Quantification of volumetric, surface area and linear airway changes after orthognathic surgery: a preliminary study

Purpose
The aim of this study was to conduct a retrospective evaluation of the volumetric, cross-sectional surface area and the linear airway changes in healthy subjects undergoing orthognathic surgery.

Materials and methods
A total of 10 patients were included in this study and categorized into two groups. The first group consisted of five patients who underwent maxillary and mandibular advancements (MMA) with genioplasty. The remaining five patients who underwent maxillary advancement with mandibular setback (MAMS) comprised the second group. The changes in airway volume, surface area, and linear values obtained from defined hard and soft tissue parameters were evaluated using preoperative and postoperative cone-beam computed tomography. A paired t-test was used to explore the statistical significance.

Results
A statistically significant increase in the airway volume (34.3%) was observed in the MMA group. The changes in the MAMS group were not statistically significant, although an average volumetric decrease of 8.8% was observed. The minimal axial surface area measurements in the MMA group at the levels of the soft palate and the tongue were significantly increased (56.8% and 44.9%, respectively). However, MAMS resulted in no significant changes at these levels (11.2% and 9.1% decrease, respectively). Linear changes showed a statistically significant increase in the airway in the MMA group, whereas the same measurements failed to produce significant changes in the MAMS group.

Conclusion
As there were no significant changes in the measured parameters, surgeons can have greater confidence that MAMS does not have any negative influence on the airway.

Keywords: Volumetric, linear, surface area, airway changes, orthognathic surgery

Introduction
Utilization of the cone beam computed tomography (CBCT) has become an invaluable tool in the diagnosis and treatment planning in oral and maxillofacial surgery. Previous analysis of soft tissue and accompanying airway changes after skeletal movements of the maxilla and mandible were limited to two dimensions with the lateral cephalogram or increased radiation and cost using traditional CT scans. With the advent of CBCT imaging, practitioners are now able to accurately define and explore changes pre- and post-operatively in patients undergoing skeletal movements of the maxillofacial region (1).

Orthognathic surgery has been associated with both positive and negative changes in patient’s airway function. The negative changes are con-
troversial and have been implicated in the creation of ob-
structive sleep apnea syndrome (2, 3). Prior studies looking at
airway changes after orthognathic surgery have been limited
in quantifying the amount and location of changes in the air-
way before and after surgical intervention (4) The complexi-
ty of the changes in the airway include alterations in tongue
position, hyoid positioning and pharyngeal wall changes that
are affected by alteration of muscular and ligamentous at-
tachments to the bone. Few studies have attempted to look
at volumetric, surface area and linear changes in the same pa-
tient (4-7). By looking at these expanded parameters, it was
aimed to help clinicians accurately predict and understand fa-
vorable and unfavorable airway changes that follow planned
orthognathic movements.

The aim of this preliminary study was to explore volumet-
ric, cross sectional surface area, and linear changes using pre-
and post-op cone-beam computed tomography (CBCT) im-
aging in healthy patients undergoing orthognathic surgery.
The null hypothesis tested in this study is that there is no
difference between the pre- and post-operative volumetric,
cross-sectional and linear measurement variables in patients
undergoing orthognathic surgery.

Materials and methods

Study population

This study was approved by the Ethical Review Board of
University Hospitals Case Medical Center, Cleveland OH,
(Protocol Approval Number: 20110805). Written informed
consent was obtained from patients who participated in this
study. Patients included in the study were chosen random-
ly from a database of orthognathic surgeries performed by
the above department. Exclusion criteria included previous
orthognathic surgery, patients with craniofacial syndromes,
midline shifts of greater than 3 mm, superior or inferior move-
ments of more than 3mm, and any other previous hard or soft
tissue surgery of the maxillofacial region including tonsillec-
tomy and adenoidectomy. Ten patients, aged 17-54 years (av-
erage age of 24.8 years), 5 women and 5 men were divided
into two groups. The first group included five patients that
had maxillary and mandibular advancements with genioplas-
sty. The second group included five patients that underwent
maxillary advancement with mandibular setback. Mandibular
surgery included bilateral sagittal split osteotomies. Maxillary
surgery included Le Fort I osteotomies. All patients under-
went rigid internal fixation of the maxilla and mandible. The
average maxillary advancement was 5.2 mm (range of 3-10
mm) for both groups. Mandibular advancement averaged 5.4
mm (range of 3-10 mm). The mandibular setback averaged
3.3 mm (range 2-5 mm). The advancement genioplasty aver-
aged 7.8 mm (range 6-11 mm) (Table 1).

| Table 1. Patient demographics, average values for maxilla-mandibular movements |
|---------------------------------|----------------|----------------|
| Average age                     | 24.8           | Range (17-54) |
| Average maxillary advancement   | 5.2 mm         | Range (3-10)  |
| Average mandibular advancement  | 5.4 mm         | Range (3-10)  |
| Average mandibular setback      | 3.3 mm         | Range (2-5)   |
| Average genioplasty (advancement)| 7.8 mm         | Range (6-11)  |

Imaging procedures

Postoperative CBCT images were obtained approximately
two months after surgery with the patient in natural head po-
sition, using the same machine and technique. Two attending
surgeons and multiple surgical residents, at the same institu-
tion, completed all of the surgeries. Pre- and post-operative
CBCT scans were acquired with CB Mercuray® (CB Mercuray;
Hitachi Medical Corporation, Tokyo, Japan) and analyzed us-
ing Invivo 5.1 (Anatomage, San Jose, Ca) and Dolphin 3D soft-
ware. Digital imaging files were imported to Invivo. The files
were then reconstructed into volumetric, sagittal, and axial
slices.

Linear and volumetric measurements

The changes in airway volume, surface area and linear val-
ues from defined hard and soft tissue parameters were re-
corded. To increase accuracy, each patient underwent three
independent measurements for the above values. These val-
ues were averaged to yield the final linear, volumetric and
surface area numbers to be analyzed. All measurements were
performed and recorded by the same specialist experienced
in craniofacial radiology and imaging. Imaging was com-
pleted using the same scanner and technician based on the
equipment specifications to acquire needed reference points
and areas.

Volumetric analysis of the airway was defined by a superior
plane at the level of the hard palate (HP), from the anterior na-
sal spine (ANS), posterior nasal spine (PNS), posterior pharyn-
geal wall (PP) and an inferior plane ending at the level of the
third cervical vertebrae (3CV). They were then reconstructed
before and after surgery (Figures 1-3). Within these boundar-
ies a minimal constricted axial surface area at the level of the
soft palate and tongue was identified and measured.
In addition to the above-mentioned parameters, linear two-dimensional measurements were recorded from the sagittal view at the level of the hard palate (HP), third cervical vertebrae (3CV), soft palate (SP) and tongue (T) pre- and post-operatively. A fourth measurement of the linear distance included the change from the genial tubercles to the hyoid pre- and post-operatively. Finally, on the axial cross sections at the level of the minimal constricted areas, (SP and T) lateral and antero-posterior dimensions of the airway were measured. Results were evaluated by calculating percent change of 3-D, 2-D, and linear values.

**Statistical analysis**

The collected data from all groups were imported to Statistical Package for Social Sciences (SPSS) for Windows software, version 22.0 (IBM Corp.; Armonk, NY, USA). Descriptive analyses were performed to calculate the mean and standard error of variables in each group. An exploratory test (Kolmogorov–Smirnov) test revealed normal distribution of the data; therefore, a paired t-test was used to explore statistical significance pre- and post-operatively. Percent change for the groups was averaged for all measurements. The confidence interval was set to 95% and p<0.05 was considered statistically significant.

**Results**

Ten patients met the inclusion criteria as outlined in the methods. In general, the results showed favorable airway changes in the maxillary and mandibular advancement group. Table 2 shows volumetric changes for the maxillary and mandibular advancement group. This group showed a statistically significant increase in airway volume of the defined areas pre- and post-operatively.

![Figure 2. Sagittal view of the reconstructed 3-D airway.](image)

![Figure 3. Pre- (blue) and post-operative (red) airway reconstruction for maxillary / mandibular advancement.](image)

**Table 2. 3-D Volumetric measurements for maxillary/mandibular advancement**

<table>
<thead>
<tr>
<th>Volumetric Measurement</th>
<th>Pre-operative Mean +/-SD</th>
<th>Post-operative Mean +/-SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>10983(4450.8)</td>
<td>15528.8(5099.2)</td>
</tr>
</tbody>
</table>

Significant if p<0.05, paired t-test, Sig: significant, measurements in mm³

**Table 3. 3-D Volumetric measurements for maxillary advancement/mandibular setback**

<table>
<thead>
<tr>
<th>Volumetric Measurement</th>
<th>Pre-operative Mean +/-SD</th>
<th>Post-operative Mean +/-SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>21162(5855.7)</td>
<td>19373.6(5915.1)</td>
</tr>
</tbody>
</table>

Significant if p<0.05, paired t-test, NS: not significant, measurements in mm³

**Table 4. Surface area changes maxillary/mandibular advancement**

<table>
<thead>
<tr>
<th>Surface Area</th>
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<tbody>
<tr>
<td>Measurement</td>
</tr>
<tr>
<td>Surface area of defined plane</td>
</tr>
<tr>
<td>Minimal axial (SP)</td>
</tr>
<tr>
<td>Minimal axial (T)</td>
</tr>
</tbody>
</table>

Significant if p<0.05, paired t-test, values in mm²

**Table 5. Surface area measurements: maxillary advancement/mandibular setback**

<table>
<thead>
<tr>
<th>Surface Area</th>
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<tbody>
<tr>
<td>Measurement</td>
</tr>
<tr>
<td>Surface area of defined plane</td>
</tr>
<tr>
<td>Minimal constricted axial (SP)</td>
</tr>
<tr>
<td>Minimal constricted axial (T)</td>
</tr>
</tbody>
</table>

Significant if p<0.05, paired t-test, NS: not significant, measurements in mm². Min: minimal, SP: soft palate, T: tongue
area. The mean starting volume of $10,983 \text{ mm}^3$ increased to 15,528 mm$^3$. This corresponded to an average increase in airway volume of 34.3%. Table 3 shows the volumetric changes in the maxillary advancement and mandibular setback group. The results in this group were not found to be significant. The mean pre-operative and post-operative volumes were 21,162 and 19,373 mm$^3$, respectively. This was an average volumetric decrease of 8.8%.

The minimal axial surface area measurements in the maxillary and mandibular advancement at the level of the soft palate and tongue were found to be significant (Table 4). The values of the soft palate mean increased from 192 to 344.5 mm$^2$. Minimal axial surface area of the tongue increased from 281.2 to 444.1 mm$^2$. This represented a 56.8 and 44.9% increase. Once again, as in the volumetric analysis, the maxillary advancement and mandibular setback group did not produce significant changes in terms of axial cross sectional surface area (Table 5). The decrease in surface area at the soft palate and tongue was 11.2 and 9.1%, respectively.

Table 6 demonstrates that linear changes in the maxillary and mandibular advancement group showed a statistical significance from the hyoid to genial tubercles. Linear changes in the maxillary advancement and mandibular setback group were not significant (Table 7). The percent change in the linear measurements in this group was minimal, a 5% decrease from hyoid to genial tubercles, a 7% decrease in the lateral dimension at the level of the soft palate and a less than 1% change in the A-P dimension at the level of the soft palate. The linear dimension at the predefined level of the tongue showed an increase of 1%. The greatest percent change occurred in the A-P dimension at the tongue, with a decrease of 39%. Two-dimensional values for both groups failed to produce statistically significant changes (Tables 8, 9).

### Discussion

The results of this study support previous findings of favorable airway changes after maxillary/mandibular advancement. The percent positive change in airway volume was significant with advancement of the maxilla and mandible. Volume was found to change less than linear or surface area values in this group. Of particular interest was the increase in the minimal axial surface area of the soft palate and tongue. This identification would not have been possible without using volumetric analysis to recreate the airway and identify areas of constriction. As expected, the increased linear distance from the hyoid to the genial tubercles followed a predicted pattern with mandibular advancement and genioplasty. Of interest to this study, a group with mandibular advancement without genioplasty would have led to further understanding of changes at this level, and provide data for statistical comparison.

The findings of the previous studies, which evaluate airway changes after mandibular setback surgeries, have so far remained controversial. Tselnik and Pogral (8) reported a reduction of the airway by 28% in distance and 12.8% in volume at retro-lingual level. Similar findings of decrease in the airway dimensions associated with mandibular setback surgeries have also been reported by Athanasiou et al. (9), Gu et al. (10) and Turnbull and Battagel (11) These studies commonly indicate postero-inferior displacement of the hyoid bone, decrease in inter-maxillary space and sequent posterior displacement of the tongue after the operation. In the present study however, the maxillary advancement/mandibular setback group failed to show significant changes after orthog-
nathic surgery. This was similar to Park et al. (6) who failed to show significant changes at the nasopharyngeal and oropharyngeal levels. Jakobsone et al. (7) also failed to show significant changes with maxillary advancement and mandibular setback. Lee et al. (12) demonstrated significant changes in linear values of the upper airway without significant changes in total airway volume. We believe that the complexity of the airway accounts for these differences. Each study, including the present one, used unique movements and positioning of the maxilla and mandible besides simple anterior or posterior repositioning. Superior movements, rotations, and asymmetric changes make uniform evaluation impossible and therefore can lead to different results.

The comparison of volumetric evaluation of changes with two-dimensional measurements has seldom been reported. Shaw et al. (13) have previously stated that two-dimensional measurements from conventional cephalometric lateral skull radiographs were comparable to those from CBCT images. Conversely, Burkhard et al. (14) reported limited comparability of linear and volumetric measurement of the pharyngeal airway space. In the present study, three-dimensional evaluations demonstrated statistically significant changes where two-dimensional values failed to identify statistically significant alterations. Although a limited number of subjects were included in this preliminary study, we find it safe to state that, three-dimensional evaluation has the potential to better determine the postsurgical morphological changes.

Several issues in the interpretation of the data need to be addressed. First, the total number of patients was limited. Larger numbers would strengthen statistical findings and future research may benefit to a great extent from the use of a larger sample size. Secondly, due to the retrospective nature of this study, no set timing of post-operative scanning existed. Multiple set post-operative images would allow the investigator to follow changes over time and lessen issues of post-operative edema, and compensation of soft tissue to new bony positions as previously reported by Becker et al. (15) and Sears et al. (16). It should also be taken into consideration that increased outcomes of volumetric airway changes may be achieved in cases of greater advancements. Future research may therefore consider the comparison of different levels of advancement to better understand the effects of orthognathic surgery on airway volume. Finally, the dynamic nature of the pharyngeal airway makes evaluation difficult. We believe that, future studies would benefit from standardization of the image recording techniques to a great extent.

Conclusion

Maxillary and mandibular advancement with genioplasty increased the volume of the pharyngeal airway. This increase in volume was greater than the increase in surface area and linear measurements. Mixed advancement of the maxilla and posterior movement of the mandible failed to produce significant changes, which can be interpreted as a positive result. Without significant changes in the measured parameters, surgeons can have greater confidence that this combination movement is not altering the airway in a negative way. Further studies with standardized movements and increased number of patients will lead to more comprehensive understanding of airway changes after orthognathic surgery.

Ethics Committee Approval: This study was approved by the Ethical Review Board of University Hospitals Case Medical Center, Cleveland OH, (Protocol Approval Number: 20110805).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: FAQ, JTW and DAB designed the study. JTW and DAB analyzed the data. OÖ conducted literature review and helped with documentation of the study. MAA wrote the majority of the original draft. All authors approved the final version of paper.

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Conflict of Interest: Dr. Altay has provided consultancy for Checkpoint Surgical LLC. in 2014, and Dr. Baur is a paid consultant for Novartis Pharmaceuticals and Checkpoint Surgical LLC. Other authors declare that they have no competing financial interests.

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References


