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Error analysis of a CAD/CAM method for unidirectional mandibular distraction osteogenesis in the treatment of hemifacial microsomia☆

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Abstract

Our aim was to investigate the errors in a computer-aided design and manufacture (CAD/CAM) method of unidirectional mandibular distraction osteogenesis. Six patients with hemifacial microsomia were selected, and studied on computed tomographic (CT) scans taken at 3 time intervals: preoperatively, at the end of the latent period, and at the end of consolidation. The plan for mandibular distraction osteogeneisis was designed using CT-based 3-dimensional visible software. The osteotomy line and site of the drill were transferred to a rapid prototyping surgical guide. The osteotomy of the mandible and implantation of the distraction device were completed under guidance. The accuracy of the transferred surgical plan was confirmed by fusion of images after the latency period. The 3-dimensional superimposition of the preoperative simulation, and the postoperative actual models at the end of consolidation, showed that the mean (SD) error between the actual and the predicted height of the ramus was 0.6 (0.6) mm. The error between the actual and predicted intercondylar distance was 8.1 (2.1) mm. There was a significant difference in intercondylar distance between the simulated and actual groups ($p = 0.00024$). The 3-dimensional CT-based planning system described in this paper was transferred precisely from the virtual plan to the real-time operation. The planning system also gave a precise prediction of the height of the ramus after mandibular distraction osteogenesis. However, because of the pull of the lateral pterygoid muscle and pseudarthrosis, the intercondylar distance decreased compared with the predicted value. These influencing factors should be considered when the planning system is refined.

Keywords: Distraction osteogenesis; Three-dimensional virtual simulation; Transferrable osteotomy guide; Hemifacial microsomia

Introduction

Distraction osteogenesis has become an important treatment in the management of patients with hemifacial microsomia since it was introduced in 1992.[1] It allows surgeons to correct hard and soft tissue simultaneously with no donor site morbidity. However, distracting the mandible on its own will not adequately correct the soft tissue deficit.[2] The use of this technique on the mandible was based on experience before the introduction of 3-dimensional simulation software.[3,4]

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The surgical planning for mandibular distraction osteogenesis can be improved with 3-dimensional simulation software, which enables surgeons to do a virtual osteotomy and reposition bony fragments to achieve optimal results. The preoperative virtual planning provides valuable information, such as the site of the osteotomy, distance to be distracted, and position of the distractor. However, in clinical practice, the outcome does not often replicate the simulations.[5] These differences are often thought to be the result of an error in transfer, an incorrect distraction vector, soft tissue interference, muscle retraction, or an inadequate osteotomy. Analysis of errors in mandibular profiles between virtual simulations and clinical outcomes is helpful in the improvement of surgical planning and understanding the actual track of mandibular distraction osteogenesis. The applications of 3-dimensional planning and reconstruction have been reported in a few cases,[6–10] and the transfer of these tools from virtual planning to the operating theatre often comprises stereolithographic guides for drilling and cutting. The virtual osteotomy guide for transferring the treatment plan in mandibular distraction osteogenesis has to our knowledge rarely been reported.

Here we describe a 3-dimensional plan and analytical model. We have assessed and illustrated the 3-dimensional movements of the proximal and distal mandibular fragments. The accuracy of the transfer from virtual planning to real-time operation is guaranteed by a rapid prototype surgical guide.[11] The actual clinical outcomes of distraction osteogenesis are assessed by comparing the postoperative and simulated results. The errors of this CAD/CAM method in unidirectional mandibular distraction osteogenesis were evaluated to refine the planning system.

Patients and methods

Selection of patients

Six patients with hemifacial microsomia who had been referred to the Department of Oral and Craniomaxillofacial Science, 9th People's Hospital, Shanghai, for further treatment and follow-up were selected. The advantages and disadvantages (such as additional exposure to radiation) were explained in detail to the legal guardians. All the patients and their families provided written consent before they took part in the study, which was approved by the ethics committee of the hospital. The mean (SD) age of the patients was 9 (2) years. They all had common symptoms including a short mandibular ramus, deviation of the chin, canting of the occlusal plane, and defects of the ear. According to Pruzansky's classification, 4 patients were Class IIA, and the other two patients were Class IIB (Table 1).[12] Computed tomographic (CT) scans were taken at 3 time intervals: preoperatively, at the end of the period of latency, and at the end of consolidation.

Reconstruction and measurement of the mandible

The preoperative CT data were imported into SurgiCase CMF 5.0 (Materialise, Leuven, Belgium) for 3-dimensional visualisation and manipulation of the facial bones including a virtual osteotomy, placement of the distractor, and distraction, combined with real-time feedback of the image. Anatomical structures, such as the tooth germ and inferior alveolar nerve, were located. Selected landmarks, such as the condylion (Co), gonion (Go), and menton (Me), were defined on the 3-dimensional model, and we measured the height of the ramus (Co to Go) and intercondylar distance (left Co to right Co).

Simulation and plan of the operation

The rotation centre of the mandibular was defined as the Co at the unaffected ramus. Distractors were selected and placed on the mandible in the virtual environment. The vector and site of the distraction device were adjusted repeatedly until the ideal virtual morphology and anatomical structure were realised (Fig. 1).

Table 1
Details of the patients studied.

Variable	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Mean (SD)
Age (years)	8	10	7	11	10	8	9 (1.5)
Pruzansky grade[a]	IIA	IIA	IIB	IIA	IIB	IIA	–
Distraction distance (mm)	15	18	12	18	17	14	15.6 (2.4)
Latency (days)	7	7	8	7	9	8	7.6 (0.8)
Consolidation (days)	93	95	124	97	99	103	101.8 (11.3)
Ramus							
Predicted height (mm)	48	44	54	56	53	46	50.0 (4.8)
Actual height (mm)	47	42	53	55	53	46	48.4 (5.2)
Intercondylar distance (mm)							
Predicted[**]	100	111	99	119	108	98	106 (8.1)
Actual	90	90	95	109	100	90	97.8 (7.4)

The site of distraction was the ramus in all except case 3, in whom it was the body of the mandible.
[a] The severity of mandibular alteration.
** $p = 0.00024$.