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Bilateral sagittal split osteotomy training on mandibular 3-dimensional printed models for maxillofacial surgical residents

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Abstract

Complications with bilateral sagittal split osteotomy (BSSO) can sometimes result from surgical inexperience. Our aim was to present a 3-dimensional printed mandibular model for BSSO training in a maxillofacial surgical education programme. A polymethacrylate mandibular model obtained from mandibular cone-beam computed tomographic (CT) images was designed and printed for use in training. Twenty-four residents were each asked to do a BSSO according to the Epker/Dal-Pont technique. The session was conducted as a simulation course with a final debriefing. A questionnaire before and after the test was filled in using a 10-point Likert scale to assess the participants' knowledge. The mandibular model provided a realistic way of handling the trabecular bone after cortical osteotomy, as well as in the splitting phase. Significant increases in knowledge and surgical skills were noted for all steps of the BSSO, particularly regarding the use of the piezoelectric device for osteotomy, and for management of wisdom teeth in the splitting zone (3.00 ±2.16 to 6.95 ±2.06 and 2.73 ±1.91 to 5.75 ±2.63, respectively; $p_1 = 0.0002$ and $p_2 = 0.0003$). We think that this is a valuable printed mandibular model for the development of surgical skills for BSSO in maxillofacial surgical residents.

Keywords: Orthognathic surgical procedure; education; models; 3D printing

Introduction

Bilateral sagittal split osteotomy (BSSO) is the most common surgical procedure used to correct mandibular deformities.[1–3] Although it is a standard, safe procedure, it can lead to perioperative complications,[4,5] among which injury to the inferior alveolar nerve (IAN),[6,7] condylar resorption,[6] and bad splitting[8,9] are the most common, occurring in 0-80%, 1%-31%, and 3%-23%, respectively. Non-union, relapse, damage to teeth, infections, and bleeding complications are

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quite rare.[6,10] A lack of surgical experience and skills are known to be associated with a higher risk of such complications, particularly regarding recovery of the sensitivity of the IAN.[11,12]

In surgery "learning by doing" remains the best way for residents to acquire the skills required to manage and treat patients properly.[13] However, technical interventions require such skills to be acquired before the procedures are undertaken with actual patients.[1,11] Simulation has been well-described for anaesthesia, intensive care, and general surgery residents,[14,15] but there have been few reports of it in maxillofacial surgical training.[16] Nevertheless, simulation-based training has been shown to increase surgical skills without risk to the patient, while it also reduces operating time and the number of complications.[11,17,18]

The use of 3-dimensional printed models as educational tools has been mainly described for sinus surgery, dental extractions, bone grafting, and repair of clefts,[11,16,18] and such models are also commonly used for planning and training in mandibular reconstruction and difficult orthognathic procedures.[2,19] As far as we know no report has yet been published about the use of 3-dimensional models to teach BSSO.

The aim of this paper was to describe and evaluate a BSSO training programme for maxillofacial surgical residents using a 3D-printed manufactured mandibular model.

Material and methods

Conception and fabrication of the model

Requirement specification: a custom-made mandibular model was designed using rapid prototyping techniques. To create a realistic model for BSSO, we used the following criteria: compliance with normal mandibular anatomy; identifiable anatomical structures - particularly the lingula, the external oblique ridge, and the mental foramen; and rigid cortical, and soft medullary, bones to allow for realistic splitting of the mandible.

Phantom design: the phantom was designed using high-resolution cone-beam computed tomographic (CT) data from two patients (field of view 120x120 mm, focused on the mandible, 110 kV, the tube current and exposure time were modulated according to the scout views). The cone-beam CT device used for acquisition of images was a wide-field model (NewTom VGI, QR). The selected mandibular specimen had a normal anatomy and came from two patients who had had BSSO to correct a Class II malocclusion; for one, the mandibular wisdom teeth were included in the mandibular ramus. Creation of the phantom started with the importing of the cone-beam CT image into 3-dimensional visualisation Anatomaker software (3D-Medlab). The lower jaw was segmented based on the voxel intensity using techniques incorporating global thresholding. The segmented mandible was then converted to a mesh model using Netfabb® software (Autodesk), then saved as a stereo lithography (STL) file and sent to a 3-dimensional printer software (Objet studio, Stratasys) to manage the 3-dimensional printing.

Fabrication: both the anatomical models were printed using PolyJet technology with a Connex 3260 3D printer (Stratasys). A mix of polymethacrylate resin was used to produce the models and to try to reproduce the mechanical characteristics of the natural mandible (such as the cortical and medullary bones, and the mandibular canal) (Support Soluble, FullCure 706 & VeroWhite Plus FullCure 835). The design time, including importing the CT images, segmentation, and export of the STL file took roughly two hours for both the inferior jaws. The 3-dimensional printing time for a mandible was around six to eight hours, depending on the model being studied. The cost of the fabrication was US$155 (ex-VAT). The models were tested and approved by three senior surgeons before they were used with maxillofacial surgical residents.

Session: a two-day national training programme for BSSO was scheduled at the maxillofacial surgery unit of Nantes University Hospital. Over two half-days, the residents were given several lectures and practical teaching about orthognathic mandibular surgery, cephalometric planning, and the manufacture of occlusal splints. For the simulation during one half-day, each resident had a 3-dimensional printed mandible, a high-speed surgical drilling system (NSK France SAS), or a piezoelectric device (NSK), and all the surgical materials necessary to do a BSSO (including a Bein dental elevator, periosteal elevators, straight osteotomes, a bone chisel, and Tessier expansion forceps) and fixation (Delphos Implants SA). They were asked to do a BSSO according to the Epker/Dal Pont technique with the standard steps: drawing of reference points; cutting (bud burr or piezoelectric) the cortical bone; additional "cut through" osteotomy of the medullary bone with an osteotome or bone chisel; splitting the mandible; and fixation with an osteosynthesis device. Assistance from a senior supervisor was available at each stage, and a final evaluation of the procedure was made for each participant.

Evaluation

Two separate questionnaires were filled in to check the validity of our models and our teaching course: one before the intervention to evaluate the theoretical knowledge of the participants, and one after the intervention for feedback. A 10-point Likert scale was used to rate each question (Table 1). The significance of the differences was analysed by a Wilcoxon test for paired observations using GraphPad Prism (version 5.0).

Table 1
Questionnaire given before and after the test to the residents who took part in the training for bilateral sagittal split osteotomy (BSSO) on 3-dimensional printed models.

Rate your level of experience of bilateral sagittal split osteotomy in the following:
- Surgical instruments required
- Identification of the lingula
- Osteotomy with a bud burr
- Osteotomy with a piezoelectric device
- Management of the wisdom tooth in the splitting zone
- Surgical splitting of the mandible
- Management of the inferior alveolar nerve
- Mandibular fixation with miniplates

Table 2
Results of the questionnaire given before and after the test to the residents who took part in the training for bilateral sagittal split osteotomy on 3-dimensional printed models.

Question	Before	After	p value
Surgical instrument required	5.68 (±1.91)	7.05 (±2.24)	0.0032
Identification of the lingula	5.09 (±2.09)	7.35 (±1.84)	0.0003
Osteotomy with a bud bur	4.64 (±2.17)	6.70 (±2.18)	0.0003
Osteotomy with a piezoelectric device	3.00 (±2.16)	6.95 (±2.06)	0.0002
Management of the wisdom tooth	2.73 (±1.91)	5.75 (±2.63)	0.0003
Splitting of the mandible	3.96 (±1.84)	6.00 (±1.81)	0.0001
Management of the inferior alveolar nerve	4.14 (±1.61)	6.25 (±1.99)	0.0002
Mandibular fixation	4.18 (±1.68)	6.40 (±1.88)	0.0002

Results

Epidemiological data

Twenty-four residents from seven different medical centres participated in our training program. Seven students were in their third year of residency, five in their second year, and five in their fourth year, while three and four of them, respectively, were in their first or last year of residency.

The pretest survey was completed by 22 of the students, and results indicated that most of the residents were satisfied with their level of experience with the surgical instruments required for the BSSO procedure, and with the first steps of the technique (including identification of the lingula) irrespective of their level of experience, with mean self-assessment scores for these items of 5.68 (±1.91), and 5.09 (±2.09), respectively. The residents were less confident of their skills as far as the osteotomy was concerned, particularly regarding the use of a piezoelectric device. Similar findings were obtained for mandibular splitting, management of the wisdom tooth and the IAN, and the osteosynthesis (Table 2).

Training on mandibular models

The 3-dimensional printed models allowed BSSO to be done according to the Epker/Dal Pont technique, irrespective of the device (a bud burr or piezoelectric device) used for the osteotomy (Fig. 1). The model proved to be realistic in terms of handling the hard cortical bone and soft trabecular bone during the osteotomy. The splitting phase with a Bein elevator positioned at the mandibular basal border was equally lifelike in terms of handling and sounding. A bad split occurred in approximately one-third of cases and could be explained by a poor cortical osteotomy, mainly in the lingula and the basal border. The presence of the wisdom tooth in the mandibular ramus was an additional difficulty, which could be overcome by an additional tooth section and splitting, as in real life. The hardness of the third molar was easy to recognise in the soft cancellous bone of the mandible. Mandibular fixation with miniplates was no problem and resembled real-life conditions (Fig. 2).

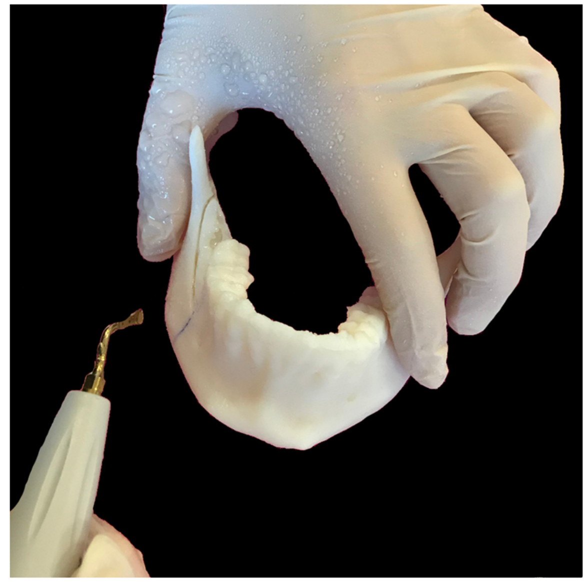

Fig. 1. Photograph of a cortical bone osteotomy done with the piezoelectric device on the right external oblique ridge.

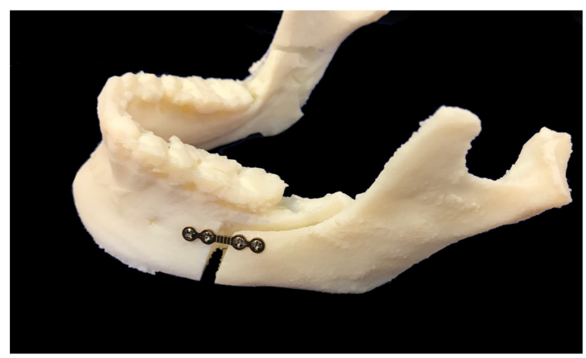

Fig. 2. Photograph of an osteosynthesis of the left mandibular sagittal split osteotomy using a four-hole, 1-mm miniplate.

Evaluation of the course

The residents reported an improvement in their surgical skills for BSSO, as reflected by the significant increase in the self-

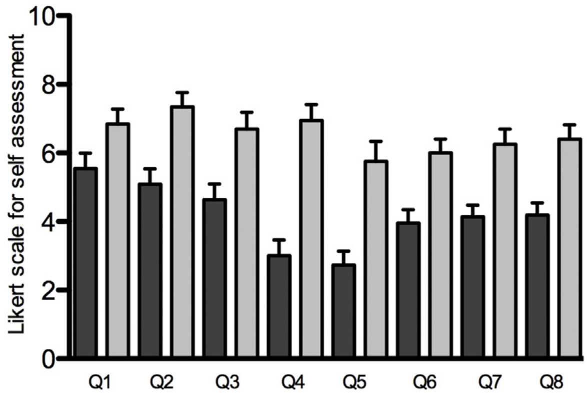

Fig. 3. The self-assessment questionnaire used to evaluate the surgical skills for bilateral sagittal split osteotomy on a 10-point Likert scale, before (dark grey) and after (light grey) participation in the training programme.

assessment scores after completion of the training course (Table 2). Osteotomy with a piezoelectric device, and management of the wisdom tooth, were particularly improved by participation in the workshop (Fig. 3). The mean score increased from 4.33 to 6.59, which indicated an increase of roughly a third in knowledge and skills.

Discussion

The importance of learning by having surgical training is underscored by the fact that a surgeon's error rate for a procedure declines as the number times that they do the procedure increases.[13] As well as classroom teaching and instruction by a senior faculty member in the operating room, various models can be used to acquire surgical skills. However, the use of cadaveric or animal models gives rise to availability, biosafety, and ethical considerations.[19] (19) Digital and mannequin simulations have, therefore, progressively become part of maxillofacial surgical educational programmes.[11,14,16,18] In a recent study, Maliha et al identified 22 simulators based on the use of a virtual reality haptic simulator, physical models, and web-based simulators.[16] The virtual reality and haptic-based simulators allow the trainees to gain experience doing an orthognathic procedure in a virtual patient,[20,21] but they fail to reflect reality properly, particularly in terms of surgical instruments and clinical accuracy.[16] Web-based simulators are an interesting tool on which to learn the main stages of an orthognathic intervention, but they fail to reflect the surgeon's technical involvement and the operating environment adequately.

Phantom heads have been used for many years in dental training programmes.[17] In maxillofacial surgery, printed models have been described in educational programmes for sinus lifts and third molar extractions,[11] endoscopic sinus surgery, craniofacial reconstruction,[19] and cleft repair.[18] Most authors suggest that stereolithographic models should be used in residency training, but such models are mainly used in simulation and planning of complex orthognathic procedures[2] or mandibular reconstructions.[19,22]

Table 3
Advantages and drawbacks of the mandibular printed model.

Advantages:	
	Personalised mandibular model from real patients
	Easy to design and manufacture
	Acceptable cost (US$ 155)
	Realistic feel (hard cortical bone, soft trabecular bone, splitting phase
	Evaluation by three senior surgeons and 22 residents
Drawbacks:	
	Created from cone-beam computed tomographic (CT) images (lower segmentation quality than CT scan)
	No soft tissue and gum envelope
	No connection between condyle and glenoid fossa
	Mandibular nerve not tagged
	No embedding of phantom head
	No biomechanical comparison with normal mandible

Here we have described a mandibular 3- dimensional printed model and its use for a trainee simulation programme of BSSO, and to our knowledge this is the first published description of such a programme. Despite the absence of biomechanical studies, our model proved to be realistic in terms of the procedures involved in an Epker/Dal Pont osteotomy, from the bone-cutting stage to the osteosynthesis, as it accurately reflected real-life conditions and, despite an elaborate manufacturing process, the production cost was not excessive (US$ 155).

As described by Werz et al, printed models have led to the concept of "personalised medicine", whereby individual patients can be transformed in a training model.[11] In our specific case, we used the cone-beam CT data from two different patients who had BSSO to correct malocclusion. Despite the quality being lower than that of a CT scan in terms of virtual planning, we did not experience problems with the numerical segmentation step. In one case, the wisdom teeth were included in the mandibular ramus to introduce a degree of difficulty to the osteotomy, which helps the trainees tackle such clinical conditions, and our model allowed the residents to develop their surgical skills in the use of two different devices for cutting the bone (a high-speed bud burr and piezoelectric technology), and how to manage the osteosynthesis. However, the model illustrates only the bony anatomy, irrespective of the attached soft tissues, which precludes the incision and the first steps of detachment of the muscle. The mandibular condyle was also not jointed to the base of the skull. Condylar positioning is an essential stage during BSSO to obtain functional results and to avoid postoperative temporomandibular dysfunction.[3]

The advantages and drawbacks of our model are listed in Table 3. Future printed models should be refined to expose a connection between the condyle and the glenoid fossa; these models should also have a coated gum and a coloured mandibular nerve structure in addition to being embedded in a phantom head, to better recapitulate the difficulty of an intraoral approach. Such new models should be compared with normal mandibular bone in terms of mechanical properties (such as resistance and elasticity).

Simulation is based on three key steps: an upstream framework; the simulation session; and a debriefing period.[14,15] Our training programme met these three requirements as each trainee was provided with a systematic analysis of the reasons for success or failure of the osteotomy. The residents who participated in the session completed a questionnaire before and after the test, which showed that there was a significant increase in knowledge and surgical skills as a result of having practiced the BSSO technique. Based on the self-assessment questionnaires, most of the residents were confident of their skills with the first steps of the technique until the bone osteotomy, as they probably usually do these stages on patients. However, they were less sure when it came to the osteotomy, splitting, and fixation, which are probably usually done by a senior surgeon. This highlights the relevance of simulation of all the steps of BSSO in physical models. Unfortunately our questionnaire was not standardised to validate the relevance of our teaching and learning methods.

Most reports of maxillofacial surgical simulation programmes have been descriptive, and have lacked scientific evidence of their validity.[16] Further studies are needed to assess the efficacy of 3-dimensional printed models as educational tools for BSSO in maxillofacial surgery, and to compare them with other methods of learning.

Conclusion

Our 3-dimensional printed mandibular model seems to be useful for maxillofacial surgical residents to obtain experience and skills for the management of bilateral sagittal split osteotomy.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

No ethics approval was required. No patient consent was needed.

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