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Potential new method of design for reconstruction of complicated mandibular defects: a virtual deformable mandibular model☆

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Abstract

The treatment of complicated mandibular defects, including misshaped and missing bones, is challenging, and the success of reconstruction depends to a large extent on the formulation of a precise surgical plan. There is still no ideal preoperative method of design for reconstruction to deal with large, cross-midline, mandibular, segmental defects. We have built a virtual deformable mandibular model (VDMM) with 3-dimensional animation software. Sixteen handles were set on the model, and these could be easily controlled with a computer mouse to change the morphology of the deformable mandibular model. The computed tomographic (CT) data from 10 normal skulls was used to validate the adjustability of the VDMM. According to the positions of the mandibular fossa of the temporomandibular joint, the maxillary dental arch, and the craniomaxillofacial profile, the model could be adjusted to an ideal contour, which was coordinated with the skull. The VDMM was then adjusted further according to the morphology of the original mandible. A 3-dimensional comparison was made between the model of the deformed mandible and the original mandible. Using 16 control handles, the VDMM could be adjusted to a new outline, which was similar in shape to the original mandible. Within 3 mm deviation either way, the absolute mean distribution of deviation between the contour of the deformed model and the original mandible was 92.5%. The VDMM might be useful for preoperative design of reconstruction of complicated mandibular defects.

Keywords: Mandibular defect; Reconstruction; Computer aided design; Deformable mandible model

Introduction

The treatment of complicated mandibular deformities is challenging as,[1] with the development of microsurgical techniques, composite mandibular defects can be repaired with various forms of osteocutaneous free flaps such as fibular or iliac flaps.[2,3] Although many studies have described the authors' personal experiences, it is difficult to achieve optimal aesthetic and functional results, particularly in those cases with large segmental defects of the mandible,[1,4–10] because it is hard to replicate its complex 3-dimensional conformation.

CAD/CAM technology has been used in calvarial bone reconstruction, orbital floor reconstruction, zygomatic reconstruction, and orthognathic surgery,[1,6,11–15] and it has been used to facilitate reconstruction of mandibular segmental defects.[5,9] A standard procedure for preoperative planning uses the mirroring tool for unilateral defects, and reconstructs the defects with its normal counterpart as the reference.[5,9] Various materials and bone grafts have been used to reconstruct mandibular defects with varying degrees of suc-

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cess. However, the mirror cannot be used in those patients in whom segmental defects cross the midline.[8] On most occasions, preoperative planning has to be done by digitally manipulating bone segments using personal experience, just as in conventional methods.

In the present study, we describe a new way of replicating the complex 3-dimensional conformation of the mandible. A virtual deformable mandibular model (VDMM) was created using 3-dimensional animation software (Autodesk®, Maya® 2013, San Rafael, CA, USA), and its morphology could be easily changed by adjusting the control handles. Computed tomography (CT) data from 10 human skulls was used to validate its adjustability.

The study was approved by the Institutional Review Board of Peking University School of Stomatology.

Material and methods

Building the VDMM

A skull from the 3-dimensional craniofacial database at the Department of Oral and Maxillofacial Surgery, Peking University School of Stomatology, was selected as the prototype on which to build a standard VDMM. This reference skull was from an adult man with excellent craniofacial proportions, good mandibular bone, no loss of teeth, good dental occlusion, no absorption of alveolar bone, and no bony lesions. Spiral CT data were collected with a 0.75 mm slice thickness, a slice reconstruction interval of 0.75 mm, in a 512×512 image matrix. The CT data were imported into the commercial software program ProPlan CMF 1.4 (Materialise, Leuven, Belgium). A thresholding and dynamic region growing tool was used to extract the contour of the mandible without teeth from the CT data. The 3-dimensional digital data of the mandibular model were constructed and saved as an ".stl" file. The digital model file was imported into Maya® 2013 (Autodesk®) to design a VDMM.

The left side of the mandible was mirrored to the right side to build a symmetrical model. The centre plane between the two central incisors and the condyles was considered to be the mirror plane. Using the animation software package of Maya® 2013, basic polygonal primitives were used to create the general shape of the outline of the mandible. Sixteen handles were then set on the VDMM to control its deformation.

Validation of the deformability of the VDMM

CT data from a total of 10 skulls (Samples 1–10 in Table 1[16]) in the 3-dimensional craniofacial database of people with normal occlusion in north China were selected to validate the adjustment ability of the VDMM.[17] All the cases were imported into ProPlan 1.4 to be segmented and reconstructed. The lower jaw was excluded and the residual skull skeleton was imported into the VDMM scene in the Maya® 2013 platform. According to the position of the fossa in the temporomandibular joint (TMJ), the maxillary dental arch, and the craniomaxillofacial profile, the model was adjusted to an ideal outline. Then the original mandibular model was also imported into the scene, and the VDMM was adjusted further to match the original mandibular morphology. The outline of the original mandible was set as the reference object. A 3-dimensional comparison was made between the morphology of the original mandible and the new deformed mandible model using Geomagic Qualify 12 (Geomagic, Cary, NC, USA).

The detailed control process using the VDMM is illustrated with Sample 1 (Table 1[16]).

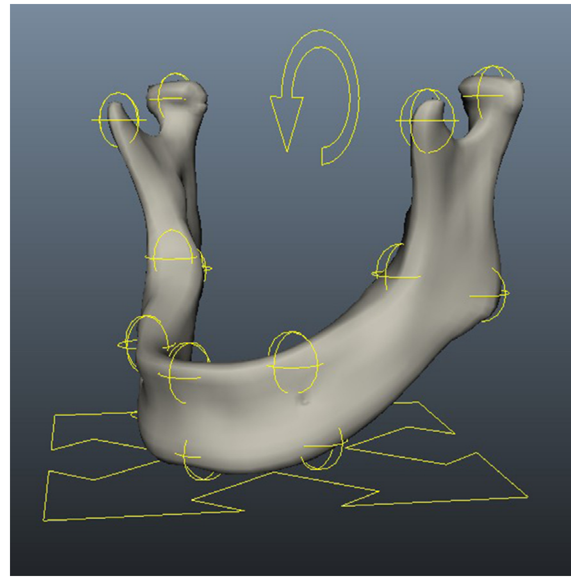

Fig. 1. Virtual deformable mandibular model (VDMM) (grey) and its 16 control handles (yellow).

Results

The VDMM had been built with 16 control handles (Fig. 1), and the contour of the model could be adjusted by moving those handles. The VDMM has the following functions: the whole mandibular model could be translated, rescaled, or rotated; its shape could be adjusted by angle, length, or volume. (Video 1, supplemental digital content 1.) The final adjusted model data could be used in conjunction with other surgical planning software.

We made a preliminary validation of the adjustability of the deformed mandibular model, followed by 3-dimensional comparisons using Geomagic Qualify 12. The contour of the original mandible was set as the reference model and the adjusted deformable mandible model was set as the test model. The mean absolute deviation, within a 3 mm deviation distribution either way, and the maximum and minimum critical values of the 10 skulls (Samples 1–10) are included in Table 1.[16]

Table 1
Results of 3-dimensional comparison between the model of the adjusted mandible and the original mandible in 10 samples of skull.

Sample number	Age (years)	Sex	Absolute mean deviations* (mm)	SD (mm)**	Deviation within 3 mm distribution (%)*	Maximum and minimum critical values (mm)*
1	22	F	1.1/-1.5	1.7	92.4	6.6
2	23	F	0.8/-1.6	1.6	88.8	6.1
3	22	F	0.5/-1.2	1.3	93.3	5.9
4	22	F	0.6/-1.7	1.5	87.7	6.3
5	21	F	0.7/-1.2	1.4	95.0	6.7
6	24	M	0.9/-1.4	1.5	94.1	6.0
7	23	M	0.8/-1.4	1.5	92.4	6.5
8	22	M	0.6/-1.4	1.4	91.5	6.6
9	21	M	0.7/-1.2	1.3	95.0	6.2
10	23	M	0.8/-1.2	1.4	95.1	6.6
Absolute mean	–	–	0.8/-1.4	1.5	92.5	6.5

* The absolute mean gives two numbers as the 3-dimensional comparison includes two directions: inward/outward.[16]

** SD of the distance of all points of the adjusted deformable model of the mandible from the contour of the original mandible.[16]

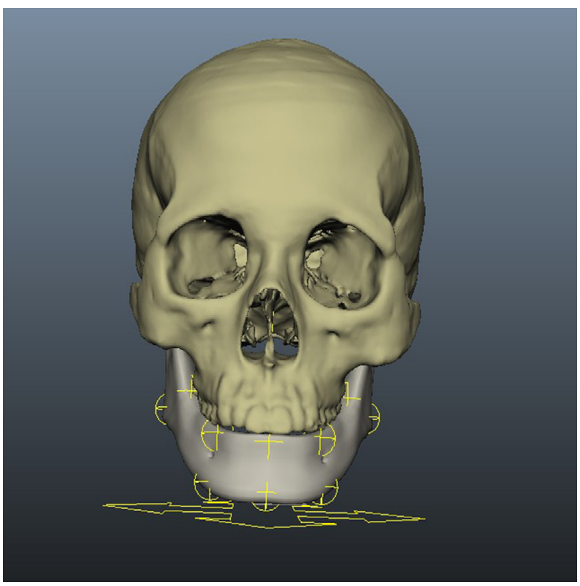

Fig. 2. The skeleton skull without the mandibular digital model imported into the VDMM in Maya® 2013. The VDMM was adjusted to adapt to the skeleton skull according to the position of the temporomandibular joint (front).

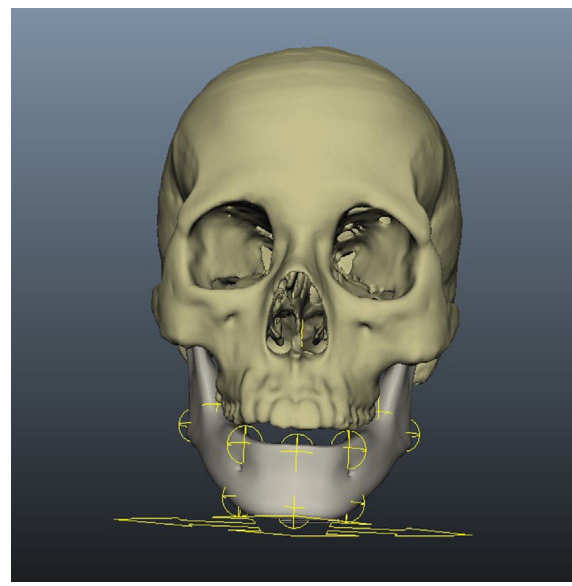

Fig. 3. The gap between the maxilla and the mandible adjusted in relation to the height of the molar crown. The arch of the lower jaw was adjusted according to the maxillary dental arch (front).

The process of using the VDMM (illustrated by Sample 1)

Step 1. the CT data of the skull for Sample 1 was imported into ProPlan CMF 1.4 for reconstruction and segmentation. The cranial skeleton was separated into two digital models, the mandibular model and the remainder of the skull skeleton, and saved as ".stl" files.

Step 2. the skeleton skull without the mandibular digital model was imported into the VDMM scene in Maya® 2013. The VDMM was adjusted to adapt to the skeleton according to the position of the TMJ by controlling the handles. The condylar process of the mandibular model was placed in the middle of the joint fossa (Fig. 2). (Video 2, supplemental digital content 2).

Step 3. the gap between the maxilla and the mandible was adjusted in relation to the height of the molar crown. (Video 3, supplemental digital content 3).

Step 4. the arch of the lower jaw was adjusted according to the dental arch of the maxilla (Fig. 3). (Video 4, supplemental digital content 4).

Step 5. the position of the mental region of the mandible was adjusted and confirmed using knowledge gained from orthognathic surgery (Video 5, supplemental digital content 5), so an ideal mandibular template was formed. If the patient has to have his mandible removed - for example, to eliminate a large mandibular lesion - then the deformable model may be used as the design template for reconstruction.

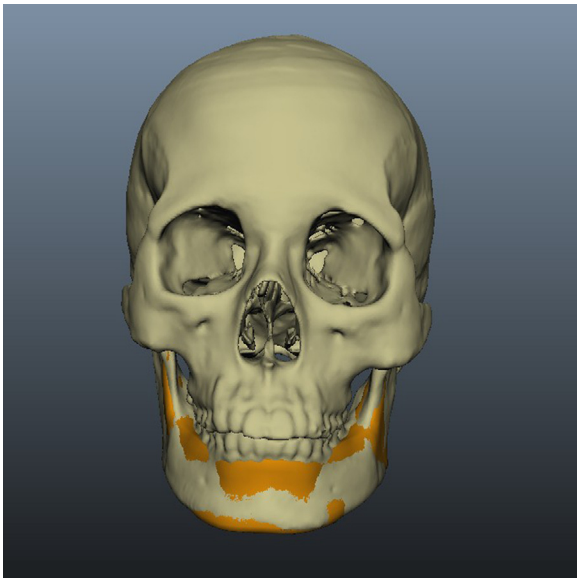

Fig. 4. Position of the mental region of the mandible was adjusted using knowledge gained from orthognathic surgery. The original mandibular model was superimposed. The virtual deformable model (orange) could be adjusted further to adapt to the contour of the original mandible (front).

Step 6. the original model of the mandible was superimposed. The handles on the VDMM could be adjusted in detail to adapt the model more closely to the shape of the original mandible (Fig. 4). (Video 6, supplementary content 6. Video 7, supplementary content 7).

Finally, the data from the original mandible and the adjusted mandibular model were exported as ".stl" files. A 3-dimensional comparison was made using Geomagic Qualify 12. The contour of the original mandible was set as the reference model, and the contour of the adjusted mandibular model was set as the test model, before deviation surface analysis. The original models were automatically computed and colour scales ranging from minimum to maximum were created that automatically displayed the assigned colour code on the model's surface. In the present study, within 3 mm deviation on either side was set as acceptable, and the green colour was distributed uniformly on the surface of the adjusted deformable mandibular model (Fig. 5). The contours of the two models were similar.

Discussion

The most important goal of mandibular reconstruction is to restore function, form, and aesthetic appearance. Large segmental defects of the mandible are difficult to reconstruct, and a mandible with cross-midline defects is even more challenging. With the traditional approach, surgeons have to reconstruct the mandible in the operating theatre, relying on their personal experience, and much time is spent approximating and repeatedly bending titanium plates, and adjusting the position of the grafted bones. A flawless result is not easy to achieve.

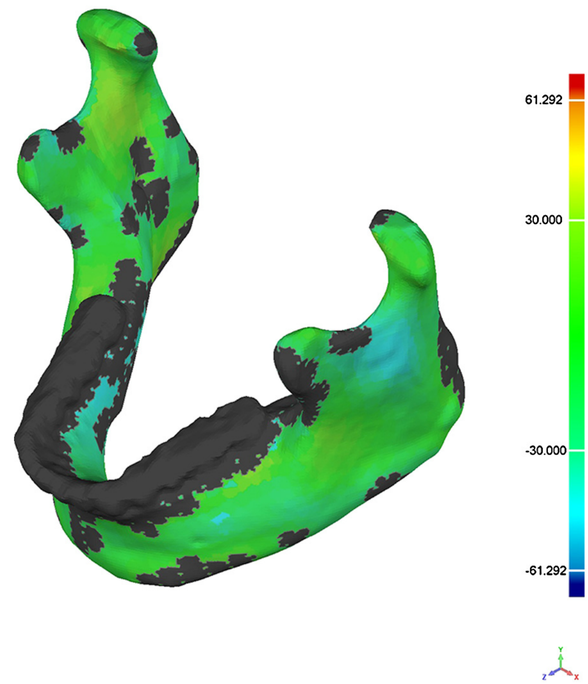

Fig. 5. Three-dimensional comparison between the adjusted deformable mandible model and the original mandible. When the deviation within 3 mm on either side was set as acceptable, the green colour was uniformly distributed.

In recent decades, several preoperative planning procedures have been proposed, and different applications have been created to simplify the operation and obtain good results.

Oral and maxillofacial surgeons started using rapid prototyping technology in the 1990s,[18] and it is a valuable adjunct to traditional methods of treatment planning for reconstruction after resection of tumours or trauma, or developmental abnormalities. A high precision anatomical facsimile can be fabricated. Operations can be simulated on the models, and implants and guide templates can be preformed on the models preoperatively.[19,20] However, some researchers have noted the limitations of this approach because of the bias in reshaping the model according to the artistic aptitude of the technician or surgeon, and these make it less useful in some complex cases.

With the development of computer technology, CAD/CAM is now being used for mandibular reconstruction. Surgeons can simulate any type of osteotomy, move and rotate the bony segments to the desired position, simulate the whole operation on a computer, and manufacture a physical model of the planned outcome.[8,21]

A mirror image tool has been reported in many papers, and it is useful for the craniofacial surgeon to assist in surgical planning.[7–9] However, the human skull has a highly intricate and irregular configuration, and it is not perfectly symmetrical geometrically. The more asymmetrical the skull, the less reliable the mirror image, which has its own limitations. In addition, cross-midline lesions or defects cannot provide a suitable mirror image for the reconstruction template.

Free-form surface geometry, and geometric morphometric methods, are other useful tools for planning craniomaxillofacial reconstructions.[5,13] The procedure is usually complicated, and software engineers are often invited to do the manipulation. The configuration of the mandible is intricate, and it is difficult to achieve designs for reconstruction of segmental defects using this technology alone.

Before embarking on surgical planning involving large segmental defects of the mandible, other sources of geometric reference may be required. The maxillary alveolar arch could be used as a guide to confirm the approximate configuration of the mandible.[8] In addition, using a similar person's mandibular model as the reference is another practical approach. In this way, a reasonable result can be obtained with minor adjustment.[9,22]

In the present study a virtual deformable mandible was modelled with Maya® 2013 3-dimensional animation software. The virtual model can be adjusted to fit the individual skull by easily manipulating the 16 controlling handles. This method of assisting in the surgical planning of reconstruction of a mandible with large segmental defects can be integrated with the advantages of other reported methods. First, the model is symmetrical and made from a normal mandible, which ensures the basic aesthetics of the mandibular contour. Secondly, the size and all the important parts of the mandibular model can easily be adjusted to fit the morphology of the individual skull. The individualisation of the mandibular configuration contributes to functional rehabilitation.

Thirdly, if required, the model can even be used to correct defects in the original mandibular morphology, such as micrognathia. The most important aspect is that surgeons can master the method quickly. It could provide a valuable aid for "form and functional restoration" in planning mandibular reconstruction. Using this virtual approach to reconstruction, problems related to asymmetry, deformation, and segmental defects could be solved in a short time and, at the same time, the subjective choices of the operator are reduced, and the reliability and reproducibility of the result increased.

Obviously using the virtual deformable mandible can produce a template of an ideal mandibular contour. Because the final deformed digital model can be saved and downloaded in "stl" format, the method can be used in conjunction with other surgical planning software.

However, there are some problems to be resolved. In the present study, the reference original model was based on one person's mandible, and although the deformable function of the virtual model is powerful, there are some differences in fit between male and female skulls. Standard models should be based on a large sample of human skulls. When these problems have been resolved, the VDMM can be used more easily. Of course, if this method can be integrated as a tool in software for surgical planning, the preoperative planning of reconstructions of large segmental defects of the mandible will be easier.

Conflict of Interest

We have no conflict of interest.

Ethics statement/confirmation of patients' permission

The study was approved by the Institutional Review Board of Peking University School of Stomatology.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bjoms.2015.11.029.

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