The Changes in Upper Airway Volume after Orthognathic Surgery Evaluated by Individual Segmentation on CBCT Images

Cosmin Ioan FAUR a, Raluca Ancuta ROMAN a, Simion BRAN a, Cristian DINU a, Alina COCLICI a, Horatiu ROTARU a, Mihaela HEDESIU a

““Iuliu Hatieganu” University of Medicine and Pharmacy, Department of Maxillofacial Surgery and Radiology, Faculty of Dental Medicine, Cluj-Napoca, Romania

ABSTRACT

Objectives: The aim of this CBCT study was to evaluate the postoperative volume changes of the rhinosinusal airway space, maxillary sinuses and nasal fossa, that occur after Le Fort I osteotomy, using individual segmentation of 3D virtual models.

Material and methods: A number of 16 patients (with Class II and Class III malocclusions) who underwent a CBCT examination for orthognathic surgery at six month-interval between preoperative and postoperative evaluations were included. Patients with thickening of the sinus mucosa, craniofacial syndromes, maxillofacial trauma, rhinoplasty or other maxillofacial pathological conditions were excluded from the study. Individual segmentation of airway volumes was performed by the ITK-SNAP 2.0 software. Paired student t-test was used for the statistical examination of volume changes and Pearson’s test for the assessment of intra-rate correlation.

Outcomes: A statistically significant decrease in the rhinosinusal volume in Class II (9.36±3.43 cm3) and Class III malocclusions (3.65±2.96 cm3) was found after Le Fort I osteotomy. A decrease in volume was also found for maxillary sinuses (5.63±1.52 cm3 for Class II and 6.72±4.5 cm3 for Class III malocclusion). Nasal fossa decreased in volume (3.79±3.8 cm3) in Class II malocclusion patients and increased (3.07±2.39 cm3) in Class III malocclusion patients. The Pearson correlation revealed a high intra-rate agreement of measurements.

Conclusion: Le Fort I osteotomy modifies the postoperative volume of rhinosinusal aerial spaces and individual segmentation on CBCT images is a useful tool to analyze the changes.

Keywords: CBCT, surgery, airway volume.
OBJECTIVES

Le Fort I osteotomy is the most commonly used surgical procedure for maxillary bone reposition in Class II and Class III malocclusion, providing a correction of the jaw relationship in all three spatial directions (1). Le Fort I osteotomy with maxillary advancement is used to correct Class III malocclusion, often in conjunction with palatal expansion (2, 3). In Class II malocclusion patients, it is used in conjunction with maxillary setback and mandibular advancement in order to achieve a stable and aesthetical appearance (1). Bimaxillary surgery improves the patient’s profile and masticatory function (3, 4).

Controversial results regarding the volumetric changes of the upper airways after orthognathic surgery have been reported in the literature. Several studies demonstrated a postoperative narrowing of the pharyngeal space volume in Class III malocclusion correction (4). The volume of paranasal sinuses was shown to be decreased after Le Fort I osteotomy and maxillary setback surgical treatment for Class II malocclusion (5). On the other hand, an increase in the upper airway volume was demonstrated after maxillary advancement and mandibular setback in Class III patients (6, 7).

There are two possible causes for these variable results: the utilization of different acquisition methods and the use of different analysis methods for measurements of the airway volume.

One explanation could be the current use of low radiation dose CBCT examination for the preoperative planning and postoperative follow up in craniofacial anomalies (8-10). A higher benefit in terms of the accuracy and reproducibility of volume measurements of the maxillary sinuses was demonstrated for 3D imaging (11, 12), as opposed to abandoned cephalometric radiographs that superpose the cranial anatomical structures (13). Other paraclinical investigations used in addition to imaging for the evaluation of the upper airways volume could be plethysmography, acoustic rhinometry and anterior rhinomanometry (14). On a plethysmography study, an increased resistance of upper airway airflow was found after bimaxillary orthognathic surgery; this increase in airflow resistance is due to a narrowing of upper aerial spaces and it can be associated with a higher risk of snoring and sleep apnea (15-17). On the other hand, rhinomanometric measurements showed a significant improvement of the total rhinosinusal airflow after orthognathic surgery (16).

The other explanation for the variability of the postoperative volumetric results of the upper airways measurements is the use of different segmentation methods on CBCT images in the literature. The segmentation of the total pharyngeal airway volume revealed a decrease in volume after bimaxillary surgery for Class III malocclusion treatment (18), while other studies, in which the individual segmentation of the pharyngeal airway volume was considered separately, showed an increase of the nasopharynx volume and a decrease in the laryngopharynx volume following orthognathic surgery (16).

However, a standardized protocol for the volumetric segmentation on CBCT images was not defined yet. The present study aims to evaluate the individual postoperative volumetric changes of the maxillary sinuses and nasal fossa following bimaxillary orthognathic surgery in Class II and Class III malocclusion by using individual segmentation methods of maxillary sinuses on CBCT images.

MATERIAL AND METHODS

Patients and examinations

Class II and Class III malocclusion patients who underwent bimaxillary orthognathic surgery in the Department of Maxillofacial Surgery, University of Medicine and Pharmacy Cluj-Napoca, between 2012-2017, have been selected for the present study. All included patients were examined on a CBCT machine (NewTom 3G, QR, Italy) at one week preoperatively and at six months postoperatively, with the following scanning protocol: 120 kV, 3-8 mAs and 0.33 mm voxel size.

The CBCT images were retrospectively analyzed in order to evaluate the volumetric changes induced by surgery of the total rhinosinusal airway space, nasal fossa and maxillary sinuses. Only patients with normal, non-visible maxillary sinus mucosa on the CBCT examination before and after orthognathic surgery were included in the present study.

Patients with craniofacial syndromes, maxillofacial trauma, rhinoplasty or other maxillofacial...
pathological conditions were excluded from the present study.

**Volumetric measurements**

The CBCT images were analyzed on a computer station by using the ITK-SNAP 2.0 segmentation software (Researchers at University of Pennsylvania and UNC, USA) (1, 20).

The preoperative and postoperative volumes of the rhinosinusal airway space were measured on CBCT images. The rhinosinus space volume was defined by the most extreme points of the maxillary bone on axial and coronal images, as shown in Figures 1 and 2.

The threshold used for the segmentation of the rhinosinusal space volume was set between -1024 and -100 Hounsfield Units (HU) (Figure 3). The air outside the region of interest (ROI) was cropped out slice by slice, and the remnant volume was then automatically calculated (Figure 4).

The same bone landmarks were considered for the individual segmentation of the maxillary sinuses as for the rhinosinusal volume, except for the medial borders of the maxillary sinuses, which were defined by a vertical plane passing through the most medial point of the sinus on coronal view. Sinuses were considered as a common volume without any difference between the left and right sinuses (Figure 5).

The nasal fossa volume was calculated by subtracting the maxillary sinus volume from the total rhinosinus volume (Figure 6).

The CBCT volumetric measurements reproducibility was evaluated by repeating the measurements within two weeks interval by the same examiner.

**Statistical examination**

Statistical analysis was performed with MedCalc 15.6. Numerical data related to the calculated
OUTCOMES

A number of 16 patients (seven with Class II and nine with Class III malocclusion) who underwent Le Fort I osteotomy were included in the study. The patients’ age range was between 18 and 42 years (mean 27±SD 5 years).

The volumetric differences between preoperative and postoperative airway volumes for Class II and Class III malocclusions are presented in Tables 1 and 2. Patients with Class II malocclusion had a significant decrease in the postoperative volume of the total rhinosinusual airway by 18.74±7.47% compared to the preoperative volume and also a decrease in the maxillary sinuses volume by 16.95%±4.57%. The volumetric differences between postoperative and preoperative measurements ranged between 8.45–15.01 cm³ for the total rhinosinusual airway and between 3.7–7.94 cm³ for the measured maxillary sinuses. Class III malocclusion patients have also showed a decrease in postoperative volumes, with differences ranging between 0.5 cm³ and 8.3 cm³ for the total rhinosinusual space (6.43 %±5.24%) and from 1.9 cm³ to 17 cm³ for the measured maxillary sinuses (16.72 %±11.20%).

The postoperative volume of the nasal fossa decreased in Class II malocclusion patients (3.79±3.8 cm³, representing 22.42%±23.17%) and increased in Class III malocclusion patients (3.07±2.53 cm³, representing 18.56%±14.44%).

<table>
<thead>
<tr>
<th>Class II malocclusion patients</th>
<th>Preoperative volumes (cm³)</th>
<th>Postoperative volumes (cm³)</th>
<th>Volume differences (cm³)*</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Nasal fossa</td>
<td>16.72</td>
<td>5.15</td>
<td>12.93</td>
<td>4.72</td>
</tr>
<tr>
<td>Maxillary sinuses</td>
<td>33.21</td>
<td>4.25</td>
<td>27.64</td>
<td>4.99</td>
</tr>
<tr>
<td>Rhinosinusual airway</td>
<td>49.93</td>
<td>6.4</td>
<td>40.57</td>
<td>6.71</td>
</tr>
</tbody>
</table>

*Volume differences represent the differences between preoperative and postoperative volumes

TABLE 1. Results of volume measurements for Class II malocclusion patients
The Pearson intra-class correlation coefficient was 0.98 for preoperative volume measurements and 0.99 for postoperative volume measurements.

DISCUSSION

Our results demonstrated the importance of the segmentation method used for airway volumetric measurements. Various methods for upper aerial space segmentation have been described until now. Panou et al. achieved the maxillary sinuses volume by manually cutting out the nasal fossa volume from a total nasal fossa and maxillary sinuses volume (21). The methods used for sinus segmentation on lateral cephalometric images superimposed the left and right sinuses as a total maxillary sinus volume, and 2D radiological examinations did not provide accurate measurements of the sinusal cavities (21-23).

In our study, different results occurred from the CBCT segmentation of the total volume of rhinosinusal airway space compared to the individual segmentation of the maxillary sinuses and nasal fossa volumes.

The total rhinosinusal airway segmentation method on CBCT images revealed a decrease in postoperative airway volumes in all patients who were included in the present study.

The maxillary sinus volumes decreased postoperatively in all patients, similar results being reported by other studies on Class II and Class III malocclusion patients treated by orthognathic surgery and Le Fort I osteotomy. According to Panou et al. (21), the volume of maxillary sinuses decreased by only $3.44\pm3.31 \text{cm}^3$ for Class III malocclusion, while we found a decrease by $6.92\pm4.5 \text{cm}^3$.

The individual segmentation of the nasal fossa on CBCT images showed a decreased postoperative volume in Class II patients subjected to Le Fort I and setback orthognathic surgery and an increased volume in Class III patients after Le Fort I with advancement surgery. These results suggest that postoperative volumetric changes of the nasal fossa are more sensitive to sagittal movements of the maxilla and that they are independent from the volume of the maxillary sinuses.

To the best of our knowledge, none of the airway volume segmentation protocols has previously performed an individual segmentation of the total rhinosinusal airway volume according to the specific bone landmarks of the maxillary sinuses. In the present study, segmentation of the maxillary sinuses was done manually, first on the right sinus and then on the left sinus, according to the specific bone landmarks of the soft tissue–air interface by using a guided 3D active contour segmentation (24). The nasal fossa volume was obtained by subtracting the volume of the maxillary sinuses from that of the total rhinosinusal airway space.

Our results demonstrated that the individual segmentation of airway structures offered a more relevant understanding of changes in the volumes of maxillary sinuses and nasal fossa after orthognathic surgery involving Le Fort I osteotomy.

Volumetric changes of the upper airways also depend on the time-point for the follow-up radiological examination. An evaluation at one year to three years postoperatively highlighted the importance of the time-point for the outcome stability in analyzing volumes (25, 26). In the present study, the postoperative volumetric changes were evaluated after an interval of six months. The high intra-class coefficient of our measurements showed that this evaluation protocol could be used on early analyzing of the orthognathic surgery long time stability.

<table>
<thead>
<tr>
<th>Class III malocclusion patients</th>
<th>Preoperative volumes (cm$^3$)</th>
<th>Postoperative volumes (cm$^3$)</th>
<th>Volume differences (cm$^3$)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Nasal fossa</td>
<td>16.54</td>
<td>8.61</td>
<td>19.61</td>
<td>9.15</td>
</tr>
<tr>
<td>Maxillary sinuses</td>
<td>40.17</td>
<td>7.21</td>
<td>33.44</td>
<td>5.92</td>
</tr>
<tr>
<td>Rhinosinusal airway</td>
<td>56.71</td>
<td>13.58</td>
<td>53.05</td>
<td>13.02</td>
</tr>
</tbody>
</table>

*Volume differences represent the difference between preoperative and postoperative volumes

**TABLE 2.** Results of volume measurements for Class III malocclusion patients
CBCT and Individual Segmentation of Upper Airway Changes after Orthognathic Surgery

Compared to CT examination, CBCT imaging of the upper airway volume offers the advantages of a reduced radiation dose, fast acquisition of data and accuracy of 3D structures, at present being widely considered the gold standard examination of the orthognathic surgical outcomes (12, 27).

Additional methods for the volumetric measurements of the upper aerial space volume such as plethysmography, acoustic rhinometry or anterior rhinomanometry could be useful to analyze functional changes of the upper airways volume induced by orthognathic surgery (15, 28). These evaluations offer information about narrowing of the upper airways after bimaxillary surgery expressed by several parameters such as increasing upper airway resistance and deterioration of breathing parameters (15, 16, 23, 29, 30). Moreover, Galbaiti et al. proved that volumetric measurements of the nasal cavities obtained with functional evaluations were well correlated with the volumes measured on CBCT images (28).

Sleep related breathing disorders are associated with airways narrowing induced by the new jaws relationship occurring after orthognathic surgery (31-34). This possible effect of orthognathic surgery on the upper airways should be taken into consideration for the treatment plan (16). The present study proved that individual segmentation on CBCT images could offer the necessary support for a correct evaluation of the upper airway volume and prevent the negative effect of surgery on the respiratory function.

**CONCLUSION**

In conclusion, orthognathic surgery using Le Fort I osteotomy induced significant volume changes of the upper airways, comprising the rhinosinusal, maxillary sinuses and nasal fossa airways. The low dose CBCT examination and additional individual segmentation of the volume proved to be precise analysis tools for the volume of the upper aerial spaces.


REFERENCES

CBCT and IndiVIdual SegmenTaTIon of upper aIrway ChangeS afTer orThognaThIC Surgery


Doi: 10.1111/eos.12068.


