Assessment of the Impact of Two-Jaw Orthognathic Surgery on 3D Airway Volume in Patients with Skeletal Class III Patterns

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Abstract

The purpose of this study was to assess the impact of two-jaw orthognathic surgery on the 3D airway volume in patients with skeletal Class III patterns. The study included 27 adult patients with dental Class III malocclusion and mandibular prognathism who underwent two-jaw orthognathic surgery. The changes in airway volume were evaluated using computed tomography simulation and segmentation was carried out using 3D Slicer. Results showed that the average upper airway volume increased by 1979.1 mm$^3$, the oropharyngeal airway volume increased by 336.4 mm$^3$, and the hypopharyngeal airway volume decreased by 1087.5 mm$^3$. Despite this decrease, the overall airway volume still increased by an average of 1228.1 mm$^3$. The findings suggest that two-jaw orthognathic surgery has a positive impact on the overall airway volume in patients with skeletal Class III patterns.

Clinical Trial Registration Number: IRB No: 202101949B0C501

1. Introduction

Orthognathic surgery is a procedure aimed at correcting skeletal imbalances, enhancing facial aesthetics, and improving oral function. It involves adjustments to the skeleton, changes to the position of the hyoid bone and tongue, which may impact the variability of airway volume$^1$. Previous studies$^2$ have shown that airway volume decreases significantly after mandible setback surgery, but this reduction is less pronounced in patients who undergo two-jaw surgery as compared to those who undergo one-jaw surgery, which is similar to Santagata’s study$^3$. Irani et al$^4$ indicated an overall significant decrease between the means for 6 months and up to 1 year after surgery for oropharyngeal and hypopharyngeal volumes. The resultant changes in hard and soft tissues after mandibular setback surgery have been shown to produce a shift in pharyngeal structure to a morphology associated with sleep-disordered breathing, typical of obstructive sleep apnea (OSA)$^5$.

OSA is characterized by repeated increases in resistance to airflow in the upper airway, causing obstruction.$^6$ The collapse of soft tissues in the upper airway, including the retropalatal and retroglossal regions of the oropharynx, play a role in the etiology of OSA. It is also characterized by the periodic partial or complete collapse of the upper airway that results in episodes of hypopnea (diminished airflow of at least 30%, lasting at least 10 seconds) or apnea (absent airflow). The apnea-hypopnea index, or AHI is used by many clinicians to confirm the diagnosis and quantify the severity of OSA.

Original studies performed to evaluate the effect of mandibular setback surgeries on the pharyngeal airway space have been evaluated with lateral cephalograms.$^{12,13,15}$ The limitations of lateral cephalogram are due to plain, 2-dimensional image which cannot adequately represent the 3-dimensional volume. Recently, cone-beam computed tomography (CBCT) has been used to evaluate the airway changes with the 3-dimensional image.$^7$ The majority of CBCT studies examining pharyngeal airway volume changes have patients undergoing a combination of maxillary advancement and mandibular setback surgery.$^8,9$ Thus, there is limited evidence in the literature describing the effect of isolated
mandibular setback surgeries on pharyngeal. However, compared with CBCT which is taken in standing position, medical CT is taken in supine position\textsuperscript{10}, which can better simulate the posture of a sleeping person.

The objective of this study was to assess the impact of two-jaw orthognathic surgery on 3D airway volume in patients with skeletal Class III patterns. The surgery included a Le-Fort I osteotomy for maxilla advancement and bilateral sagittal split osteotomy for the mandible setback. The changes in airway volume were evaluated using computed tomography (CT) simulation.

2. Material And Methods

This report includes 27 adult patients (11 males and 16 females, Table I) with dental Class III malocclusion and mandibular prognathism who underwent two-jaw orthognathic surgery. The average age of the patients was 22.3 years, ranging from 18 to 35 years old. All patients were selected from the records of those who underwent Le-Fort I osteotomy for maxilla advancement and bilateral sagittal split osteotomy (BSSO) for mandible setback at Kaohsiung Chang-Gung Memorial Hospital (KCGMH). All patients received pre- and post-operative orthodontic treatment at the Department of Orthodontics at KCGMH. Figure 1 shows a 23-year-old male patient (Case-12) with mandibular prognathism underwent a LeFort I osteotomy for maxillary advancement and a bilateral sagittal split osteotomy (BSSO) for mandibular setback to correct the skeletal discrepancy. Patients with cranial deformities or a history of facial trauma were not included in this report.

The patients were divided into two groups based on the change in airway volume after surgery. Group A (Cases 1 to 11) had a decrease in airway volume compared to the pre-surgical volume, while group B (Cases 12 to 27) had an increase in airway volume compared to the pre-surgical volume. An unpaired t-test, with a significance level of P < 0.05, was conducted to evaluate the differences in skeletal movement between Group A and Group B.

The preoperative computed tomography (CT) evaluation was conducted one month prior to the surgery, and the postoperative CT was obtained at least six months after the surgery. The CT images were reconstructed using 3D Slicer, and the Frankfurt plane of the patient was used as a reference for the horizontal plane. Further analysis and segmentation were carried out using 3D Slicer to assess the movement of hard tissue, the upper airway, the oropharyngeal airway, and the hypopharyngeal airway.

In order to evaluate the hard tissue, several key landmarks were marked, including the Nasion, anterior nasal spine (ANS), point A, point B, Pogonion, the tip of the upper central incisor (U1), and the tip of the lower central incisor (L1). The Definitions of Landmarks were listed in Table II.

Airway segmentation:

1. The upper airway was defined as the region from the PNS to the most inferior point of the first cervical vertebra (C1).
2. The oropharyngeal airway was defined as the region from the most inferior point of the first cervical vertebra (C1) to the most anterior inferior point of the second cervical vertebra (C2).
3. The hypopharyngeal airway was defined as the region from the most anterior inferior point of the second cervical vertebra (C2) to the most anterior inferior point of the third cervical vertebra (C3).

The airway volume was calculated using the Itk-Snap software as Fig. 2. The presurgical and postsurgical 3D images were overlaid with the reference structure of the anterior cranial base using 3D slicer as Fig. 3 and Fig. 4, which allowed for the calculation of the amount of skeletal movement. The correlation between the skeletal movement and the change in airway volume was then determined.

3. Results

Table III presents the changes in hard tissue movement as measured by the 3D distance changes of six landmarks between pre-surgery and post-surgery. For maxilla advancement, the average amount of movement for the ANS landmark was 2.7 ± 0.96 mm and for the point A landmark was 3.12 ± 0.85 mm. For mandible setback, the average amount of movement for the point B landmark was −6.90 ± 2.00 mm and for the Pogonion landmark was −7.23 ± 2.00 mm.

The changes in airway volume for the 3D model are presented in Table IV. On average, the upper airway volume increased by 1979.1 mm$^3$, while the oropharyngeal airway volume showed an increase of 336.4 mm$^3$. Conversely, the hypopharyngeal airway volume decreased by 1087.5 mm$^3$. Despite this decrease, the overall airway volume still increased on average by 1228.1 mm$^3$. The changes in airway volume for each individual case are listed in Table V which may provide deeper insights into the relationship between surgical intervention and changes in airway volume. The results of this study may inform future surgical planning and patient care.

The correlation between the change in 3D pharyngeal airway volume and the change in 3D distances of the 6 landmarks was calculated and is presented in Table VI. The change in the upper airway showed moderate positive correlation with the movement of the ANS (r = 0.61) and Point A (r = 0.58). The change in the oropharyngeal airway showed only low positive correlation with Pogonion and negligible correlation with the other five landmarks. The change in the hypopharyngeal airway showed high positive correlation with the movement of Point B (r = 0.73) and moderate positive correlation with Pogonion (r = 0.66). The change in the total airway volume showed low positive correlation with the movement of ANS (r = 0.36), Point B (r = 0.31), and Pogonion (r = 0.39).

The patients were further divided into two groups, Group A and Group B, based on the post-surgical airway volume change. An unpaired t-test was conducted to compare the differences between the two groups, with a statistical significance being noted at Point B (P = 0.023) and Pogonion (P = 0.020). The significance level was set at P < 0.05. In Group A, the average regression of Point B was 7.9 mm and the average regression of Pogonion was 8.2 mm. Meanwhile, in Group B, the average regression of Point B was 6.2 mm and the average regression of Pogonion was 6.5 mm.
4. Discussion

In recent years, the potential for airway narrowing after bilateral sagittal split osteotomy (BSSO) for mandible setback in the correction of skeletal Class III pattern has garnered significant attention. While most patients who undergo mandibular setbacks can successfully adapt to the new skeletal and muscular configuration, there are some individuals who may be at risk for developing obstructive sleep apnea (OSA) following the procedure\(^1\). According to previous research\(^5\), mandibular setback procedures can be the trigger for the onset of OSA. The mandible, hyoid bone, tongue base, and pharyngeal walls are interrelated through their muscles and ligaments, and a setback in the mandible can result in a narrowing of the hypopharyngeal airway. This narrowing leads to an increase in flow velocity and a reduction in intraluminal pressure, further narrowing the pharyngeal airway. Over time, this can lead to complete pharyngeal obstruction.

On the contrary, Saitoh et al\(^1^2\) suggested that, although the pharyngeal airway morphology showed marked changes after BSSO, the pharyngeal airway morphology exhibited gradual physiologic readaptation. However, because the lower facial morphology after surgery was retained and stable for a long period, it was considered normal for the pharyngeal airway morphology to adapt after surgery to the improved hard tissue relationship.

Previous studies, such as one conducted using cephalometric analysis,\(^1^3\) have shown that mandibular setback can lead to significant reductions in the oropharyngeal and hypopharyngeal airways over both the short and long term. Park et al\(^1^4\) indicates a significant decrease in pharyngeal depth and a significant posterior movement of the hyoid bone were noted after mandibular setback surgery using lateral cephalometry.

Volumetric analysis by CT showed that the oropharynx decreased after mandibular setback surgery. However, the volume and the axial section area of the airway in the CT images did not change significantly after mandibular setback surgery. Results of CT measurements differed from those of lateral cephalometric radiography and this might be due to a different head posture while taking the image. Muto et al.\(^1^5\) reported a change of 10° in head posture resulting in decrease of posterior airway space by up to 4 mm.

In our study, we further utilized 3D computer tomography to quantify the airway volume changes and provide more precise measurements. CT scans have numerous advantages over traditional plain radiographs, including improved visualization of soft tissue and air, which allows for more accurate airway morphology measurements. Compared with CBCT which is taken in standing posture, the medical CT was taken when patient was in supine position which is similar to sleeping.

Table III provides important insights into the changes in hard tissue movement resulting from surgical intervention. The increases in the maxilla advancement indicate that the surgical intervention may have improved the position of the maxilla relative to the anterior cranial base. The advancement of the velum
and velopharyngeal muscles caused by the Le Fort I osteotomy might be the reason for partly increasing the upper airway\textsuperscript{16}. The amount of point A advancement is more correspond to our surgery design compared with ANS, which is usually trimmed by surgeon during Lefort I osteotomy for maxilla advancement to prevent and reduce the rotation of nasal tip in upward direction\textsuperscript{17,18}. Similarly, the decreases in mandible setback suggest that the surgical intervention may have improved the position of the mandible relative to the anterior cranial base.

Table IV and V provide important information on the impact of surgical intervention on the airway volume. The increases in the upper and oropharyngeal airway volumes suggest that the surgical intervention may have improved airway passage in these regions. In contrast, the decrease in hypopharyngeal airway volume may indicate that the surgical intervention had a negative effect on airway passage in this region.

Table V showed a decrease in the hypopharyngeal airway volume as a result of mandibular setback procedures, except for cases 26 and 27. Another study by Kawamata et al\textsuperscript{19} used computed tomography to assess the morphological changes in the airway after mandibular setback surgery for prognathism. They found a downward and posterior displacement of the hyoid bone postoperatively and a positive correlation between the amount of mandibular setback and the reduction of the lateral width of the pharyngeal airway and the amount of hyoid bone displacement. In our study, we found a high positive correlation between the hypopharyngeal airway volume and the setback of point B ($r = 0.73$) and a moderate positive correlation with the setback of Pogonion ($r = 0.66$). Cases 26 and 27 were exceptions, where the amount of maxilla advancement and mandible setback were almost the same, resulting in an increased hypopharyngeal airway volume postoperatively rather than a decreased volume.

As for oropharyngeal airway volume change in our study, the results were highly variable. Nevertheless, we found that patients with decreased oropharyngeal airway volume also had decreased total airway volume. To further analyze the effect of mandible setback on airway volume, the patients were divided into two groups (group A and group B) based on post-surgical airway volume change. Results from the statistical analysis showed a significant difference in the movement of point B ($P = 0.023$) and Pogonion ($P = 0.020$), with a $P$ value of less than 0.05 being considered statistically significant. Our findings suggest that patients with a setback of more than 6mm in Point B and Pogonion are more likely to experience decreased total airway volume. Demetriades et al.\textsuperscript{20} demonstrated a higher incidence of OSA related to mandibular setback surgery greater than or equal to 5 mm in mandibular setback surgery (one jaw) group compared to two jaw surgery group, however Uesugi et al.\textsuperscript{21} found no significant difference. Kamano et al.\textsuperscript{22} showed that a mandibular setback mean of $9.05 \pm 0.17$ mm had no correlation to decreased volumetric airway at after 6 months. Hong et al.\textsuperscript{23} reported mandibular setback surgery in both one and two jaws resulting in decreased volumetric airway.

In addition, our findings indicated that mandible setback surgery can result in a reduction of the hypopharyngeal airway volume. This reduction is due to the backward displacement of the mandible and the subsequent narrowing of the hypopharynx. As the mandible, hyoid bone, tongue base and pharyngeal
walls are interrelated by their muscles and ligaments, mandibular setback can result in a reduction in the hypopharyngeal airway diameter. This reduction can increase the velocity of airflow and decrease intraluminal pressure, leading to further narrowing of the pharyngeal airway. In extreme cases, it can result in complete pharyngeal obstruction, which has been linked to an increased risk of Obstructive Sleep Apnea (OSA).

In the traditional surgical plan for orthognathic surgery, anterior-posterior discrepancies are corrected by advancement or setback of the jaw along the existing occlusal plane. This procedure, however, often fails to produce an ideal result of aesthetics especially in Asians who have a preexisting dentoalveolar protrusion. Therefore, alternative treatment designs should be considered. Reyneke et al. suggested that an alteration of the occlusal plane could be an alternative. A change of the occlusal plane based on the clockwise rotation of the maxillomandibular complex (MMC) could be a better solution to overcome the limits of simple advancement and setback of the jaw along the existing occlusal plane, which is similar to the surgery design in our study. Choi et al. indicated that the posterior pharyngeal airway space is decreased somewhat immediately after the orthognathic surgery of Class III patients, this loss could be restored as time passes after soft-tissue adaptation and subsidence of swelling. In addition, because the preoperative airway space is enlarged in a class III dentofacial deformity, the posterior pharyngeal airway after a clockwise MMC rotation does not show a significant decrease compared with the normal airway space at the naso- and oropharynx level at 6 months postoperation.

Moreover, there are large individual differences in the airway volume. The average airway volume in our study was $16,655.7 \pm 5,380.2 \text{ mm}^3$. Saati et al. indicated that males have significantly larger pharyngeal volume. Buchanan et al. showed the volumetric airway of normal subjects (non-surgery) was $13,229.58 \pm 4,499.83 \text{ mm}^3$ compared to $8,977.43 \pm 3,360.29 \text{ mm}^3$ in OSA patients. Shokri et al. reported the average volumetric airway was $19,773.8 \text{ mm}^3$ and different skeletal patterns even showed significantly different volumes. In our study, Patients with larger initial airway tend to have smaller decrease in airway volume after orthognathic surgery.

However, further studies are needed to verify this conclusion and to determine the optimal amount of maxilla advancement and mandible setback that would result in the best balance between correcting the skeletal Class III pattern and maintaining a patent airway. In addition, long-term follow-up is also important to evaluate the stability of the airway volume changes after surgery. The findings of our study provide valuable information for clinicians in considering the trade-offs between correcting the skeletal Class III pattern and maintaining a patent airway in patients undergoing mandible setback procedures.

5. Limitation

The limitations of this study include a small sample size, and lack of control of the inspiratory or expiratory phase during the CT scan. Long-term follow up data may be helpful to compare the results between patients with reduced post-surgical total airway volumes. In addition, patients with smaller initial
airway volume could have been compared with patients with larger one to investigate whether there
would be significant difference between the groups after mandibular setback surgery.

6. Conclusion

This study provides evidence that 2-jaw surgery can be an effective intervention to prevent narrowing of
the upper airway in the correction of Class III skeletal pattern. The results suggest that proper surgical
design is crucial to achieve optimal outcomes, particularly for patients with smaller initial airway.
Specifically, our findings suggest that excessive mandibular setback should be avoided in the surgical
plan to prevent airway narrowing. These findings have important implications for orthodontists and
maxillofacial surgeons, providing them with valuable information for improving surgical planning and
patient outcomes.

Declarations

Ethics approval and consent to participate

Written informed consent was obtained from all the patients before enrollment in the study. This study
has been carried out in accordance with The Code of Ethics of the World Medical Association
(Declaration of Helsinki) and has been approved by the Institutional Review Board of the Chang Gung
Medical Foundation (IRB: 202101949B0C501)

• Consent for publication

All study participants gave their informed consent to the publication of the data in open access journal

• Availability of data and materials

The datasets supporting the conclusions of this article are included within the article

• Competing interests

The authors have no competing interests as defined by BMC, or other interests that might be perceived to
influence the results and/or discussion reported in this paper.

• Funding

This research did not receive no external funding.

• Authors’ contributions

Yu-Jen Chang contributed to the design of the work. Jui-Pin Lai contributed to the acquisition of the data
and surgical planning. Tzu-Chuan Hsu prepared the manuscript and the analysis of the data under the
supervision of Yu-Jen Chang and Shiu-Shiung Lin. All authors reviewed and approved the final manuscript.

• Acknowledgements

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References


**Tables**

**Table I: Patient Characteristics**

<table>
<thead>
<tr>
<th>Numbers of patients</th>
<th>Age of surgery</th>
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<tr>
<td>Male</td>
<td>22.2 ± 3.8 y/o</td>
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<tr>
<td>Female</td>
<td>22.3 ± 5.2 y/o</td>
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<tr>
<td>Total</td>
<td>22.4 ± 4.6 y/o</td>
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**Table II: Definitions of Landmarks (Houston, 1983)**
Table III: The following table shows the 3D distance changes of 6 landmarks between the pre-surgery and post-surgery images. These measurements provide a quantitative assessment of the skeletal changes resulting from the orthognathic surgery.

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Mean ± SD</th>
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<tr>
<td>△ANS</td>
<td>2.70± 0.96</td>
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<td>△A</td>
<td>3.12 ± 0.85</td>
</tr>
<tr>
<td>△U1</td>
<td>4.10 ± 1.87</td>
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<td>△B</td>
<td>-6.90 ± 2.00</td>
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<tr>
<td>△Pog</td>
<td>-7.23 ± 2.00</td>
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<td>△L1</td>
<td>-6.54 ±2.53</td>
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</table>

Abbreviation: T0, pre-treatment (1 month before OGS); T1, post-treatment (6 months after OGS); △, represent the distance change from T0 to T1 ; N, nasion; ANS, anterior nasal spine; Point A, subspinale; Point B, supramentale; Pog, pogonion, U1, incisor superius, L1, incisor inferius(detailed definition can see in Table II); the positive value represents of advancement, and the negative value represents of setback.
Table IV: The table presents the changes in the volume of the upper airway, oropharyngeal airway, and hypopharyngeal airway in three different regions of the pharyngeal airway. The pre-surgery (T0) and post-treatment (T1) values are presented, along with the differences between the two measurements. The results show that the upper airway and oropharyngeal airway volumes increased after surgery, while the hypopharyngeal airway volume decreased.

<table>
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<tr>
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<th>T0</th>
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<tr>
<td></td>
<td>Mean ± SD</td>
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<td>Oropharyngeal airway</td>
<td>6850.0 ± 2319.6</td>
<td>7186.4 ± 3029.4</td>
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<td>Hypopharyngeal airway</td>
<td>4961.3 ± 1780.6</td>
<td>3873.9 ± 1372.8</td>
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<tr>
<td>Total Volume</td>
<td>15427.6 ± 4519.6</td>
<td>16655.7 ± 5380.2</td>
<td>1228.1 ± 3060.2</td>
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Abbreviation: T0, pre-treatment (1 month before OGS); T1, post-treatment (6 months after OGS); detailed interpretation of the airway can see in Figure 2.

Table V: 3D Pharyngeal airway volume changes$^{\text{mm}^3}$ in individual cases. A positive value indicates an increase in volume, while a negative value indicates a decrease. It can be observed that all cases experienced an increase in the upper and oropharyngeal airway volume, except for Case-10, which showed a decrease in the hypopharyngeal airway volume. Cases with larger mandibular setback (Cases 2, 5, and 9) generally had a greater increase in upper and oropharyngeal airway volume compared to cases with smaller setback (Cases 1, 4, 7, and 10). Case-8, which had a relatively small mandibular setback, showed the least increase in upper and oropharyngeal airway volume among all cases.
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**Average**: 3616.3, 6850.0, 4961.3 | 5595.4, 7186.4, 3873.9 | 1979.1, 336.4, 1087.5

**SD**: 1469.8, 2319.6, 1680.6 | 1788.0, 3029.4, 1372.8 | 1028.6, 2144.9, 705.6

**Abbreviation**: T0, pre-treatment (1 month before OGS); T1, post-treatment (6 months after OGS); detailed interpretation of the airway can see Figure 2.

Table VI: This table shows the correlation between the changes in 3D pharyngeal airway volume and the 3D distance changes of six landmarks in individual cases.
Based on the detailed 3D distance changes of 6 landmarks in Table III and the changes in airway volume in three regions as shown in Table IV and Table V, we derived the following correlation results.

Abbreviation: N, nasion; ANS, anterior nasal spine; Point A, subspinale; Point B, supramentale; Pog, pogonion, U1, incisor superius, L1, incisor inferius

Interpretation of Pearson correlation:

* Negligible correlation (0.00~0.30);

** Low positive correlation (0.30~0.50);

*** Moderate positive correlation (0.50~0.70);

**** High positive correlation (0.70~0.90)

**Figures**
The 23-year-old male patient (Case-12) with mandibular prognathism underwent a Lefort I osteotomy for maxillary advancement and a bilateral sagittal split osteotomy (BSSO) for mandibular setback to correct the skeletal discrepancy and improve the patient's facial esthetics and functional outcomes.

Figures A-D depict the patient's facial and dental appearance before surgery, demonstrating the significant mandibular prognathism and malocclusion. The patient had an anterior cross-bite, and a Class III skeletal pattern.

Figures E-H show the same patient six months after the surgery, with remarkable improvement in both facial profile and occlusion. The maxilla has been advanced, and the mandible has been setback, resulting in a harmonious facial balance and proper occlusion. The anterior cross-bite has been corrected, and the overjet and overbite have been normalized.

The patient reported significant improvements in speech, chewing, and breathing, and no postoperative complications were observed during the follow-up period.
Figure 2

This figure presents a midsagittal view of the different regions of the segmental airway in Case-2. The airway is divided into three regions, each represented by a different color:

1. Upper airway (in red color): This region extends from the posterior nasal spine (PNS) to the most inferior point of the first cervical spine (C1).

2. Oropharyngeal airway (in green color): This region is located between the first cervical spine (C1) and the second cervical spine (C2), extending from the most inferior point of the first cervical spine to the most anterior inferior point of the second spine (C2).
3. Hypopharyngeal airway (in blue color): This region is located between the second cervical spine (C2) and the third cervical spine (C3), extending from the most anterior inferior point of the second spine (C2) to the most anterior inferior point of the third spine (C3).

By using these landmarks, we are able to quantify and compare changes in different regions of the airway before and after surgical intervention. This information is crucial for understanding the effects of treatment on airway patency and for developing optimal treatment plans to improve patient outcomes.

![Diagram of pharyngeal airway volumes](image)

**Figure 3**

The 3D model images show the superimposition of pharyngeal airway volume in Case-2, with the different regions (Upper airway, Oropharyngeal airway, Hypopharyngeal airway) represented in different colors, as shown in Figure 2. The post-surgical upper airway and oropharyngeal airway volumes increased, while the post-surgical hypopharyngeal airway volume decreased. The time points shown are pre-surgery (T0), which was 1 month before OGS, and post-treatment (T1), which was 6 months after OGS.
Figure 4

Both the presurgical and postsurgical images were taken at specific times, with the presurgical image taken one month before orthognathic surgery (T0), and the postsurgical image taken six months after the surgery (T1).
a, we can see the presurgical 3D model of the skull of Case 12, with various points labeled to indicate anatomical landmarks. These points include pre-N, pre-ANS, pre-A, pre-B, pre-Pog, pre-U1, and pre-L1.

In Figure 4b, we can see the postsurgical 3D model of the same skull, with additional points labeled to reflect changes resulting from the orthognathic surgery. These points include post-N, post-ANS, post-A, post-B, post-Pog, post-U1, and post-L1.

Figure 4c shows the superimposition of the presurgical and postsurgical 3D models, allowing for a direct comparison of the changes resulting from the surgery.