Changes of Stress Distributions Around Pterygomaxillary Junction With Different Osteotome Angulations

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Abstract: The aim of this study was to investigate how the alteration of the angulation of osteotome at pterygomaxillary junction affects lateral pterygoid plate, maxillary tuberosity, palatal surface of maxilla, palatine bone and body of sphenoid bone. Following reconstruction of 3D modelling of maxilla, Osteotomes' tip was angulated 45° and 90° to sagittal plane to simulate pterygomaxillary osteotomy. Finite element analyses (FEA) was performed and Von Misses stress distributions were analyzed for two different angulations. Independent sample t test was used to compare differences between 45° and 90° angulations. Von Misses stress values on lateral pterygoid plate were higher in 45° angulation (0.71 ± 0.21 MPa) than 90° angulation (0.54 ± 0.28 MPa). This difference was statistically significant ($P < 0.01$). Placement of osteotome's tip with 90° angulation had higher stress value than 45° angulation on maxillary tuberosity region. However; difference wasn't significant ($P = 0.44$). Stress values on body of sphenoid bone were 0.45 ± 0.17MPa for the case of 90° angulation and 0.19 ± 0.09MPa for 45° angulation. Difference between these values were statistically significant ($P < 0.01$). Possible risk of unfavourable lateral pterygoid plate fracture and complications related with body of sphenoid bone during pterygomaxillary osteotomy was remarkably increased in case of narrow angulation (45°). Keeping osteotome at right angle with sagittal plane may avoid these complications.

Key Words: Angulation of curved osteotome, finite element analysis, lefort 1 osteotomy, pterygoid plates

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Le Fort I osteotomy technique requires pterygomaxillary separation by curved osteotome before down fracturing of maxilla.[1] Improper positioning of curved osteotome at pterygomaxillary junction may result in undesired fractures on pterygoid bone.[1,2] Due to incomplete separation of pterygomaxillary junction, many complications such as extensive bleeding, fractures of maxillary tuberosity, palatine bone, lateral pterygoid plate and fractures of different levels in base of skull were reported.[3] To reduce unwanted fractures of pterygoid plate, many techniques for formal pterygomaxillary separation have been proposed, including positioning of osteotome, the use of various micro-oscillating saws and ultrasonic devices.[1,2,4] Different osteotome angulations may result in unfavorable fractures in this complicated anatomic area. Computed tomography is routinely taken for virtual planning and assesment of cranial structures before orthognathic surgery. Especially in axial images, it is possible to determine in detail the location of pterygoid plates and pterygomaxillary fissures and angle of osteotomy. There are only few studies investigating effects of alteration of angle of the osteotome with sagittal plane and they are all anatomical ones[1,3,5]

Finite element analysis (FEA) provides visualizing of response of the craniofacial skeleton to forces during osteotomy in three dimensional vision. Advantages of FEA is being non invasive technique and assessing of stress distribution at any given point which is difficult to assess otherwise.

The aim of this study was to evaluate stress distributions by finite element analysis (FEA) on lateral pterygoid plate, maxillary tuberosity, palatal surface of maxilla, palatine bone, body of sphenoid bone on cranial base in different osteotome angulations during separation of pterygomaxillary junction. Results of this study may help to decide ideal ostetome angle and to take precautions during pterygomaxillary osteotomy to prevent potential complications.

MATERIAL AND METHODS

Computed tomography (CT) was used to obtain mathematical digital model of maxilla and cranium of a healthy adult without skeletal deformity. Three dimensional CT scanning (i-CAT 17–19; Imaging Sciences International Inc, Hattfield, PA) was performed with following parameters which are 120 kVp and 20.27 mAs using a 16 × 6 cm field of view, and 0.30 voxels. DICOM files were converted into STL format (Stereo Lithography) using the Mimics software (Materialise NV, Leuven, Belgium). ANSYS version 10 (ANSYS Inc, Canonsburg, PA), a 3-D modeling and analysis software program, was used to generate solid and finite element models of the maxilla and cranium considered in the study. ANSYS Mechanical APDL was used to generate finite element models of the maxilla and cranium for performing stress analyses. Finite element meshes were generated using tetrahedral elements for the model which consist of 187,597 quadratic elements and 297,992 nodes. Young modulus of model were 13.7 GPa for cortical bone, 1.37 GPa for cancellous bone and 0.069 GPa for sutures. Poisson's ratio used in the analyses was 0.3 for both cortical bone and cancellous bone and 0.45 for suture.[6,7] Boundary conditions were defined such that the maxilla and cranium surface nodes were constrained in all directions.

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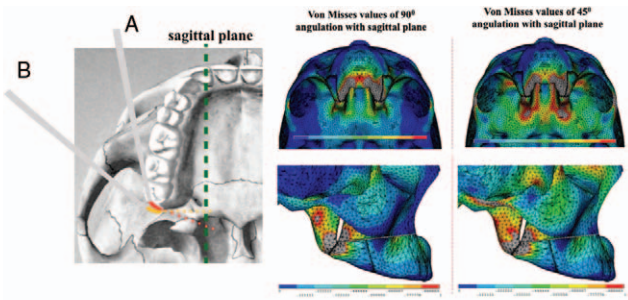

FIGURE 1. Curved osteotome tip was placed on the pterygomaxillary junction at 450 (A) and 900 (B) angulations with sagittal plane. Von Mises stress values were between 0 and 1 MPa and on the gray areas stress values were more than 1 MPa.

Le Fort I osteotomy was performed on maxillary models. As the osteome-induced force was assumed to be 150 N in previous studies,[8,9] 150 N load simulating mallet force (along on handle of osteotome) was applied to bilateral pterygomaxillary sutures with 2 different angulations of curved osteotome' tip with sagittal plane (45° and 90° angles) (Fig. 1). We have applied 150 N with one step due to that the finite element analyses are performed under linear elastic conditions, the applied force-deformation/stress relations are also linear. Von Mises analysis was used to identify stress distributions.

Statistical Analysis

Von Misses values of each elements on investigated areas were transferred Statistical Package for the Social Sciences (SPSS for Windows version 18.0; SPSS Inc, Chicago, IL) All data were expressed in terms of the mean and standard deviation of mean (Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B303, http://links.lww.com/SCS/B304). Independent sample t test was used to compare difference between 45° and 90° osteotome angulations.

RESULTS

Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B303, http://links.lww.com/SCS/B304 shows stress distributions on investigated regions located in craniofacial complex. Maximum stress value was obtained at osteotome-bone contact point in both 45° (11.9 MPa) and 90° (12.2 MPa). Mean stress value on lateral pterygoid plate was 0.71 ± 0.21 MPa for 45° angulation and 0.54 ± 0.28 MPa for 90° angulation (Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B303, http://links.lww.com/SCS/B304, Fig. 1). This difference was statistically significant ($P < 0.01$). Mean stress value on body of sphenoid bone was remarkably higher in 45° (0.45 ± 0.17 MPa) than 90° (0.19 ± 0.09 MPa) (Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B303, http://links.lww.com/SCS/B304, Fig. 1). This difference was significant ($P < 0.01$). Mean stress value in 45° was 0.61 ± 0.66 MPa for maxillary tuberosity, 0.34 ± 0.008 MPa for palatal surface of maxilla and 1.15 ± 0.59 MPa for palatine bone. Mean stress value in 90° angulation was 0.76 ± 0.91 MPa for maxillary tuberosity, 0.32 ± 0.002 MPa for palatal surface of maxilla and 1.09 ± 0.541 MPa for palatine bone (Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B303, http://links.lww.com/SCS/B304, Fig. 1). Difference of these values were statistically insignificant ($P > 0.05$).

DISCUSSION

Techniques and instruments for pterygomaxillary separation during Le Fort I osteotomies were analyzed in some studies.[1,5,10–13] Majority of complications related to pterygoid separations was caused by improper placement of osteotome, fractures that occur during pterygomaxillary separation or during down fracturing of maxilla.[10,13,14] In order to avoid these complications, increasing angulation of the osteotome with sagittal plane has been recommended. However; increased angulation of osteotome caused undesired separation of palatine bone due to weak connection with maxilla in other studies.[15,16]

Additionally it was stated that increasing the angle between the handle of the osteotome and sagittal plane more than 80° is not clinically possible due to limitation of soft tissues.[1] There are 2 different angle, one is angle between the handle of osteotome and sagittal plane, the other is angle of the tip of the osteotome with sagittal plane. Chin et al[17] recommended $102 \pm 4°$ angulation of the tip of osteotome with sagittal plane considering pterygomaxillary suture and sagittal plane angle obtained in their retrospective study. Stajcic[1] considered the handle of the osteotome and it was 50° and 80° with sagittal plane. We angulated osteotome's tip 45° and 90° with sagittal plane similar to Stajcic,[1] to standardize the findings as the angulation of the tip of the osteotome is different with every manufacturer.

Incidence of lateral pterygoid plate fracture with 50° and 80° osteotome angulations was studied on 12 cadavers.[1] There were 9 undesired fractures out of 12 osteotomy sites when 50 degree angulation of the osteotome with sagittal plane was obtained. However, there was 5 undesired fractures out of 12 sides when 80° angulation of osteotome was obtained. In one site, palatine bone was separated from maxilla unexpectedly at 80° angulation. Hiranume et al[18] compared strain distributions around pterygomaxillary suture by Obwegeser osteotome and swan's neck osteotome. The design of swan's neck osteotome allows applying force to pterygomaxillary junction more obtuse angle than obwegeser osteotome. The strain values were higher in obwegeser osteotome group than swan's neck osteotome. Pterygoid plate was compressed posteriorly in Obwegeser osteotome group due to large strains. Lanigan and Guest[19] haven't recommended use of Obwegeser osteotome because of leading high rate of pterygoid plate fracture near the base of the skull. Parkar et al[9] recommended to locate blade of curved osteotome obliquely to avoid posterosuperior compression of the pterygoid plates. Static et al[1] have not recommended increasing osteotome angle due to risk of separation of palatine bone from maxilla. However; in our study; stress values on palatine bone wasn't statistically significant for two investigated angulations ($P > 0.05$).

Effects of transmitting stresses in the cranial base during pterygoid osteotomy hasn't clearly determined. Lanigan and Mintz[20] reported a patient with occulomotor nerve paralysis following surgically-assisted rapid maxillary expansion. In previous study; it was reported that unexplained stress and deformations on sphenoid bone may have caused undesired sphenoid bone fracture.[17] In addition to this, there were some case samples stating that stress in the cranial base during pterygoid osteotomy was the most important factor for the development of major complications such as severe bleeding and nerve palsies.[21,22]

In the present study, maximum stress values on lateral pterygoid plate and body of sphenoid bone with 45° angulation was doubled when 90° angulation is applied (Fig. 1). The risk of unwanted pterygoid fracture increases which was also the finding of Stajcic.[1] Mean stress values on maxillary tuberosity and palatine bone weren't affected significantly from alteration of osteotome angle. Serious complications related to pterygoid plate may be avoided by increasing the angulation of osteotome with a little or no risk of maxillary tuberosity fracture.

CONCLUSION

Considering stress values on lateral pterygoid plate, the risk of unexpected fracture was increased and cranial base was exposed to more stresses in narrow osteotome angulation. Due to that handle of the osteotome should be tilted as more perpendicular to the sagittal plane as possible to avoid possible complications.

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