Theoretical Considerations for the Surgical Correction of Mandibular Deformity in Hemifacial Microsomia Patients Using Multifocal Distraction Osteogenesis

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Purpose: This theoretical pilot study investigated the geometric changes necessary to normalize the mandibular shape in hemifacial microsomia. Using the mandibular deformity of a 13-year-old patient affected by hemifacial microsomia as an example, we addressed 2 main issues. First, the number of segments needed for adequate reshaping of the deformed mandible is evaluated. Second, the geometry of the intersegmental gaps resulting from reposition of the segments is correlated with established parameters of distraction osteogenesis to theoretically predict the practicability of correction using multifocal distraction osteogenesis.

Materials and Methods: Virtual surgery was performed on a solid mandible model created from computed tomography (CT) data from a patient with hemifacial microsomia type IIB. In the first step, ideal mandibular reshaping was achieved according to anthropometric standard measurements using 7 osteotomies. By scanning and superimposition of the virtual models and variation of distraction sites and numbers, we assessed the minimal number of osteotomies necessary for optimal correction of the deformity. Geometrical evaluation of the regeneration and assessment of the possibilities of continuous curved distraction were also performed.

Results: Three osteotomies were shown to be sufficient for complete mandibular reshaping. Using accepted parameters for distraction osteogenesis, the geometry of the regenerate allows for continuous curved distraction. However, simultaneous movements at several distraction sites result in interfering vector forces, making coordination of multifocal distraction difficult.

Conclusions: Theoretical assessment of a severe mandibular hypoplasia in hemifacial microsomia revealed the 3-dimensional (3D) complexity of the deformity for corrective procedures, especially distraction osteogenesis. Despite precise planning and transfer of the plan to the patient, multifocal 3D distraction may result in deviations from the planned result. Manipulation of the fresh regeneration may be necessary to correct inaccuracies.
The mandibles of patients with hemifacial microsomia (HFM) reveal a complex 3-dimensional (3D) deformation characterized by shortening of the ascending ramus, retruded chin, and deformed mandibular body. Through the work of Mc Carthy and other researchers, distraction osteogenesis was introduced into the craniomaxillofacial technical armamentarium, and correction of the mandibular deformity in HFM became one of the universally accepted indications for this technique. The literature is replete with publications addressing the use of distraction osteogenesis in HFM.

The planning of distraction osteogenesis using computer simulation has proven to be of great value in increasing the predictability of changes introduced with distraction osteogenesis. However, the correlation of geometrical data with established parameters of distraction osteogenesis and soft tissue influence during the lengthening procedure has not yet been published.

Regarding the number of distraction sites, 1 or 2 osteotomies located at the mandibular angles were used in conjunction with unidirectional or multidirectional distraction. However neither of these protocols allows the physician to change the shape of the mandibular body, especially the width, which is an essential element of 3D correction. Three-dimensional reshaping of the mandible through the simultaneous use of several distraction sites is theoretically possible. Our pilot study was undertaken to investigate not only the feasibility, but also the problems associated with using distraction osteogenesis at several distraction sites for a complete reshaping of the hypoplastic mandible in hemifacial microsomia.

We addressed a number of questions. First, what is the optimal number of osteotomies to allow for a complete reshaping of the mandible? Second, what is the geometry of the regeneration if correction is performed using distraction osteogenesis? The answer to this latter question will help determine whether continuous angular distraction, within the established parameters of distraction, can be used without risk of premature consolidation at the inner cortex or non-union at the outer cortex. Third, are there possible problems between different distraction sites during the lengthening process? Finally, we asked, could the angles necessary for correction of severe mandibular hypoplasia be created using continuous curved distraction osteogenesis?

**Material and Methods**

**MODEL SURGERY**

First, mandibular reshaping was performed on solid models obtained as copies of a stereolithographic model of a 13-year-old patient. The patient was diagnosed with hemifacial microsomia type IIb according to the criteria of Kaban et al (Fig 1), characterized by severe shortening of the mandibular ramus and a milder deficiency of the horizontal body and hypoplasia of the condyle and the glenoid fossa, revealing an anterior medial position of the TMJ complex. Midfacial hypoplasia affected the maxillary complex and orbital development, resulting in an oblique maxillary cant and a cranial position of the hypoplastic left orbit.

The mandibular models were osteotomized and, using wax as a filler between osteotomies, the physician created a normal mandibular shape, according to the criteria of Riolo based on Bolton standards of dentofacial developmental growth. Arbitrarily, 7 osteotomies were chosen as the maximum number (Fig 2).

**Scanning and Superimposition of the Models**

In the next step, models of the hypoplastic and of the corrected mandible were scanned in 3D using a Minolta Vivid 700 3D scanner (Minolta Europe, Langenhagen, Germany) and integrated into a program that allowed the creation of a 3D mesh-frame model (Polyworks; Innovmetric, Quebec, Canada).

**Virtual Variation of Distraction Sites and Number**

Visualization and animation of the models was created with Maya software (Maya; Alias Wavefront, Toronto, Canada). By varying the osteotomy sites and
virtual distraction, the hypoplastic mandible was brought into congruence with the ideally reconstructed model (Fig 3) to assess the minimal number of osteotomies necessary for optimal correction of the deformity.

**3D Analysis of the Regenerate Between Osteotomies**

Analysis included measurement of the resulting angles between the osteotomies after completion of the distraction process (Fig 4). Angles were calculated in horizontal and vertical planes. In addition a “maximal distraction angle” was determined, indicating the maximal 3D angulation between fragments.

**Assessment of the Possibilities of Continuous, Curved Distraction**

We presumed a maximal distraction rate of 0.5 mm/d at the inner cortex and 1.5 mm/d at the outer cortex. Using this parameter, the angles achieved by continuous curved distraction were separately calculated to determine whether continuous curved distraction would fulfil the clinical requirements necessary to create the desired angles.

**Results**

It could be shown that correction using 3 osteotomies was sufficient to correct the mandible in 3D. Vertical, horizontal, and combined angles between the osteotomy sites are listed in Table 1. The length of the interfragmentary distances at the basal and the crestal site of the regenerates, as well as the height of the mandible at the osteotomy sites, were measured (Fig 5).

Using accepted parameters for distraction (a minimal rate of 0.5 mm/d required to avoid fusion and maximal rate of 1.5 mm/d required to avoid consolidation problems), the geometry of the regenerate allows predictive statements about the theoretical practicality of continuous angular distraction with multiplanar devices for every distraction site. The maximal angle that can be achieved using distraction depends on osteotomy length and the lengthening time, and has been calculated for a set of osteotomy lengths and distraction times (Table 2).

The angulation necessary for correction in the model presented would allow for continuous angular distraction in each regenerate. However, as demonstrated in Figure 6, where different planes at the beginning and end of the lengthening process are shown, interferences between vector forces occur during distraction. These represent a possible reason for deviation of the final from the planned result.

**Discussion**

The mandibular deformity in hemifacial microsomia is complex. Three-dimensional reshaping must include correction of the mandibular body and both of the angular regions. Our results show that a minimal number of 3 osteotomies is necessary and also sufficient to create a normal mandibular frame. Although this investigation was performed on 1 single model, we speculate that 3 osteotomies will be sufficient in most cases.

Our method to determine the optimal number and site of osteotomies for creation of a normal mandible

**Table 1. ANGLES IN VERTICAL AND HORIZONTAL PLANES AND MAXIMAL COMBINED ANGLE IN REGENERATES FROM DISTRACTION OSTEOGENESIS AS SHOWN IN FIGURE 1**

<table>
<thead>
<tr>
<th>Fragments</th>
<th>Angle Vertical Plane</th>
<th>Angle Horizontal Plane</th>
<th>Maximal Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue : violet</td>
<td>27.6°</td>
<td>15.8°</td>
<td>30.7°</td>
</tr>
<tr>
<td>Violet : green</td>
<td>1.2°</td>
<td>3.5°</td>
<td>4.3°</td>
</tr>
<tr>
<td>Green : red</td>
<td>5.7°</td>
<td>13.5°</td>
<td>14.0°</td>
</tr>
</tbody>
</table>

**Table 2. ANGLES ACHIEVED BY CONTINUOUS CURVED DISTRACTION**

<table>
<thead>
<tr>
<th>Distraction Time (d)</th>
<th>Length of Osteotomy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 mm</td>
</tr>
<tr>
<td>10</td>
<td>38.1°</td>
</tr>
<tr>
<td>20</td>
<td>76.3°</td>
</tr>
<tr>
<td>30</td>
<td>114.4°</td>
</tr>
</tbody>
</table>

NOTE. Parameters used were a minimal distraction rate of 0.5 mm/d and a maximal distraction rate of 1.5 mm/d.
included the use of a solid model of the deformed jaw, which was cut into segments and reassembled with wax interfaces to obtain a normal shape. Virtual surgery was performed using scanned surface data of both the normal and deformed mandible. Currently available computer technology allows for visualisation and interactive manipulation of 3D computed tomography data. In the future, planning procedures using data from individuals with normal mandibles as templates that are superimposed on hypoplastic jaws, virtual osteotomies could be performed entirely on the screen. It should even be possible to develop an algorithm automatically relating the geometric data of the interface between the segments with accepted parameters of distraction osteogenesis. These parameters could include minimal and maximal daily distraction rates or angular changes during the lengthening process. Thus, planning could be continuously counterchecked for feasibility when continuous angular distraction as presented by Jonsson and Siemssen\textsuperscript{18} and Seldin et al\textsuperscript{19} is considered.

As shown by this experiment, each distraction site reveals a complex geometry. Correction using multiplanar distraction osteogenesis is theoretically possible; however, the movements at the 3 distraction sites interfere with each other. This makes coordination of simultaneous 3D distraction difficult. Gateno et al\textsuperscript{11,12} showed the feasibility of a computer-based algorithm in the planning of monofocal mandibular distraction. Our future research is directed toward developing a tool that can be used in the planning of multifocal distraction.

Nevertheless, limitations of planning have been shown by various authors,\textsuperscript{13,20,21} especially the problem of accounting for exact soft tissue resistance. It is to be expected that even with optimal planning meth-
ods, considerable discrepancies will occur between the plan and the final result. Three-dimensional molding of fresh regenerates, which has been discussed in literature to provide precise and stable results, can solve this problem. Our experimental data concerning early callus manipulation are available and confirm the clinical results mentioned above.

The problem of glenoid fossa malposition had not been considered in our study. In HFM type I and II, the missing fossa can be reconstructed to a nearly normal position, facilitating a later correction. However, type IIIB deformation is characterized by a medially and anteriorly malpositioned articular fossa. To the best of our knowledge, the question of whether the entire articular fossa can be surgically repositioned (necessitating a craniotomy) has not yet been addressed in the literature, and it is not part of this study. Even with a malpositioned articular fossa, however, 3D reshaping of the mandible provides a nearly normal contour of the lower facial frame.

Conclusions

Theoretical questions regarding correction of the complex mandibular deformity in hemifacial microsomia using multifocal distraction osteogenesis have been analyzed and can be summarized. First, 3 osteotomy sites are sufficient for complete mandibular reshaping. Using accepted parameters for distraction (a minimal rate of 0.5 mm/d to avoid fusion and a maximal rate of 1.5 mm/d to avoid consolidation problems), the geometry of the regenerates theoretically allows for continuous angular distraction. The complex shape of the regenerates and the interference between distraction vectors at different distraction sites require exact computer-based planning algorithms. Finally, simultaneous multifocal 3D distraction results in interferences of distraction vectors that may lead to major deviations from the planned results. Manual shaping of the fresh regenerate could be necessary to correct inaccuracies.

References

22. Grayson BH, Santiago PE: Treatment planning and biomechanics of distraction osteogenesis from an orthodontic perspective. Semin Orthod 5:9, 1999