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Influence of different orientations and rates of bidirectional distraction osteogenesis of the mandibular corpus: a three-dimensional study.

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Abstract: Objective: The objective of this study was to evaluate the biomechanical effect of mandibular corpus distraction osteogenesis with different orientations and rates. Materials and Methods: A three-dimensional model of the mandible was created. The vertical surgical cut was made, the force was applied horizontally in a bidirectional manner within two orientations: parallel to the occlusal plane and parallel to the inferior border of the mandible with three rates (0.5mm, 1mm and 1.5mm). Results: The maximum values for von Mises stress when the force was applied parallel to the inferior border of the mandible with all three rates were smaller than those with force direction parallel to the occlusal plane. The displacement in all three directions x, y, and z were not parallel and prominent in the anterior part of the mandible, while the movement at the posterior part is negligible, x and z displacement were bigger when force was applied parallel to the inferior border of the mandible, z displacement was more prominent than x and y displacement, both directions produced upward rotation of the mandible, this rotation was more noticeable when the force was applied parallel to the inferior border of the mandible. Conclusions: A vertical cut can be used in the patient with a long anterior face. This site of distraction achieves more lengthening of mandible than expansion.

Keywords: Osteogenesis, distraction; mandible; bone lengthening; finite element analysis.

INTRODUCTION.

Distraction osteogenesis (DO) is a treatment option for adults and children with dental overcrowding and mandibular retrognathia, which can be congenital or acquired.[1-2]

The use of DO has increased in the last two decades since the introduction of the new intraoral devices. It involves gradual, controlled displacement of a surgically created fracture that results in expansion of soft tissue and bone volume. In other words it can be understood that it is a slow and continuous application of a constant force to a created osteotomy gap, resulting in formation of new bone and soft tissues.[3] The forces of traction applied to the osteotomized bone segments at a rate of (0.5mm -1.5mm) per day.[4]

The location of the osteotomy line and the distractor position may be one of the most important parameters to achieve a better DO treatment in terms of occlusion of teeth and callus stability.[5] Another important factor is the force level, which detects the amount of stress and displacement that occur during this operation.

computer aided design modeling model has been used to investigate the biomechanical effect of device orientation and force level during mandibular distraction osteogenesis.[6]

MATERIALS AND METHODS.

A dry normal mandible was used to create a three-dimensional model using AutoCAD Software version 2010, all measurements were taken using digital vernier. The fracture line in the model at the site of osteotomy was detected. There are differents possible sites for osteotomy.[7]

In this study, a surgical cut in the mandibular corpus (the part of the mandible that holds the teeth) distal to the last molar before gonial angle extended vertically to the inferior border of mandible was studied. This site of distraction osteogenesis produces mandibular body lengthening.

The model was transported to finite element program Autodesk Inventor Professional software Autodesk Inventor® version 2012. For the convenience of the analysis one-half of the mandible was used for analysis. The mechanical properties of the materials were considered to be homogenous, isotropic, and linear elastic as in the previous studies.[5,8] As the boundary conditions, the mandible was supported by restraining all the movements at the top of the condyle resembling glenoid fossa and simulated unilateral occlusion on cusped teeth.

Using the auto mesh order, the final mesh consisted of 654104 nodes, 450018 elements; finite element results are very sensitive to the number of elements included in the model and become more accurate as the number of elements increases.

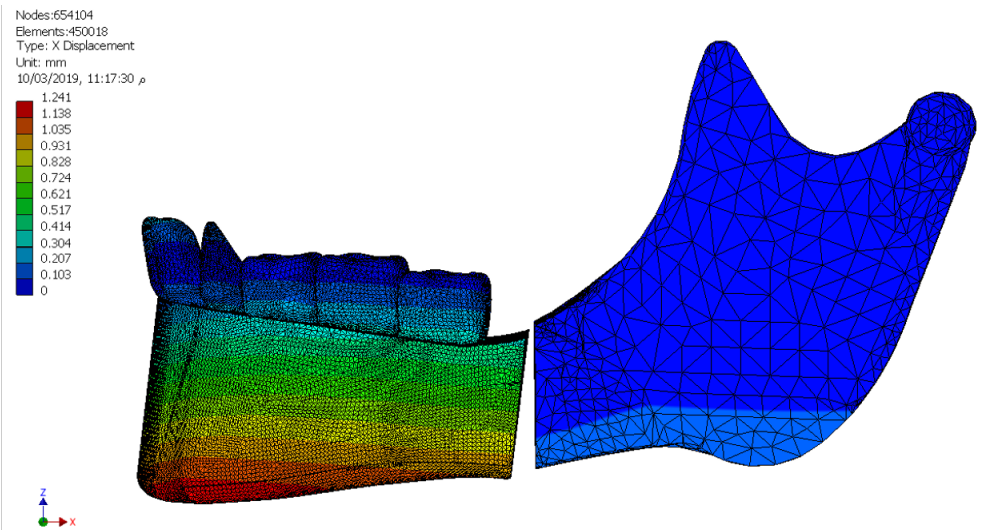
The force was applied horizontally in two orientations: parallel to the occlusal plane, parallel to the inferior border of the mandible, in a equally bidirectional manner with three rates for both directions (0.5mm, 1.0mm, 1.5mm).

According to Robinson *et al.*,[9] study distraction of 1mm is equivalent to a force of 35.6 Newton, so we have 35.6 Newton divided by two to get the necessary force to distract the osteotomized site 0.5mm, and 35.6 Newton as the amount of force needed to distract the osteotomized bone 1mm and 35.6 Newton multiplied by 1.5 to determine the force need to distract the osteotomized site 1.5mm. The loads acting on the body are modeled as forces applied to the node.

Table 1. Maximum values for von Mises stress and displacement.

Distraction distance and direction	Von mises (megapascal)	x-displacement (millimeter)	y-displacement (millimeter)	z-displacement (millimeter)
0.5mm parallel to the occlusal plane	119.7	0.413	0.307	0.679
0.5mm parallel to the inferior border	102.9	0.494	0.299	0.789
1mm parallel to the occlusal plane	239.5	0.825	0.614	1.358
1mm parallel to the inferior border	206.0	0.988	0.597	1.577
1.5mm parallel to the occlusal plane	359.0	1.241	0.928	2.046
1.5mm parallel to the inferior border	308.9	1.482	0.896	2.366

Figure 1. x-Displacement, force 1.5mm parallel to the occlusal plane.



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RESULTS.

The results in term of von Mises and displacement in x, y and z-direction were studied. Maximum values for von Mises stress and displacement for both orientations with different rates are shown in Table 1.

A color scale with 13 values and 12 colors was used for quantitative visualization of results, as shown in Figure 1, the blue range represent the minimum variable value while the red one corresponds to regions with maximum variable value.

Von Mises

The maximum values for von Mises stress when the force was applied in the direction parallel to the occlusal plane were higher than the maximum values for von Mises stress when the force was applied parallel to the inferior border of mandible. Maximum stress values for both directions was seen in the fixation zone and region of force application.

Displacement

In this study the displacement in all three direction, x, y and z, for both orientations were prominent in the anterior part of the mandible while movement at the posterior part is negligible, x and z displacement were greater when force was applied parallel to the inferior border of the mandible.

x-displacement

In this study, x-displacement represent movement in sagittal plane (anterior-posterior), a positive value means anterior movement. The maximum x-displacement values when the force was applied parallel to the inferior border of mandible were higher than those were when force was applied parallel to the occlusal plane, and certainly the displacement value increased as amount of force increased.

For both directions, the maximum x-displacement was seen in the pogonion region and along the inferior border of the mandible with slight differences in the pattern of displacement that appear in the mandible with both orientations during the distraction procedure.

y-displacement

In this study, y-displacement represent translation in transverse (in-out) plane, positive values indicate movement (expansion), this movement was more prominent in pogonion part and incisor region. The occlusal parallel direction gave slightly more y displacement than other directions. In general, distraction force at this site lengthened the mandible more than expansion.

z-displacement

In this study z-displacement represents vertical rotation of mandible (up down), positive values mean upwards movement. We found that there was more z displacement than x and y displacement, and both directions produced upwards movement but it was higher when the force was applied parallel to the inferior border of the mandible, for both the maximum displacement zone was seen along the incisor teeth and the related alveolar bone.

DISCUSSION.

Distraction osteogenesis is a biological process of producing new bone and overlying soft tissue by gradual and controlled traction of the surgically separated bone segments. Prediction of the distraction results is very important, Sensoy *et al.*,[5] suggest finding patient-specific optimum osteotomy line computationally in order to minimize disadvantages of conventional distraction osteogenesis protocols.

The basic general guidelines for distraction are the site of osteotomy and force direction and rates. Von Mises is equivalent stress at which yielding is predicted to occur. In this study, the maximum values for von Mises were found when force was applied parallel to the inferior border of mandible, with all three rates smaller than those when force direction was parallel to the occlusal plane. This was expected a the force will influence the two components x and z, and this mainly affects the stress values.

The maximum stress value for 0.5mm distraction for both orientations were near ultimate tensile stress for bone (135 MP) while for 1mm and 1.5mm were higher than the ultimate value in both directions, when the bone was not amenable enough to withstand such

stress, this damage would trigger the formation of new mesenchymal tissue.[3]

The bone in the distracted site was seen to move in a non-parallel manner. The displacement in all three directions, x, y, and z, for both orientations was prominent in the anterior part of the mandible, in agreement with Tehranchi *et al.,*[10] who found that at this site of osteotomy the movement was prominent in the pogonion, while the movement in the posterior part was negligible, although the force was applied in a bidirectional manner. As such the distal component of the force is considered to be a wasted component and produces unwanted stress in the temporomandibular joint.

Both directions resulted in upward rotation of the mandible and in agreement with Tehranchi *et al.,*[10] who mentioned that a vertical surgical cut will result in a clockwise rotation of the mandible, and upward movement of the mandible was higher when the force was applied parallel to the inferior border of the mandible, which is logical as in this direction the force has a vertical component which results in a more upward rotation of the mandible, and z-displacement was more prominent than x and y-displacement. Certainly the displacement and stress values increase as the force amount increases.

In this study, the force was applied in Newton units according to Robinson *et al.,*[9] and the results were in mm making the present study relevant and comparable. Although finite element analysis in this study did not show tooth movement occurring from distractor forces, it is thought to be not considered because teeth and the mandible are expanded as a unit

CONCLUSION.

When the force was applied parallel to the inferior border of the mandible, less stress values and more x and z-displacement was seen in the mandible than in other the directions tested in this study. This study suggests using the unidirectional type of distractor. In general, this site of osteotomy resulted in more lengthening than expansion of the mandible as well as upward rotation of the mandible, which results in deep bite occlusion and reducing the anterior facial height.

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