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Original Article

Assessment of nasal respiration and three-dimensional airway volume changes in orthognathic surgery patients

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A B S T R A C T

Objectives: The aim of this study was to evaluate the effect of maxillary movements in orthognathic surgery on nasal airway volume change and its correlation with airflow and resistance.
Materials and methods: This study included 25 patients (8 male, 17 female) with Class II (6 patients) or Class III (19 patients) malocclusion. All patients underwent Le Fort I and bilateral sagittal split ramus osteotomy. Nasal airflow and resistance were measured by using rhinomanometry and acoustic rhinometry pre and six months post-operatively. Nasal volume was measured using computed tomography before surgery and six months after surgery.
Results: Nasal volume increased in 10 out of 11 patients with CCW (counterclockwise) rotation and decreased in 1 patient while, nasal volume increased in 5 patients with CW (clockwise) rotation and decreased in 9 patients. Superior nasal airway volume increased significantly, while the effects on nasal flow and resistance were not significant. Additionally, no significant correlation was found between airway volume changes and variations in airflow and resistance.
Conclusion: CCW rotation in orthognathic surgery patients significantly increased superior nasal airway volume but did not improve nasal airway flow and resistance

1. Introduction

Orthognathic surgery is a procedure performed to correct dentofacial deformities. The main purpose of this surgery is to improve patients' aesthetic appearance, occlusion, and function [1]. Surgery also effects the surrounding soft tissues, including the muscles attached to the jaws and pharyngeal walls, leading to significant volume changes in the pharyngeal airway. Additionally, different movements during surgery have varying effects on nasal and labial morphology [2,3].

Rhinomanometry and acoustic rhinometry measurement devices have been used in numerous studies to evaluate changes in the nasal airway following orthognathic surgery [4]. In clinical practice, degree of nasal obstruction is generally based on the subjective evaluation of the patient. However, the reliability of such statements is questionable [5,6]. Nasal airflow and resistance measurements represent an objective and quantitative assessment of nasal patency. Acoustic rhinometry and rhinomanometry are the most reliable and widely used methods to evaluate these parameters [7]. Rhinomanometry measures nasal airflow and transnasal pressure loss during breathing, providing essential data on nasal resistance and airflow patterns [8]. Acoustic rhinometry, a rapid method requiring minimal patient cooperation, measures the cross-sectional area and volume in different areas of the nose based on acoustic wave reflection on the nasal walls. These measurements are expressed graphically, relating the cross-sectional area to the distance within the nasal cavity. It has been reported that as the cross-sectional area decreases, nasal resistance increases in a non-linear manner [9].

Another method for evaluating postoperative volumetric results of upper airway measurements is through tomography images. Computed tomography is a convenient and reliable diagnostic tool for airway evaluation because it can obtain three-dimensional (3D) airway images. Additionally, computed tomography can be used to calculate the volume of these 3D shapes, providing detailed volumetric analysis [10]. The aim of this study is to evaluate changes in nasal airflow and nasal airway resistance using rhinomanometry and acoustic rhinometry, and to assess nasal airway volume using computed tomography, both preoperatively and postoperatively.

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2. Materials and methods

2.1. Study design and participants

This prospective study initially included 28 patients, but was completed with 25 patients (8 male, 17 female) with Class II (6 patients) or Class III (19 patients) malocclusion. Their ages ranged from 18 to 40 years, with a mean age of 26.7 years. The study received approval from the Istanbul Medipol University Clinical Research Ethics Committee (Approval No: E-10,840,098−772.02−869) and adhered to the principles outlined in the Declaration of Helsinki regarding medical protocol and ethics. All participants provided informed consent.

2.2. Surgical procedure

All patients underwent a combination of one-piece Le Fort I osteotomy and bilateral sagittal split ramus osteotomy. The distinction between Class II and III patients was analysed by computed tomography. All surgeries were performed by the same surgical team between January 2021 and January 2022.

Le Fort I osteotomy was performed through a circumvestibular incision between the first premolars. The perinasal muscles were carefully dissected. The soft tissues were dissected as minimally as possible without laceration, and after down-fracture of the maxilla the septum was stabilised without deviation. The fixation of the maxilla was followed by the reattachment of the dissected perinasal muscles to minimize the effect of change in the alar base, during the suturing of the incision. No additional procedures such as inferior turbinate resection, nasal septum resection, nasal septum shortening, and piriform aperture shaping were performed in this study.

Individuals with a history of allergy, nasal surgery, or medication, as well as those with a nasal and/or paranasal sinus infection or a major structural nasal disorder such as septal deviation or turbinate hypertrophy, were excluded from the study.

2.3. 3D computed tomography evaluation

Preoperative computed tomography images of the patients in their natural head position were evaluated for surgical treatment planning. Routine postoperative follow-up CT scans were standardised and recorded at the sixth months after surgery, maintaining each patient's natural head position.

Pre- and postoperative nasal volume measurements were conducted from the nostrils to the space between the posterior nasal spine and the sphenoid rostrum line. This measurement includes the total volume of the nasopharynx and nasal cavity, referred to as superior nasal airway volume, and also encompasses the paranasal sinuses (Fig. 1). The measurement termed as total airway volume included the retropalatal and retroglossal volumes in addition to the superior nasal airway volume, extending to the retropharyngeal area up to the C4 cervical vertebra (Fig. 2). Computed tomography images were saved in DICOM format, and three-dimensional volume calculations were performed using 3D Slicer 5.6.2 software (The Slicer Communiy, http://www.slicer.org)

2.4. Nasal air flow measurements

Preoperatively, recordings were taken using a rhinomanometer and acoustic rhinometer to evaluate the nasal airflow and objectively measure nasal airway resistance. Acoustic rhinometry is based on sound reflection analysis. Three days before surgery, cross-sectional areas for the right and left nasal passages were calculated with a rhinometer (A1, GM Instruments Ltd., Kilwinning, UK) (Fig. 3). The sound pulse (150−10,000 Hz) generated by a spark propagates through the sound tube and is reflected due to local acoustic impedance changes, and the cross-sectional area changes are determined by comparing the incident and reflected waves. These reflected waves are converted into an area-distance graph in a computer environment and the amount and location of the stenosis is calculated from the

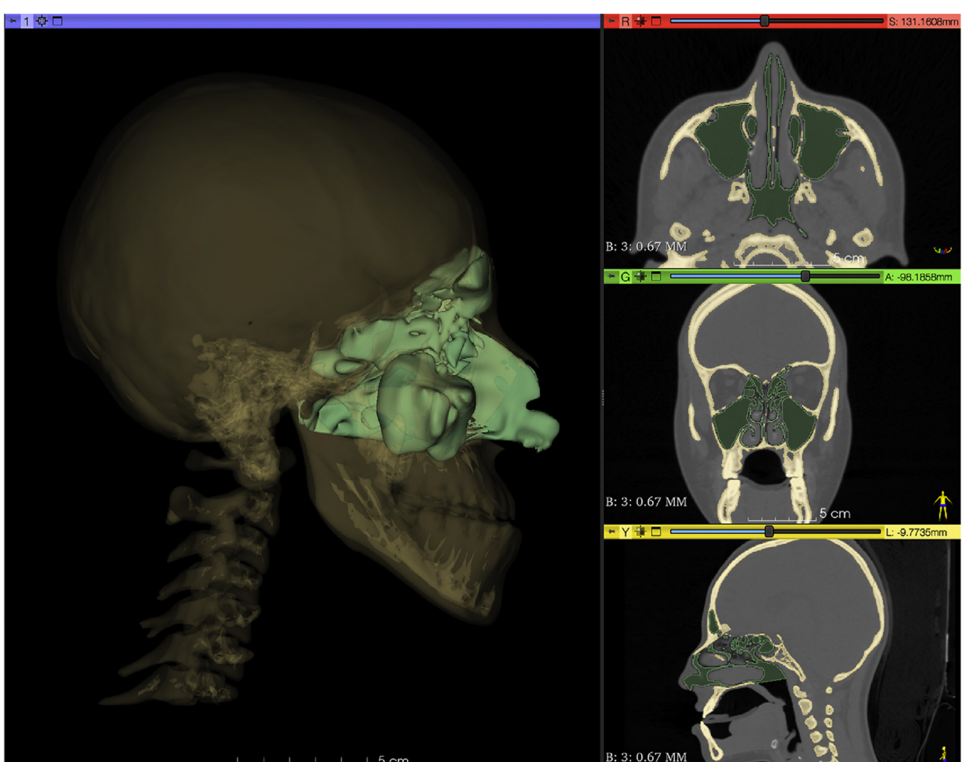

Fig. 1. 3D superior nasal airway volume.

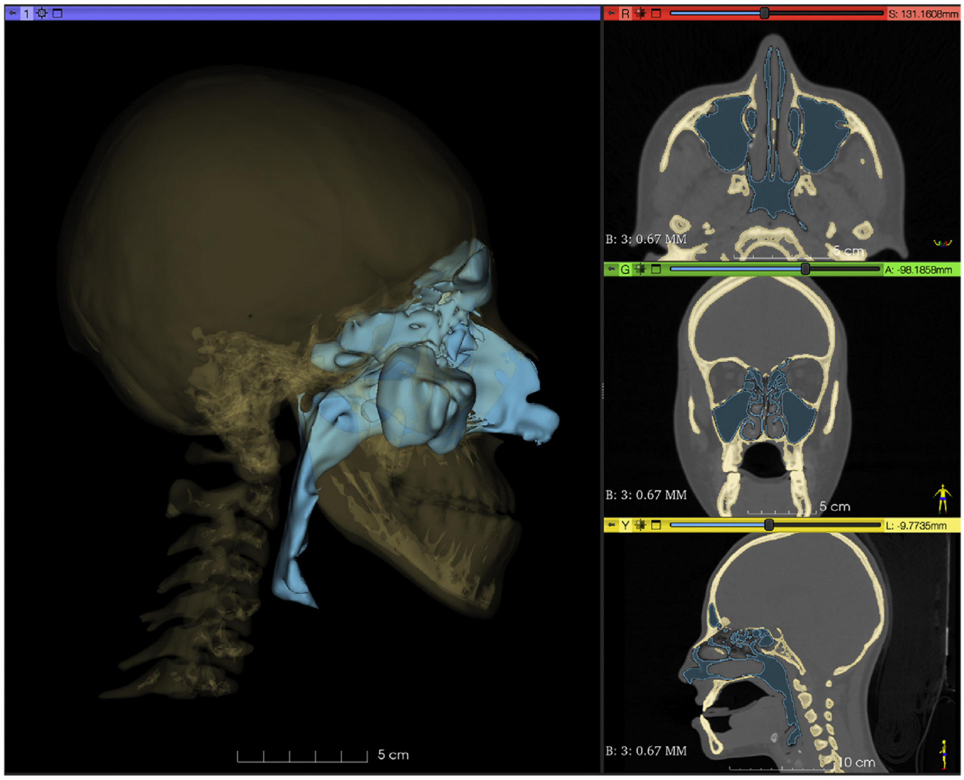

Fig. 2. 3D total airway volume.

intensity, phase and latency of the acoustic signals sent into the nasal cavity. The MCA (mean cross-sectional area) of the nasal cavities was calculated by utilizing changes in acoustic impedance. By measuring the time difference between the transmitted and reflected sound waves, the location of the cross-sections is determined. MCA 1 represents the level of the nasal isthmus and MCA 2 represents the inferior or middle turbinate head. For each patient, an anatomically compatible nose piece was used to ensure the probe was fully inserted into

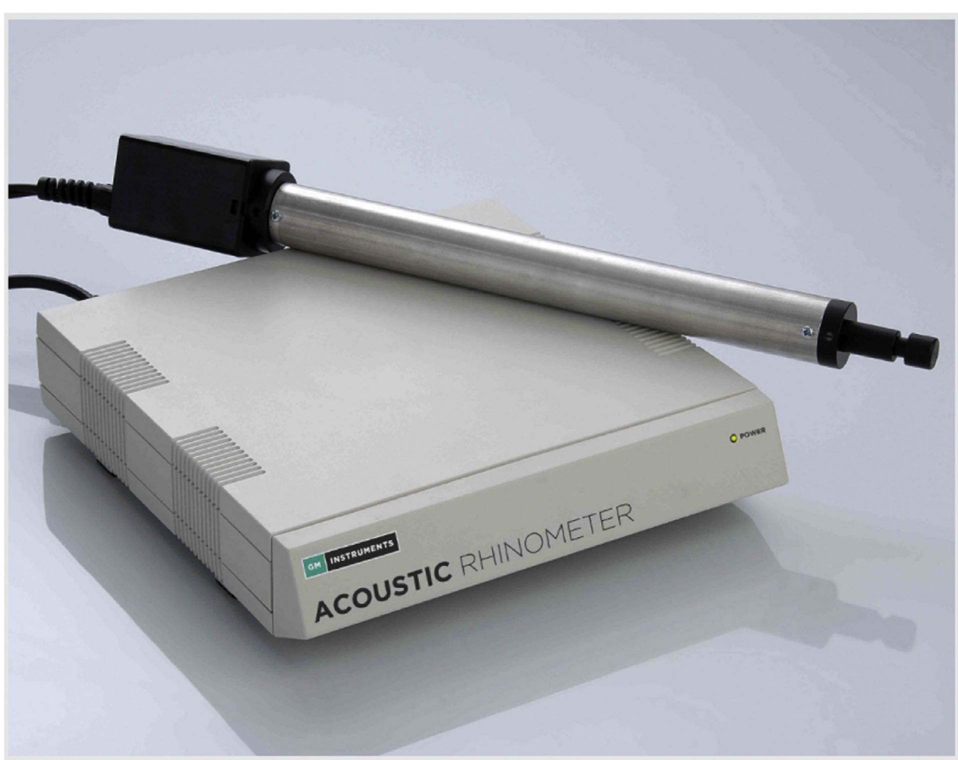

Fig. 3. Acoustic rhinometry (A1, GM Instruments Ltd., Kilwining, UK).

the patient's nose and sat at a 45-degree angle with the base of the nose. The calculated criteria were evaluated on the acoustic rhinogram.

Three days before surgery, active anterior rhinomanometry was performed using a computerised rhinomanometry system (NR6, GM Instruments Ltd., Kilwinning, UK) (Fig. 4). Mini-recordings were taken for 3 to 5 breaths under a constant transnasal pressure of 150 Pa in the sitting position, with the mouth closed and during quiet breathing. In accordance with the recommendations of the International Rhinomanometry Standardisation Committee, this pressure level was chosen to ensure laminar airflow during inspiration. Nasal airflow was measured with a flowmeter attached to the end of a mask that was tightly fitted to the face, free of air leakage. In this procedure, one nasal passage is closed while the airflow through the other passage was measured with a flowmeter connected to the end of the mask. During inspiration and expiration, the airflow data obtained from one nostril and the transnasal pressure data measured from the opposite side were combined and recorded as 'pressure-airflow' curves. Total nasal airflow and nasal airway resistance of both nasal cavities were measured, and values were expressed in pascals per cubic centimetre per second. The same examination protocol was repeated six months after surgery for each patient. Fig. 5. shows rhinomanometry of one patient.

The acoustic rhinometry and rhinomanometry equipment were calibrated for each new measurement to avoid possible technical errors. The results of the acoustic rhinometry measurements were calculated with the NARIS V 2.8.0.469 software (NARIS B.V., https://www.naris.com). Both tests were performed in all patients by the same experienced physician in accordance with the recommendations of the "Acoustic Rhinometry and Rhinomanometry Consensus Report" [11].

2.5. Statistical analysis

All data were statistically analyzed by using SPSS (Version 26.0, SPSS Inc., Chicago, IL, USA). In statistical comparisons, the Chi-Square test was used for categorical data, and the suitability of continuous data for normal distribution was assessed using the Kolmogorov-Smirnov test. Despite the normal distribution of continuous data, non-parametric tests (Kruskal-Wallis and Mann-Whitney U tests) were used for intergroup comparisons because these tests are less sensitive to small sample sizes and can handle outliers more effectively than parametric tests. Spearman correlation analysis was used to evaluate correlations, and the Wilcoxon signed-rank test was used for intra-group comparisons. For statistical significance, a p-value below 0.05 at 95 % confidence interval was considered significant.

2.6. Power analysis

Power analysis was performed using the G*Power (v3.1.9.7) software to determine the sample size. The power of the study is expressed as 1-β (Type 2 error probability), with general studies requiring 80 % power. Based on Cohen's effect size coefficients and assuming a medium effect size (d = 0.5) for evaluations within a dependent group, it was determined that at least 25 participants were needed at an α = 0.05 level. From the 28 patients initially considered, 25 met the inclusion criteria; three patient was excluded due to a sinusitis diagnosis. Five randomly selected patients were re-evaluated to determine the level of error in the measurements.

3. Results

From the initial 28 patients, 25 met the inclusion criteria; three patients were excluded due to a sinusitis diagnosis. Among the 25 patients, 11 underwent maxillary advancement and impaction, while the remaining 14 had maxillary advancement and vertical lengthening.

The CW occlusal plane was rotated in 14 patients, while the CCW occlusal plane was rotated in 11 patients. Age and gender distributions did not significantly differ between the two groups ($p > 0.05$).

The mean maxillary advancement across all patients was 4.18 ± 2.17 mm. Mean impaction was 1.28 ± 1.54 mm, and mean

Fig. 4. Rhinomanometer (NR6, GM Instruments Ltd., Kilwining, UK).

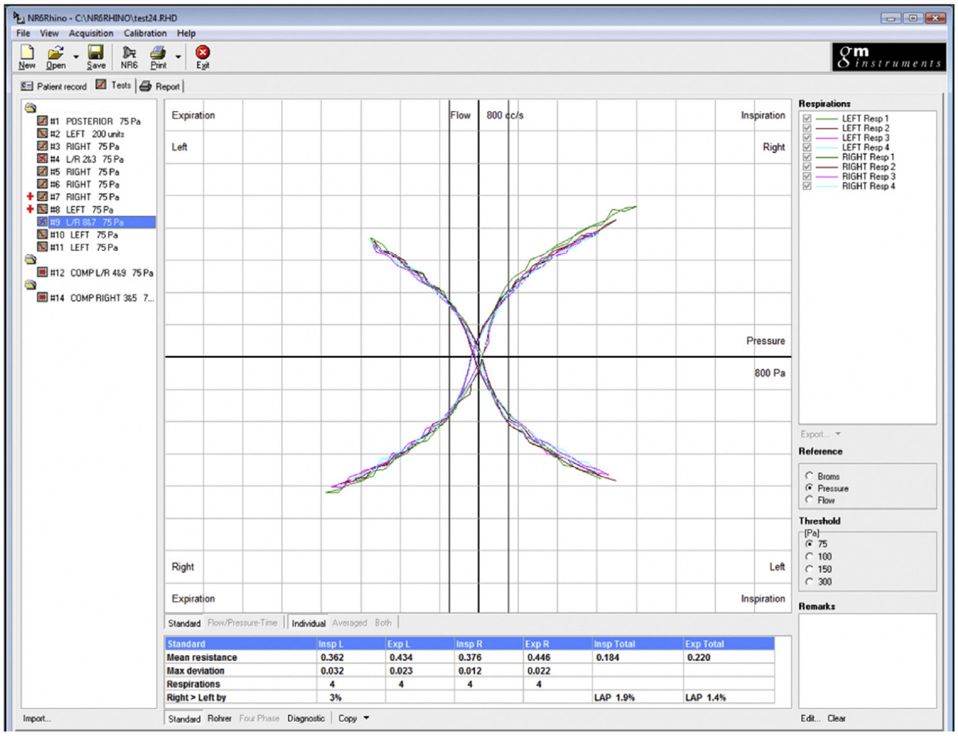

Fig. 5. Postoperative rhinomanometry of one patient. The graph shows the nasal airflow and resistance measurements taken after the surgical procedure.

vertical lengthening was 1.11 ± 1.62 mm. There was no significant correlation between impaction, vertical lengthening and nasal volume, nasal airflow and rhinomanometer resistance ($p > 0.05$).

Superior nasal volume increased in 10 patients who underwent CCW rotation and in 5 patients who underwent CW rotation and this difference was statistically significant ($p < 0.05$).

Mean preoperative superior nasal airway volume was 95.73 ± 22.02 cm^3 which increased to 99.27 ± 25.16 cm^3 postoperatively, this difference was significant. ($p < 0.05$).

Mean preoperative rhinomanometric resistance was 0.45 ± 0.3, which decreased postoperatively to 0.38 ± 0.25, though this reduction was not statistically significant ($p > 0.05$). Acoustic rhinometry showed a decrease in MCA 1 from a preoperative 0.48 ± 0.18 to a postoperative 0.45 ± 0.16, and a decrease in MCA 2 from 0.59 ± 0.23 to 0.57 ± 0.2 postoperatively; both changes were not statistically significant ($p > 0.05$).

Preoperative main nasal airflow was 548.56 ± 112.8 ml/s, which increased to 552.76 ± 157.07 (ml/s) postoperatively, but this increase was not statistically significant ($p > 0.05$). No significant correlations were found between pre- and postoperative MCA1, MCA2, rhinomanometric resistance, nasal volume and nasal airflow ($p > 0.05$).

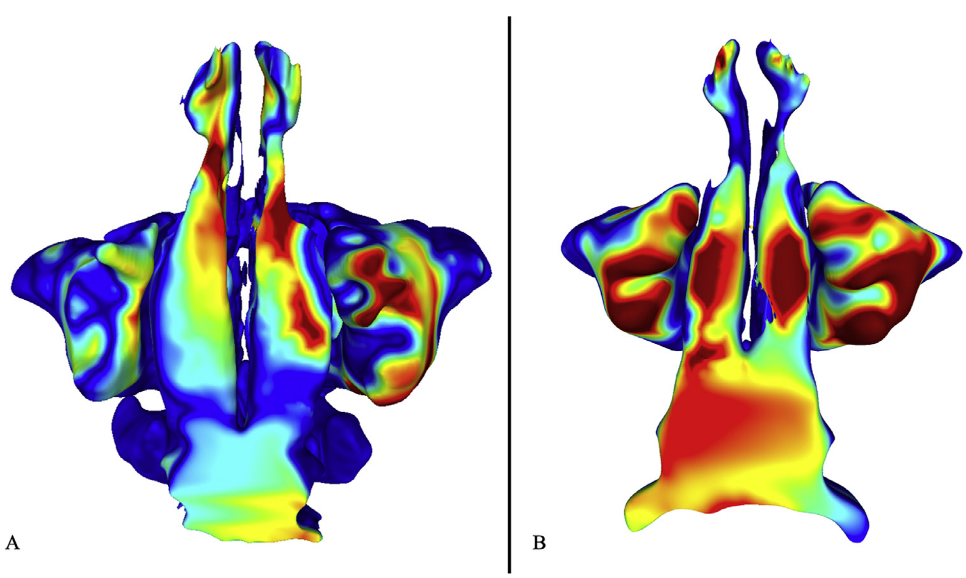

Fig. 6. Inferior view of superior airway volume heatmap, showing preoperative and postoperative overlay. The red regions indicate areas with the most significant changes, while the green and blue regions indicate areas with lesser changes. A- Clockwise rotation: The posterior nasal passage shows no significant change, while there is an increase in the pharyngeal area, attributed to maxillary advancement. B- Counterclockwise rotation: There is a notable increase in the volume of the posterior nasal passage.

Table 1
Analysis of differences in nasal volume, nasal airflow, and rhinomanometer resistance based on occlusal plane rotation.

	CW (n:14)		CCW (n:11)		p-Value
	Mean	SD	Mean	SD	
Total Airway Volume Difference (cm^3)	−0.63	9.06	8.84	3.55	**0.009**
Superior Nasal Airway Volume Difference (cm^3)	−2.11	6.99	4.44	5.05	**0.025**
Nasal Airflow Difference (ml/s)	11.24	140.24	−4.77	203.07	0.582
MCA1 Difference	−0.03	0.18	0.00	0.20	0.467
MCA2 Difference	−0.03	0.21	−0.02	0.26	0.737
Rhinomanometer Mean Resistance Difference	−0.09	0.31	−0.04	0.40	0.572

Superior nasal airway volume and total airway volume changes with occlusal facial rotation were significant ($p < 0.05$). (Table 1).

Table 2
Comparative analysis of nasal airflow and resistance differences based on volume No significant correlation was found between changes in volume and variations in nasal airflow and rhinomanometry resistance ($p > 0.05$) (Table 2).

	Volume Difference Decrease (n:12)		Volume Difference Increase (n:16)		p-Value
	Mean	SD	Mean	SD	
NasalAirflow Difference	5.53	165.63	9.21	174.18	0.955
Resistance Difference	−0.11	0.31	−0.05	0.37	0.568

Furthermore, the intra-rater reliability, as determined by intraclass correlation coefficients, exhibited high levels of agreement for all measurements (97.8 %−100 %, $P = 0.000$), thereby demonstrating the evaluator's consistent measurement accuracy (Tables 2 and 3).

4. Discussion

Predicting changes in nasal function parameters in patients following maxillary surgery is challenging. Various movements applied to the maxilla during Le Fort I osteotomies influence nasal morphology [12]. Rhinomanometry and acoustic rhinometry are reliable and objective methods for assessing the functional and geometric changes in the nasal cavity. Kunkel & Hochban were the first to describe the effect of maxillary movement on nasal volume assessed by acoustic rhinometry [4].

The findings of this study indicate that CCW rotation can enhance nasal airway function. Specifically, superior nasal airway volume increased in 10 of 11 patients who underwent CCW rotation. The observed increase in total airway and superior nasal airway volume was statistically significant, indicating that CCW rotation effectively enhances overall airway volume.

The study by Karim et al. showed a significant increase in postoperative nasal airway volume, whereas the mean total nasal airflow remained almost unchanged [13]. Similarly, in our study, while the increase in nasal airway volume was significant, the change in nasal airflow and resistance was not. Koç et al. aimed to evaluate the effects of different maxillary movements on nasal anatomy and airflow, they reported an increase at nasal cavity volume in isolated maxillary advancement [14]. Ha et al. mentioned that maxillary impaction and advancement decrease nasal cavity volume [15]. Turvey et al. found that superior repositioning of the maxilla usually results in decreased nasal resistance [16]. However, Erbe et al. found no change in nasal airway flow after Le Fort I impaction or advancement [17]. Spalding et al. reported that nasal resistance cannot be predicted for any individual patient [18].

None of these studies consider the occlusal plane rotation. In this study, we specifically emphasize the role of occlusal plane rotation by separately evaluating both upper nasal airway volume and total airway volume. Our results demonstrate that while the upper nasal airway volume significantly increased postoperatively, changes in nasal airflow and resistance were not significant, suggesting that occlusal plane rotation primarily influences the anatomical space without markedly affecting functional airflow parameters.

Another study by Hongyu et al. demonstrated significant reductions in maxillary sinus and nasal cavity volumes one year postoperatively following bimaxillary surgery. However, no significant change was observed in nasal function [19]. In contrast, our findings show that Le Fort I advancement significantly increases superior nasal airway volume, but similarly, no significant change was observed in nasal function. The unexpected decrease in nasal cavity and maxillary sinus volumes observed in the previous study could potentially be attributed to postoperative soft tissue hypertrophy or the formation of soft tissue around plates and screws, which narrows the passages and thereby affect volume measurements. We eliminated these possible measurement errors and excluded 3 patients with chronic sinusitis and/or maxillary sinus mucosal hypertrophy at postoperative 6th months.

The significant increase in nasal and total airway volume observed in patients undergoing CCW rotation can be attributed to the anatomical and physiological changes induced by this specific maxillomandibular movement. The surrounding musculature, including the genial and suprahyoid muscles, as well as the soft palate, is typically stretched during CCW rotation. Our study supports these findings, particularly in demonstrating that CCW rotation significantly increases superior nasal airway volume, offering new insights into the benefits of this surgical approach [20]. Mehra et al. reported that double-jaw surgery with CCW rotation resulted in a 47 % increase in pharyngeal airway space at the level of the soft palate and a 76 % increase at the base of the tongue, both corresponding to mandibular advancement [21].

Table 3
Results of superior nasal airway volume measurements for CW and CCW groups.

(cm^3)	Preoperative Mean ± SD	Postoperative Mean ± SD	p-Value
CW(n = 14)	72,07 ± 18,62	69,95 ± 19,45	0,278
CCW(n = 11)	86.35 ± 15	90.79 ± 16	**0.013**

No significant correlation was found between preoperative and postoperative measurements for superior nasal airway volume in the CW group ($p > 0.05$). In contrast, the CCW group showed a significant increase in superior nasal airway volume postoperatively ($p < 0.05$). (Fig. 6).

This study is the first to examine the impact of occlusal plane rotation on superior nasal airway volume and function in patients undergoing maxillary advancement. The findings indicate that maxillary advancement combined with CCW rotation has a positive effect on the airway, significantly increasing superior nasal airway volume, although it does not improve nasal airway flow and resistance. The specific regions where these changes occurred were not identified, and the regions with the most significant volume changes might not coincide with areas of resistance or minimum cross-sectional areas. This lack of detailed regional analysis might explain the absence of correlation between volume changes and resistance and airflow. In contrast, similar advancements and vertical movements in CW rotation do not yield the same beneficial effects on airway volume. This highlights the crucial role of CCW rotation in enhancing nasal airway volume.

The limitations of this study include a relatively small sample size and the lack of consideration for the extent of occlusal plane rotation angles. Future research should include larger samples and varying rotation angles to validate and expand upon these findings.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Hayrunisa Koçyiğit Daştan: Writing – original draft, Software, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Mustafa Temiz:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Sümer Münevveroğlu:** Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Data curation. **Sina Uçkan:** Writing – review & editing, Supervision, Methodology.

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