

Biomechanical effects of distraction device angle in unilateral mandibular lengthening by distraction osteogenesis using a finite element model

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Abstract

Aim: Analyzing the changes made during distraction osteogenesis (DO) in asymmetric mandibles

Materials and methods: This study was performed on a three dimensional model of a desiccated mandible, based on a finite element method. The distraction devices were placed with an angle of 90, 60 or 30 degrees to the oblique surgical cut. The directions of the pins were such that the 30 and 60 degree pins were placed in a counterclockwise direction relative to the perpendicular pin. The distractors were opened for 15 and 30 mm. The amount and direction of movement of proximal and distal segments and the displacement of pogonion were evaluated in all three planes of space.

Results: In the distal segment, the maximum change in pogonion was seen in 30 degree angle. In the proximal segment, if the distraction device was used with 90 degree angle, the condylar process rotated in the clockwise rotation. In 30 degree angle, this process rotated in a counterclockwise direction and the minimum rotation was seen in 60 degree angle.

Conclusion: If gonial angle is to be augmented in a downward direction maximally, the angle of distraction device to the surgical cut is critically important (that is, it should be perpendicular to surgical cut). By use of perpendicular mode, ramus slopes more posteriorly. It is better to use the distraction pin with a thirty degree angle if the ramus needs to be uprighted. The oblique surgical cut, irrespective of the distraction pin angle, increases the anterior facial height.

Keywords: Distraction Osteogenesis, mandibular asymmetry, mandibular lengthening, finite element method

Distraction osteogenesis (DO) is a popular and accepted method for mandibular lengthening in patients with craniofacial deformities. Although Codivilla ¹

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used this method for the first time in 1905, it was Ilizarov ² who made this method popular for correcting limb deformities in congenital defects and patients with trauma.

Synder in 1973 ³ and Michieli and Miotti in 1977 ⁴ modified DO for mandibular lengthening in their animal studies. In 1992, McCarthy ⁵ reported on a case suffering from hemifacial microsomia whose mandibular deformity was corrected by DO for the first time and since then; this technique has been applied to different bones of craniofacial skeleton ⁶.

In this surgical procedure single or multiple surgical cuts are made in specific sites of a bone and tensile force is applied across these sites using a distraction device. During this phenomenon the bone and its associated soft

tissues are stretched gradually and so the new bone is added to the gap which is formed and so no bone grafting is required⁷⁻¹⁰. It is assumed that relapse tendency is reduced because all the soft tissues including skin, muscles, nerves and vessels are stretched during the process of distraction⁸. Compared to the traditional method of bone grafting, DO has less tendency for relapse and has fewer complications and then; its popularity is increasing during recent years^{11,12}. Precise treatment planning is the primary indicator of treatment success in DO. By invention of 3D imaging techniques, it is now possible to create 3D images of craniofacial structures. Virtual surgeries can be performed on these virtual models before the real surgery and in this way the effects of every individualized procedure can be observed and predicted¹³. Controlling the direction of distraction vector is mandatory for gaining predictable and precise results during this procedure. As mandible goes through rotational as well as linear changes during the process of distraction, prediction is more important and also more complicated in mandibular DO¹³.

Maxillofacial distraction osteogenesis is performed by intra-oral and extra-oral devices. The advantages of intra-oral devices include lack of visibility and facial scars. Although multidirectional distraction devices are becoming more popular recently, a large number of patients still benefit from unidirectional devices. The important point about unidirectional devices is that they are largely dependent on the direction of distraction force or in other terms, distraction device orientation.

Due to importance of the precise prediction of the results before distraction different attempts have been made to simulate the distraction procedure preoperatively¹⁴⁻¹⁷, but simulating the surgical procedure preoperatively is neither cost-effective nor clinically practical. So formulation general guidelines based on the factors affecting the three dimensional results of distraction treatment is recommended.

One of the most important factors affecting treatment results is the distraction device orientation. Mikhail et al.¹⁸ investigated the effects of distraction device orientation on the treatment results in a 2-D computer model in an

attempt to formulate some general guidelines. As mentioned above, mandibular changes during DO are 3 dimensional and also, many patients needing DO are affected by asymmetric conditions like hemifacial microsomia. Analyzing the changes made during DO in asymmetric mandibles using a 3-D computer model would hopefully help more accurate treatment planning in this category of patients. This article will consider the effect of distraction device orientation on the results of treatment in this often seen category of patients.

Method and materials

This study was performed on a three dimensional model of a desiccated mandible, separated from a young human skull. For transferring the dimensions of this mandible to the computer and making a virtual model, the following steps were followed based on finite element method (FEM):

1. Measurement of the dimensions
2. 3-D modeling by Nisa II software
3. Definition of boundaries of the model
4. Analyzing the forces applied on the model

The measurement step is performed using contact technique by coordinate measuring machine (CMM). The mandible is fixed on the platform of this machine and a suitable sensor is selected and installed on the arm of the machine. Each time the sensor touches the surface of the mandible, a signal is sent to the control unit and the Cartesian coordinates of the points are saved as a file in this unit. Then these data are processed by the microprocessor unit. Now, these data are ready to be viewed in the display window of Nisa II software as a 3D virtual mandibular model.

To make this model more accurate, two boundaries on the outermost parts of both left and right condyles were specified resembling glenoid fossae.

Using this specification, the movement of proximal segments of the mandible during distraction was made possible in all directions except in the vertical direction (resembling the restriction imposed by the glenoid fossae on this

movement). In the next step, one oblique surgical cut was made on the right side of the mandible from distal line angle of right third molar to the right gonial angle.

The distraction devices were placed with an angle of 90, 60 or 30 degrees to the surgical cut and with a 5 mm distance on either side. The directions of the pins were such that the 30 and 60 degree pins were placed in a counterclockwise direction relative to the perpendicular pin. Then, they were opened first for 15 mm and then for 30 mm. Both the proximal and distal segments moved the same amount (that is, for the 15 mm opening, 7.5 mm movement for each segment).

To make the measurement of the amount and direction of movement of distal segments easier, multiple points were highlighted on the lower border of the mandible, from surgical cut to a point corresponding to this point on the lower border of the other side. By evaluating the movements of these points, the movement of distal segment was elucidated more easily and accurately.

Assuming the most anterior point of the chin (that is; pogonion) as the zero coordinate, the amount and direction of movement of proximal and distal segments and pogonion were evaluated in all three planes of space. The movements in the transverse dimension were traced on the x axis so that the negative values represented movements to the distraction side and the positive values indicated the movement to the other side. The movements in the sagittal dimension were depicted on the Y axis, with positive values indicating posterior movements. The movements in the vertical axis were shown on the Z axis in a way that positive values indicated upward movement. The movements are shown first in three planes separately in their respective diagrams and then the result movements have been shown three dimensionally for distal and proximal segments.

Results

The displacements in transverse dimension (Fig 1):

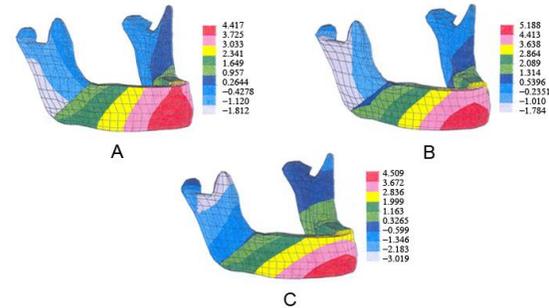


Fig1. Mandibular changes with 30 (a), 60 (b) and 90 (c) angles in the transverse dimension, following 15 mm of distraction

In the X axis the region showing the maximum amount of displacement changed with altering the distraction device angle. In the distal segment, this maximum displacement changed from a region near inferior border of the mandible, adjacent to pogonion, to a region between alveolar ridge and pogonion and finally to the alveolar crest by changing the distraction device angle from 90 to 60 and to 30 degrees respectively. The maximum net result for pogonion displacement in this dimension was for 60 degree angle. This pattern was seen both for 15 mm and 30 mm distraction. The amount of displacement of pogonion in these two conditions is shown in table 1.

In the proximal segment, the maximum amount of displacement was seen around the coronoid process to the right side when the distraction device angle was 90 degrees. As this angle changed to 60 or 30 degrees, the result would be changing the maximum displacement to the posterior border of ramus near the osteotomy site.

Table1. The amount of pogonion displacement (mm) in different angles of distraction device for 15 mm of distraction

| Device angle | X axis displacement (mm) | Y axis displacement (mm) | Z axis displacement (mm) | Result displacement (mm) |
|--------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 30 degrees | 4.37 | -6.36 | 7.08 | 10.47 |
| 60 degrees | 5.19 | -5.56 | 4.71 | 8.94 |
| 90 degrees | 4.49 | -3.75 | 1.71 | 6.09 |

The displacements in anterior-posterior dimension (Fig2):

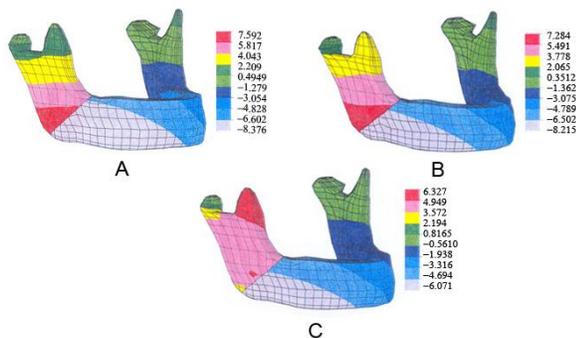


Fig2. Mandibular changes with 30 (a), 60 (b) and 90 (c) angles in the sagittal dimension, following 15 mm of distraction

In the distal segment, the maximum displacement in pogonion was seen in 30 degree angle and the pogonion moved anteriorly in all three conditions (see table1, the movements are negative).

In the proximal segment, the maximum displacement was seen in posterior border of ramus near the osteotomy site in 30 and 60 degree angles and these points moved posteriorly. In the 90 degree angle the coronoid

process was displaced maximally and in the positive direction.

The displacements in vertical dimension (fig3):

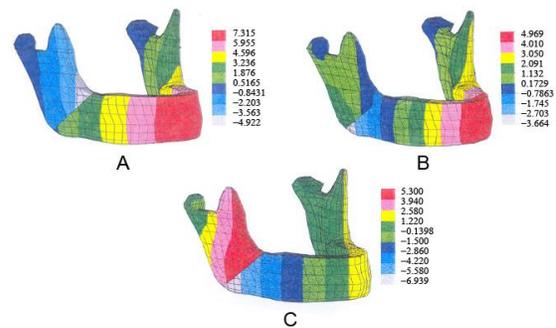


Fig3. Mandibular changes with 30 (a), 60 (b) and 90 (c) angles in the vertical dimension, following 15 mm of distraction

In the distal segment pogonion point displaced significantly in the vertical direction in the 30 degree angle but the displacement in this direction was not as significant. The amount of this displacement for 30 degree angle was approximately three times the amount of movement for 90 degree angle (see table1). Indeed, in all three conditions, the distal movement has gone through the process of counterclockwise rotation and so, pogonion has moved superiorly.

In this segment, the maximum downward displacement was seen on the lower border of mandible adjacent to the osteotomy site. The amount of displacement was maximum for 90 degrees and minimum for 30 degrees.

In the proximal segment, the anterior border of ramus moved upward in 90 degree angle but downward in 30 degree angle.

The resulted displacements (fig 4):

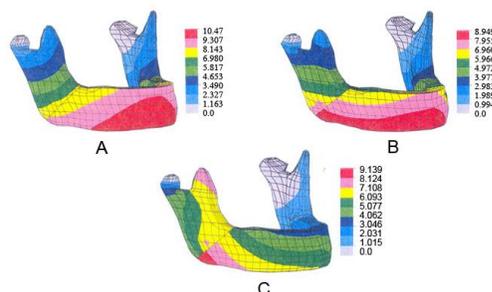


Fig4. Resultant Mandibular changes with 30 (a), 60 (b) and 90 (c) angles, following 15 mm of distraction

In the distal segment, the maximum change in pogonion was seen in 30 degree angle (see table 1).

In the proximal segment, if the distraction device was used with 90 degree angle, the condylar process and obviously, the coronoid process, rotated in the clockwise rotation. In 30 degree angle, the same processes rotated in a counterclockwise direction and the minimum rotation was seen in 60 degree angle.

The pattern of the changes for 30 mm distraction was the same as 15 mm distraction, but the amounts of all the visualized changes were two times the amounts for the latter.

Discussion

We evaluated the pattern and amount of movement of proximal and distal segments and pogonion in three spatial planes during the process of unilateral mandibular distraction osteogenesis in the present study. Previous

studies such as that done by Mikhail et al. 18 considered the proximal segment to be static during distraction and also this study evaluated the displacements during bilateral distraction of the mandible using a two dimensional computer model. In our study the general pattern of displacement of bony segments was evaluated more accurately because a three dimensional finite element model was used and also both proximal and distal segments could translate reciprocally.

Sophisticated diagnostic methods including data from 3D CT scanning and data resulting from other procedures like photography, clinical exam and mock surgery have been used by Remmler et al. 19, Paeng et al. 13 and Reina Romo et al. 17 to predict the best individualized surgical approach for correction of facial asymmetry in specific patients using advanced computer software. Application of these complicated procedures to all the patients with asymmetry problems is not possible and practical clinically. As a result, design of a study to investigate the translational and rotational changes that would occur during the process of distraction for the common problem of facial asymmetry seemed mandatory.

The results of the present study indicate that the amount of displacement for 30 mm of distraction was two times the amount of displacement for 15 mm of distraction. This finding may not be completely accurate because we could not simulate the soft tissues of the facial skeleton including mastication muscles and ligaments in our computer model; then, we do not know in which point of distraction the tension of soft tissues would begin to affect the movement of bone segments. It is worth mentioning that the displacement of proximal and distal segments is affected by the limitations imposed on them by these soft tissues despite adaptive changes of soft tissues during DO.

As the results of the present study are to be used as general guidelines for those patients having asymmetric mandibles, it would probably be better to use an asymmetric mandible in our study; however, we could not find an asymmetric mandible to be simulated. The other technical limitation was precise simulation of glenoid fossae. We limited the superior displacement of the condyles by the assumption

that two lateral poles of them are static during distraction. In fact by this assumption, rotational movement in the glenoid fossa was possible but translational movements were restricted.

In all the pin angles we used with an oblique surgical cut, the gonial angle in the distal segment was displaced inferiorly. The maximum displacement was seen for perpendicular pin angle. So, especially in patients for whom we need to augment the gonial angle in a downward direction maximally, the angle of distraction device to the surgical cut is critically important (that is, it should be perpendicular to surgical cut). This can be seen in the treated cases illustrated in Molina article 20.

In perpendicular mode, the anterior border of ramus in proximal segment was displaced superiorly but in the 30 degree angle this border moved in the inferior direction. It means that by use of perpendicular mode ramus slopes more posteriorly. It also means that when we need the ramus to be more upright, it is better to use the distraction pin with a thirty degree angle.

In all three conditions we evaluated in this study the distal segment and pogonion rotated in the counterclockwise direction. So, the oblique surgical cut, irrespective of the distraction pin angle, increases the anterior facial height.

It is important to note that we should use the results of this study for treatment planning in patients with asymmetric mandibles to get the best results with the knowledge of all its limitations. Each patient needs an individualized approach to his/her treatment but using the general guidelines of this study is a cost effective method for getting the best results.

Conclusion

In patients for whom we need to augment the gonial angle in a downward direction maximally, the angle of distraction device to the surgical cut is critically important (that is, it should be perpendicular to surgical cut). By use of perpendicular mode, ramus slopes more posteriorly. When we need the ramus to be more upright, it is better to use the distraction

pin with a thirty degree angle. The oblique surgical cut, irrespective of the distraction pin angle, increases the anterior facial height.

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