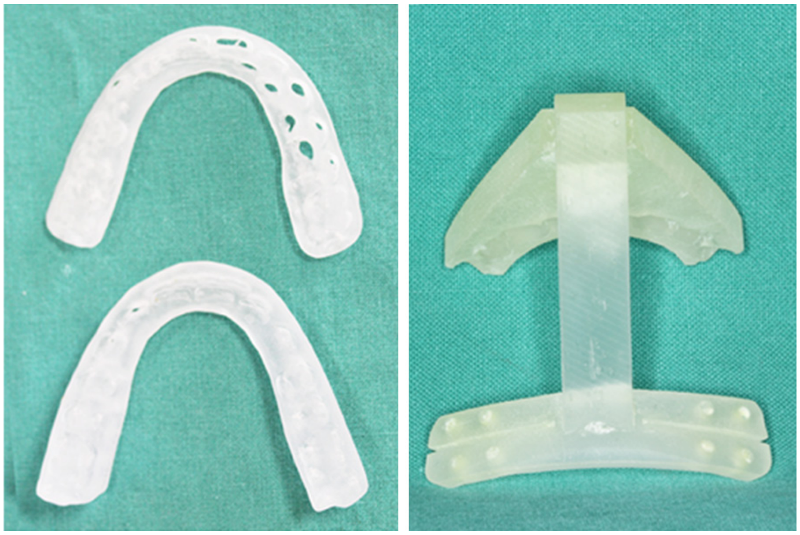

Figure 3. 3-D print of the digital splint and genioplasty guide.

The osteotomy was performed according to presurgical planning. Under the guidance of surgical splints and guides, the position of the jaw and the osteotomy line of contouring structure were defined. Craniofacial CT scans were obtained 3 months after surgery. Quantitative postoperative evaluation of the intervention was performed by comparing the surgical plan and the real result. For this purpose, 3D images of the postoperative model were superimposed upon the virtual plan. This allowed for the measurement of the maximal deviation between the postoperative model and preoperative plan (**Figures 4**, **5**).

Results

Using splints and guides constructed from presurgical models, corrective surgeries were performed successfully in all patients. The digital craniomaxillofacial dentition model, established by combined 3D CT and laser-scanned dentition model, limits “streak” artifacts caused by the presence of steel orthodontic brackets and wires. This modeling better represents the anatomy of the jaw, allowing for the improved identification and modeling of dental occlusions. With the implementation of a surgical plan for orthognathic correction based on a pre-surgical model, the prediction of the postoperative jaw morphology and the boned scope and volume were simplified and readily visualized, which was especially helpful for patients with facial asymmetry

The facial contour was examined by postoperative CT, and it matched well with preoperative planning. At the same time, the defects in facial symmetrywere obviously corrected. The maximal deviation between our surgical plan and the final surgical result was less than 2 mm.

Discussion

Precise surgery plan and accurate intraoperative realization are the keys to obtain satisfactory orthognathic results. In traditional orthognathic surgeries, after repositioning the maxillary segment to the desired position, surgeons usually rotate or adjust the mandibular segment to obtain a relatively idealrelationship with the maxillary dentition to calculate the virtual terminal occlusion splint [10]. However, during this process it becomes difficult for surgeons to avoid penetrability, overlap, or the introduction of an overly large space between the maxillary and mandibular dentition.

Fortunately, digital model surgery, which is based on three-dimensional medical image visualization and modeling technology, offers new treatment options for patients with dento-maxillofacial deformities. Three-dimensional medical image visualization technology, which overcomes the limitations of conventional CT or two-dimensional X-ray images, uses specialized software and computer graphics methods to display the complete structural information of any three-dimensional surface and profile. Three-dimensional geometric modeling technology, based on spiral CT-DICOM data, is one of the methods widely used at present worldwide [5]. Digital model surgery establishes a craniomaxillofacial dentition model through the combined use of 3D CT and laser-scanned dentition models. Based on this model, three-dimensional cephalometrics, virtual surgical planning, simulation and postoperative prediction can be successfully and more accurately performed. Simultaneously, the surgical splints and guides can be manufactured directly by the 3-D printing technology.

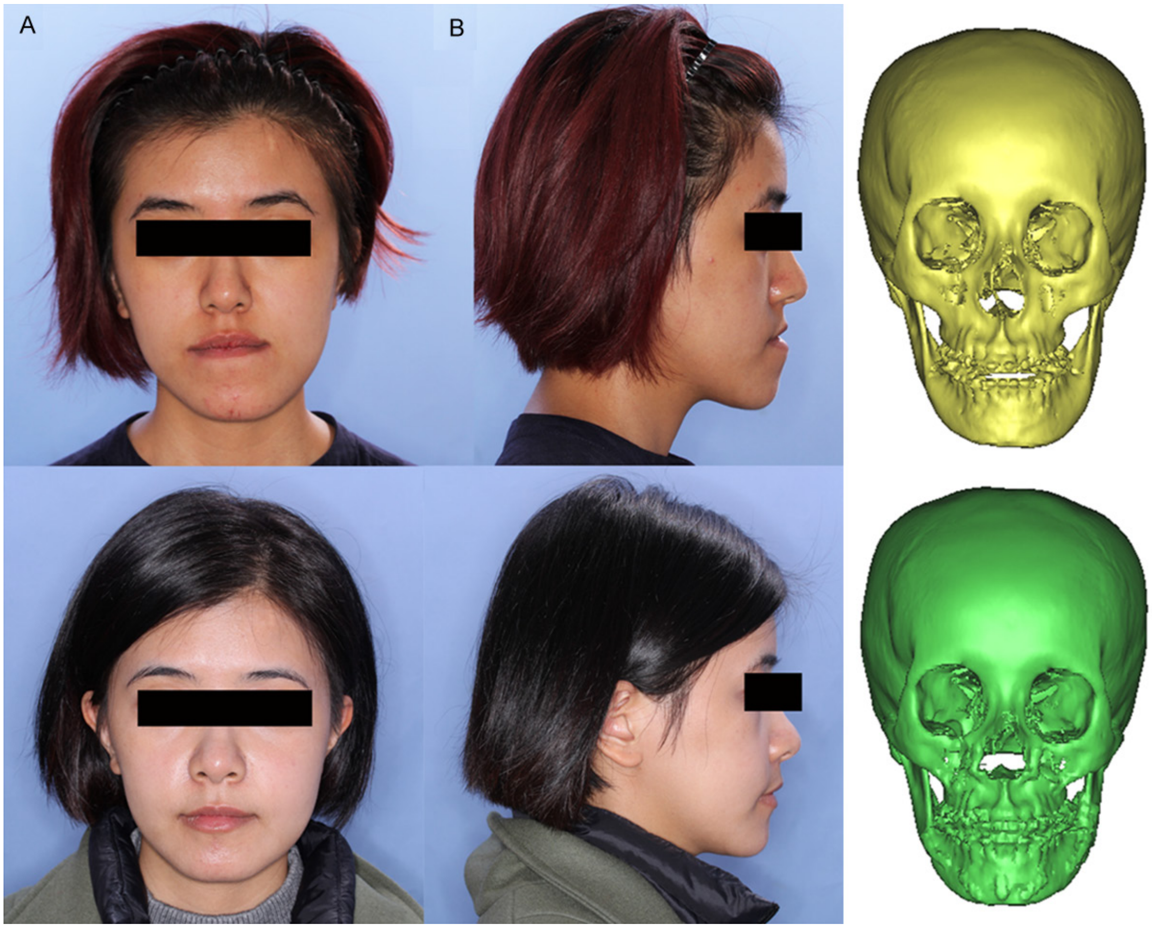

Figure 4. Facial morphology and CT scan before and after surgery (A. frontal view; B. lateral view).

Through precise use of surgical splints and guides during surgery simulation, surgeons can approximate the positioning of jaw to ensure its later stability following surgery.

This approach has several advantages. First, for the surgery plan, this model allows surgeons to gain more essential information. Occlusal cants, generally undetected by traditional cephalometric analysis and traditional model surgery, may be detected by digital model surgery data, as could some other asymmetric facial deformities [3, 11, 12]. Digital model surgery highlights the importance of recording an accurate centric relationship when bimaxillary surgery begins with the maxilla [11, 13, 14]. There are reports that TMJ pressure can be alleviated, while the surgical accuracy increases [6, 15]. Also, the predicted postsurgical facial symmetry is available and viewable, particularly the mandibular symmetry, which could give potential indications for genioplasty and facial contouring surgery. Second, for the intraoperative realization, the surgical accuracy of maxillary positioning with digital model surgery-is comparable to conventional model surgery [16-18]. Better yet, digital model surgery offers a virtual surgery simulation and vividly displays the location of the osteotomy, bone structure movement, and gives a sense and range of the displacement and bony premature contact, which facilitates the operation [11, 19]. Third, for communication, the simulation is highly visual, which is convenient for the communication between surgeons and patients.

Traditional model surgery is also generally more time-consuming and involves a number of complicated steps, especially when the surgery plan needs to be adjusted. In contrast, digital model surgery is readily adjustable; multiple surgery plans could be created to arrive at an

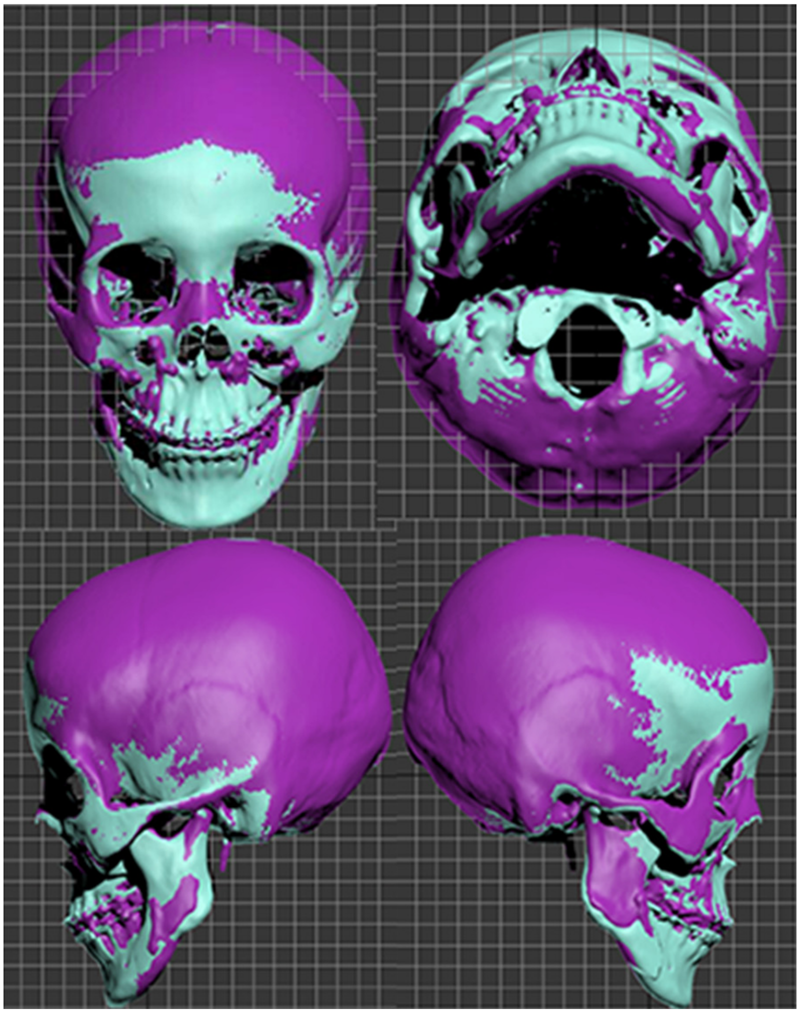

Figure 5. Merger of CT scan after surgery and virtual design before surgery (the blue represents the virtual design, while the purple represents the CT reconstruction 3 months post-surgery).

optimal result, while keeping costs to a minimum. Digital model surgery enables the surgeon to manipulate and fully utilize the 3D images, while data may be readily stored electronically, aiding in data management. All data can be readily shared electronically for clinical teaching, medical aid, and Tele-Medicine, to name a few applications [11, 20, 21].

Three-dimensional printing technology has facilitated the rapid prototyping of splints and guides, which is of great benefit during surgery [22]. Different software programs are available for the 3D planning and printing of surgical splints and guides using CAD/CAM (Computer Aided Design/Computer Aided Manufacturing), which ensures accuracy and improves work efficiency.

However, digital modeling does have some shortcomings. The dentition in the dento-maxillofaical model cannot identify premature contacts during surgical planning, which may lead to difficulties in placing the splints and increased instability of the splint during surgery. Also, multiple uses of the 3D CT model and laser-scanned dentition model may magnify any errors, because the accuracy of each step is built upon the accuracy of the previous step. Therefore, each step much be executed with precision [13]. The last practical issue is there is an immediate (high) cost forsoftware and hardware used for modeling, although repeated use of this technology should result in long term cost benefits.

Digital model surgery, a new and widely used technology, represents a significant development in surgical medicine. It can help to overcome the shortcomings of traditional model surgery while better correcting dento-maxillofacial deformities. Digital model surgery has a numerous clinical applications and shows a relatively high success rate and agreement with more traditional methods, as well as close agreement with actual surgical results using digital modeling as a guide. Therefore, we believe that additional investigation into the application of this methodology for craniofacial surgery is warranted.

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Disclosure of conflict of interest

None.

Address correspondence to: Hongbo Yu and Steve Guofang Shen, Department of Oral & Cranio-Maxillofacial Surgery, Shanghai Ninth People's Hospital, Shanghai Jiaotong University School of Medicine, No. 639, Zhizaoju Road, Shanghai 200011, People's Republic of China. Tel: +86-21-23271207; Fax: +86-21-63136856; E-mail: yhb3508@163.com

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