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

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**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-

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troversial and have been implicated in the creation of obstructive 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 airway before and after surgical intervention (4) The complexity 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 attachments to the bone. Few studies have attempted to look at volumetric, surface area and linear changes in the same patient (4-7). By looking at these expanded parameters, it was aimed to help clinicians accurately predict and understand favorable and unfavorable airway changes that follow planned orthognathic movements.

The aim of this preliminary study was to explore volumetric, cross sectional surface area, and linear changes using pre- and post-op cone-beam computed tomography (CBCT) imaging 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 randomly 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 movements of more than 3mm, and any other previous hard or soft tissue surgery of the maxillofacial region including tonsillectomy and adenoidectomy. Ten patients, aged 17-54 years (average 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 genioplasty. 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 underwent 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 averaged 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) |

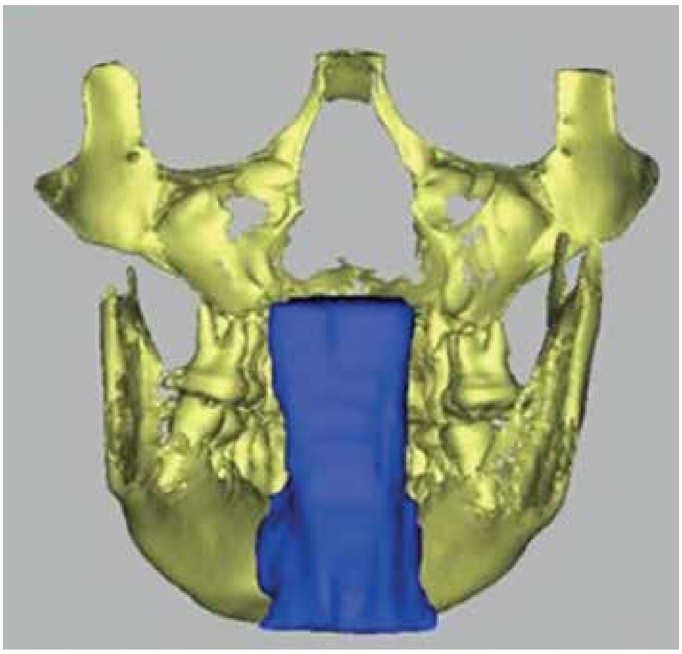

***Figure 1.*** *Reconstruction of the 3-D airway.*

*Imaging procedures*

Postoperative CBCT images were obtained approximately two months after surgery with the patient in natural head position, using the same machine and technique. Two attending surgeons and multiple surgical residents, at the same institution, 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 using Invivo 5.1 (Anatomage, San Jose, Ca) and Dolphin 3D software. 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 values from defined hard and soft tissue parameters were recorded. To increase accuracy, each patient underwent three independent measurements for the above values. These values 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 completed 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 nasal spine (ANS), posterior nasal spine (PNS), posterior pharyngeal 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 boundaries 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.

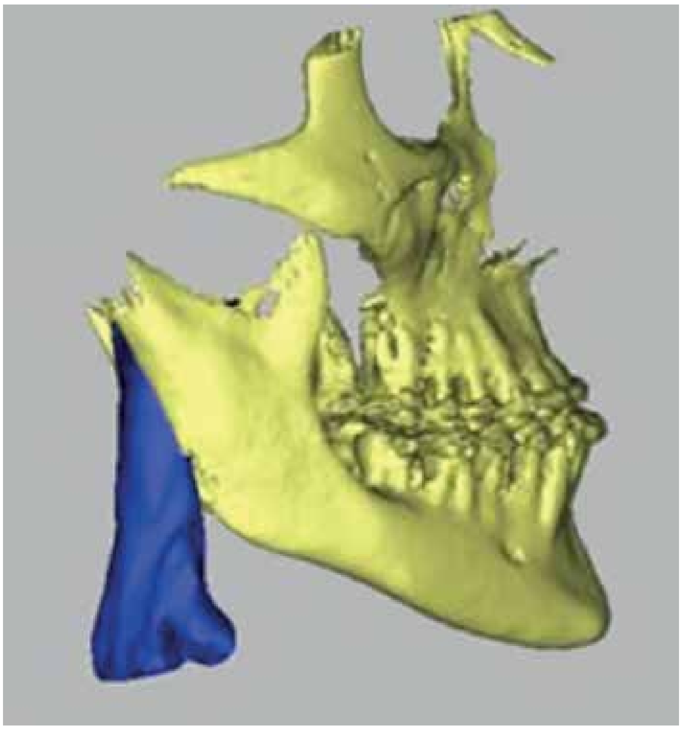

***Figure 2.** Sagittal view of the reconstructed 3-D airway.*

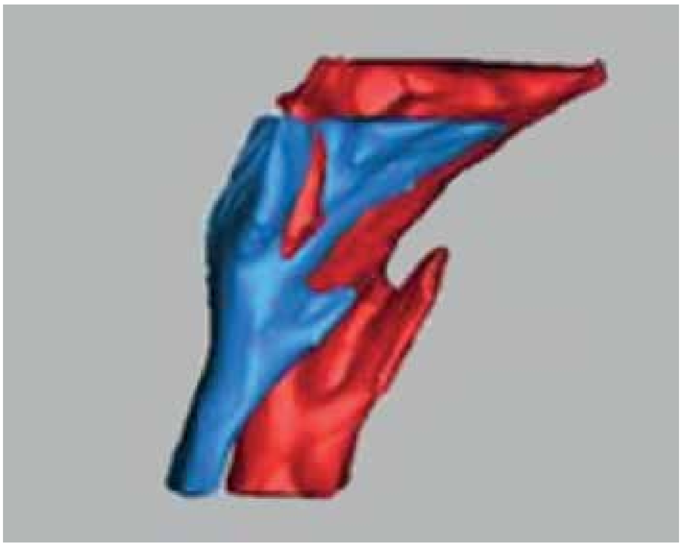

***Figure 3.** Pre- (blue) and post-operative (red) airway reconstruction for maxillary / mandibular advancement.*

## 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

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

| | Volumetric | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| Volume | 10983(4450.8) | 15528.8(5099.2) | Sig |

Significant if p<0.05, paired t-test, Sig: significant, measurements in $mm^3$

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

| | Volumetric | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| Volume | 21162(5855.7) | 19373.6(5915.1) | NS |

Significant if p<0.05, paired t-test, NS: not significant, measurements in $mm^3$

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

| | Surface Area | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| Surface area of defined plane | 5228.8(910) | 5932(1312.2) | NS |
| Minimal axial (SP) | 192.0 (151.8) | 344.5 (137.6) | Sig |
| Minimal axial (T) | 281.2 (233.3) | 444.1 (193.0) | Sig |

Significant if p<0.05, paired t-test, values in $mm^2$

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

| | Surface Area | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| Surface area of defined plane | 6800.6(1848.6) | 6220.6(1755.4) | NS |
| Minimal constricted axial (SP) | 555.67(209) | 496.6(216.5) | NS |
| Minimal constricted axial (T) | 467.3(304.8) | 426.6(242.3) | NS |

Significant if p<0.05, paired t-test, NS: not significant, measurements in $mm^2$. Min: minimal, SP: soft palate, T: tongue area. The mean starting volume of 10,983 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 lateral 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).

**Table 6.** *Linear measurements: maxillary/mandibular advancement*

| | Linear Measurements | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| Hyoid-genial tubercle | 28.3 (2.6) | 37.8 (3.6) | Sig |
| Lateral dimension (min SP) | 17.8 (3.8) | 22.2 (4.3) | NS |
| A-P dimension (min SP) | 5.7 (5.4) | 8.9 (6.1) | NS |
| Lateral dimension (min T) | 19.9 (7.5) | 23.9 (4.9) | NS |
| A-P dimension (min T) | 7.1 (5.1) | 10.5 (4.0) | NS |

Significant if p<0.05, paired t-test, NS: not significant, measurements in mm
Min: minimal, SP: soft palate, T: tongue

**Table 7.** *Linear measurements: maxillary advancement/mandibular setback*

| | Linear Measurements | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| Hyoid-genial tubercle | 39.5 (6.6) | 37.6 (7.1) | NS |
| Lateral dimension (min SP) | 24.8 (7) | 23.2 (5.3) | NS |
| A-P dimension (min SP) | 12.0 (2.2) | 11.8 (3.1) | NS |
| Lateral dimension (min T) | 23.8 (6.8) | 25.5 (3.9) | NS |
| A-P dimension (min T) | 14.4 (7.5) | 5.7 (3.5) | NS |

Significant if p<0.05, paired t-test, NS: not significant, measurements in mm
Min: minimal, SP: soft palate, T: tongue

**Table 8.** *2-D measurements for maxillary/mandibular advancement*

| | 2-D measurements | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| HP sagittal | 15.4 (4.4) | 19.0 (3.03) | NS |
| SP sagittal | 6.9 (6.1) | 10.8 (6.4) | NS |
| T sagittal | 7.2 (4.99) | 10.7 (4.3) | NS |
| 3 CV sagittal | 10.3 (4.6) | 11.7 (4.0) | NS |

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

**Table 9.** *2-D measurements for maxillary advancement/mandibular setback*

| | 2-D measurements | | |
|---|---|---|---|
| Measurement | Pre-operative Mean +/-SD | Post-operative Mean +/-SD | |
| HP sagittal | 21.0 (2.7) | 22.3 (2.52) | |
| SP sagittal | 12.3 (2.8) | 12.6 (2.7) | NS |
| T sagittal | 12.6 (2.7) | 12.4 (4.4) | NS |
| 3 CV sagittal | 12.1 (4.4) | 9.7 (2.0) | NS |

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

## 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 orthognathic 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 HAQ generated and gathered the data. MAA, FAQ, JTW and DAB analyzed the data. ÖÖ 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.

**Financial Disclosure:** The authors declared that this study has received no financial support.

***Türkçe öz:*** *Ortognatik cerrahi girişim uygulanmış sağlıklı bireylerde havayolunda meydana gelen hacimsel, lineer ve kesit yüzey alanındaki değişimlerin incelenmesi. Amaç: Bu çalışmanın amacı, ortognatik cerrahi girişim uygulanmış sağlıklı bireylerde havayolunda meydana gelen hacimsel, lineer ve kesit yüzey alanındaki değişimlerin geriye dönük olarak incelenmesidir. Gereç ve Yöntem: Çalışmaya 10 hasta dâhil edilmiştir. İlk grupta maksiller ve mandibuler ilerletme (MMİ) ile birlikte genioplasti uygulanmış beş hasta yer almaktadır. İkinci grupta ise maksiller ilerletme ile birlikte mandibuler geriletme (MİMG) uygulanmış beş hasta yer almaktadır. Belirlenen sert ve yumuşak doku parametreleri kullanılarak, operasyon öncesi ve sonrasında konik-ışınlı bilgisayarlı tomografi (KIBT) ile ölçülen havayolu hacmi, yüzey alanı ve lineer değerlerdeki değişimler incelenmiştir. Eşleştirilmiş t-testi kullanılarak istatistiksel değerlendirmeler gerçekleştirilmiştir. Bulgular: MMİ grubunda havayolu hacminde istatistiksel olarak anlamlı bir artış (%34,3) gözlenmiştir. MİMG grubunda, havayolu hacminde ortalama %8,8'lik bir azalma gözlenmesine rağmen, meydana gelen değişim istatistiksel olarak anlamlı bulunmamıştır. MMİ grubunda, yumuşak damak ve dil seviyesinde yapılan ölçümlerde minimal aksiyal yüzey alanında anlamlı artış* gözlenmiştir (sırası ile %56,8 ve %44,*9). MİMG grubunda bu seviyelerde yapılan ölçümlerde istatistiksel olarak anlamlı değişim* gözlenmemiştir (sırası ile %11,2 ve %9,*1 azalma). MMİ grubunda yapılan lineer ölçümlerde havayolunda istatistiksel olarak anlamlı bir artış gözlenirken, MİMG grubunda bu ölçümlerde anlamlı bir fark bulunmamıştır. Sonuç: Ölçülen parametrelerde anlamlı bir değişikliğe neden olmayışı ile havayolu üzerinde olumsuz bir etkisi olmadığı belirlenen MİMG cerrahisi güvenle uygulanabilir bir yaklaşımdır. Anahtar kelimeler: Hacimsel, lineer, yüzey alanı, havayolu değişikliği, ortognatik cerrahi*

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