European Archives of Oto-Rhino-Laryngology

Nasalance and perceived voice changes in patients undergoing septoplasty and turbinate hypertrophy reduction

--Manuscript Draft--

Manuscript Number:	EAOR-D-21-00755R1
Full Title:	Nasalance and perceived voice changes in patients undergoing septoplasty and turbinate hypertrophy reduction
Article Type:	Rhinology (Original Article)
Keywords:	Septoplasty, nasalance, nasal cavity, voice, quality of life, Voice Handicap Index
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Nasalance and perceived voice changes in patients undergoing septoplasty and turbinate hypertrophy reduction

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Abstract

Purpose: The purpose of this study was to investigate the changes in voice nasality after septoplasty and turbinate hypertrophy reduction and to evaluate the effect of these changes on patients' voice - related quality of life.
Methods: Sixty patients with nasal obstruction symptoms caused by septal deviation and inferior turbinate hypertrophy who underwent septoplasty and inferior turbinate hypertrophy reduction and 25 healthy controls were included. Active anterior rhinomanometry and acoustic rhinometry were utilized for the evaluation of nasal patency and nasometry was used for quantitative assessment of nasalance. All participants completed validated questionnaires for assessing nasal obstruction symptom severity, psychological status and the impact of voice performance on their quality of life preoperatively and six months after septoplasty.
Results: Patients presented preoperatively statistically significantly lower nasalance scores and higher VHI scores than controls ($p.<0.05$). Septoplasty and inferior turbinate hypertrophy reduction led to improvement of nasalance for the nasal text and the physical subscale of the VHI scores. Postoperatively, there were no statistically significant differences in nasalance and VHI scores between patients and controls. Significant correlations were found only for the baseline and the postoperative nasalance scores for the nasal text and the total nasal cavity volume ($p.<0.05$). Postoperatively, patients who presented significant improvement of nasal obstruction symptoms and resolution of stress levels were more likely to positively evaluate the impact of their voice quality on their daily life (OR:2.32, 95% CI:1.08 – 5.15, p.=0.041 and OR:3.06, 95% CI:1.15 – 7.04, p.=0.038 respectively).
Conclusion: Septoplasty and inferior turbinate hypertrophy reduction may increase the nasal resonance, but in the long term this change appears not to be significant enough. The severity of nasal obstruction symptoms and psychological status mainly affect the patients' perceptual assessment regarding the effect of voice performance on their quality of life.

Keywords: Septoplasty, nasalance, nasal cavity, voice, quality of life, Voice Handicap Index

Introduction

Voice and speech play a crucial role in social life, allowing individuals to express themselves and to communicate. Voice is mainly produced in the larynx with the vibration of the vocal cords. The acoustic characteristics of voice are determined by the vocal tract that includes various anatomical structures such as the supraglottic larynx, oropharynx, nose and paranasal sinuses, oral cavity, tongue, lips, and palate [1]. The nasal resonance is one of the most important elements of speech quality. The nasal cavity and paranasal sinuses as components of the vocal tract have been considered to play an important role in the resonance of voice [2]. Therefore, obstruction of any segment of the nasal cavity and paranasal sinuses may affect the resonance of the nasal airway and articulation of the voice and may consequently result in a perceptual change of the quality of nasal sound and alteration of the results of voice analysis [3]. Nasal obstruction, one of the most common symptoms of patients examined in a general otorhinolaryngology clinic, may play an important role in the features of voice [4] and can lead to a hyponasal speech by decreasing the transfer action of nasal sounds in the nasal tract [5]. Nasal septal deviation usually accompanied with nasal turbinate hypertrophy is one of the main reasons of nasal obstruction. Septoplasty and turninate reduction is the standard treatment for nasal septal deviation and is among the most commonly performed otolaryngological operations. This surgical procedure aims to widen the nasal passage and to improve nasal patency. Changes in the nasal volumes following septoplasty have been reported to produce substantial changes in nasal resonance and voice quality [1, 4]. These effects highlight the importance of monitoring resonance alterations in individuals with septal deviation and nasal turbinate hypertrophy who undergo surgical treatment. Furthermore, patients, and particularly voice professionals, should be informed about possible changes in voice following surgical interventions on the nasal septum and the nasal turbinates.

Several studies have examined the effects of nasal septal surgery on voice [1, 4, 6 - 18]. We used objective methods of measurement of the nasal patency, anterior rhinomanometry (ARM) and acoustic rhinometry (AR), aiming to evaluate the relationship between nasal resistance and nasal cavity volumes, and nasalance scores in patients who underwent septoplasty and turbinate reduction and to investigate the mechanism for changes in nasal resonance and voice. The purpose of the present study was to evaluate the postoperative nasalance changes, and demonstrate the effect of this procedure on patients' perception of voice. Furthermore, it aimed to investigate potential predictive factors of clinically significant improvement of patients' subjective evaluation of voice after septoplasty and turbinate reduction, such as the severity of nasal obstruction symptoms and patients' psychological status.

Materials and Methods

A prospective case–control study was conducted to evaluate the effects of septal and turbinate surgery on the acoustic parameters of voice. The study protocol was performed in accordance with the Declaration of Helsinki and was approved by the local Institutional Review Board. Written informed consent was signed by all participants. Sixty patients, with nasal obstruction due septal deviation and nasal turbinate hypertrophy and 25 controls with neither nasal obstruction nor nasal–septal deviation and turbinate enlargement were enrolled. The patients were adults younger than 65 years with nasal septal deviation and inferior turbinate hypertrophy diagnosed by anterior rhinoscopy and nasal endoscopic examination and symptoms of nasal obstruction lasting for at least six months. Exclusion criteria comprised any nasal and/or paranasal sinus pathology other than septal deviation, such as chronic rhinosinusitis with or without nasal polyposis, allergic rhinitis, granulomatous diseases, polyposis or neoplastic lesions, an active upper respiratory tract infection, use of nasal decongestants or any other medication for nasal obstruction at the time of the study, any type of organic or neurological pathology related to voice production, a history of previous laryngeal pathology, recurrent laryngitis, hearing loss, speech disorder, mental retardation and craniofacial anomalies such as cleft lip and/or palate or submucosal cleft palate. The presence of a laryngeal disease or a speech disorder could have a negative impact on the subjective evaluation of an individual's voice performance and act as a potential confounding factor affecting the results of the present study. Therefore, patients with these health problems were excluded from the study. We also excluded from the study patients with a history of previous nasal and/or paranasal sinus surgical procedure and other otorhinolaryngological surgery, such as any laryngeal surgery, tonsillectomy, uvulopharyngopalatoplasty, or a combination of these.

A clinical patient history was obtained from each participant including demographic data (age, gender), weight and height and whether they have or not an intensive use of the voice in their professional activity. Patients were preoperatively subject to a detailed ear, nose and throat examination, including anterior rhinoscopy, nasal endoscopy and flexible fiberoptic nasopharyngeal endoscopy to exclude the presence of velopharyngeal incompetence. Computed tomography scanning for nose and paranasal sinuses and skin prick tests (when medically justified) were performed for the identification of those who met the exclusion criteria.

Nasal resistance ($R = \Delta p/Qv$) is defined as the ratio of the transnasal pressure drop Δp (nostrils to choanae) to the volumetric nasal airflow rate Qv [19]. Nasal obstruction is defined as a subjective sensation of insufficient airflow through the nasal cavity and can be anatomical, physiological or of combined aetiology [20]. Voice is the sound produced by human beings by means of lungs and vocal folds and resonated by the cavities of head and pharynx. The definition of voice sound is an articulation made by the vocal apparatus [1]. Speech sound is defined as any one of the smallest recurrent recognizably same constituents of spoken language produced by movement or movement and configuration of a varying number of the organs of speech in an act of ear-directed communication [3]. Nasality is a quality of the voice that is produced by nasal resonance [5]. Nasalance refers to the ratio of nasal acoustic energy to the sum of oral and nasal acoustic energy expressed as a percentage [21].

For objective evaluation of nasal patency among all the participants, active anterior rhinomanometry and acoustic rhinometry were performed. Active anterior rhinomanometry (Homoth – 400, Medizinelektronik GmbH, Belgium) for the assessment of nasal resistance was performed in all participants. Nasal resistances in each nostril were separately measured. Then, total nasal resistance (TNR) was calculated using the standard formula total NR = (right NR x left NR)/(right NR+left NR) [19]. Nasal resistance was measured at standard value of pressure (150Pa). Acoustic rhinometry (Acoustic Rhinometer A1, GM instruments, UK) measurements were performed separately for the two nasal passages, for the assessment of minimal cross-sectional area (MCSA) and volume (VOL) over a length of 5cm into the nasal cavity. Mean values of total minimal cross-sectional area (TMCSA) and total nasal cavity volumes (TVOL) were defined as the average of left and right nasal passage values for minimizing the effect of the nasal cycle [22]. Ten minutes before nasal measurements, each nostril was decongested with two puffs of 0.1% xylometazoline spray to diminish the potential effect of the nasal cycle [22]. Both tests were performed by the same physician in a quiet room with a minimal level of background noise, in accordance with the recommendations of the ''Acoustic Rhinometry and Rhinomanometry Consensus Report'' [23].

For objective assessment of nasal resonance, nasometry measurements were performed at baseline and six months after surgery. Nasometry measurements were made with the Nasometer II (model 6200-3, Kay Elemetrics, Lincoln Park, New Jersey). Calibration, data recording and calculation of nasalance scores were performed according to the manufacturer's instruction manual. The ratio of the acoustic energy output detected from the nasal cavity, for a particular speech passage, over the sum of oral and nasal acoustic energy is expressed as percentage and is referred to as a nasalance score. The value for nasalance can theoretically vary from 0 % (no sound from the nose) to 100 % (all sound from the nose). The following Greek testing materials were utilized: (1) an oral text containing 100% oral sounds; (2) a nasal text containing 23.1% nasals, and (3) an oronasal text containing representative ratios of nasal and oral sounds for spoken Greek, i.e. 8.6% nasals and 91.3% oral sounds [21]. The participants were informed about the test and practiced production of the text before voice recordings were obtained. Only productions of the speech samples that were accurate for both articulation and voicing were included for analysis. The sounds were recorded while these passages were being read, and the nasalance scores of the oral, nasal and oronasal passages were calculated using the nasometry system software. All measurements were made by the same person in a quiet room with minimal interference from ambient sound that could affect the results. The objective nasal measurements and assessments of nasalance were performed preoperatively and six months after surgery.

At the same time-points all subjects also filled in three questionnaires, translated, and validated into the Greek language: the Nasal Obstruction Symptom Evaluation (NOSE) [20, 24], assessing severity of nasal obstruction symptoms, the Short Anxiety Screening Test (SAST) [25, 26] evaluating levels of stress and the Voice Handicap Index (VHI-30) [27, 28] for subjective evaluation of their voice. The NOSE questionnaire was completed by patients before the surgery and at 6 months postoperatively to evaluate the subjective impact of nasal obstruction. NOSE consists of five questions that are rated on a five-point Likert scale from zero to four. The final score ranges between zero (no symptoms) and 100 (severe nasal obstruction). SAST includes 10 questions related to somatic manifestations of stress. Each item is scored from one to four and the total score ranges between 10 and 40, with higher scores being associated with a higher degree of anxiety symptoms. VHI-30 is a validated 30-item questionnaire measuring the functional, physical and emotional handicapping impact of a voice disorder on daily life with three subscales (a functional, a physical and an emotional subscale). The first domain (functional subscale) comprises of statements that describe the effect of a patient's voice on his or her daily activities. The second domain (physical subscale) comprises statements related to the patient's perception of voice output characteristics. The third domain (emotional subscale) shows the person's affective responses to his or her voice disorder. Each domain includes 10 items. Patients rate each question on a five-point scale (0 – 4). Total scores range between 0 to 120 points. A higher score indicates a more severe subjective voice disorder.

All patients underwent septoplasty and inferior turbinate hypertrophy reduction under general anesthesia and were operated by the same surgeon who did not participate in the questionnaires' collection and analysis of data. The septal surgery followed Cottle principles, designed to correct osteocartilaginous deviations, in all patients. The standardized surgical procedure included partial resections and reshaping of the deviated areas of the septum and submucosal radiofrequency tissue ablation for the inferior nasal turbinates' volume reduction. None of the patients had major complications postoperatively.

Statistical Analysis

Statistical analysis was performed using the IBM SPSS Statistics for Windows (IBM Corp., Armonk, NY, USA) version 25.0. Descriptive statistics were obtained; quantitative variables are presented as means with standard deviation (SD) while qualitative variables are presented as frequencies and percentages. Kolmogorov–Smirnov test was employed to check whether data followed a normal distribution. Differences between normally distributed data were assessed with the use of independent sample *t* test and the paired sample *t* for independent and related samples respectively. Mann-Whitney *U* test and Wilcoxon signed-rank test were used for the comparison of the data with not normal distribution. The Chi-square test was applied for differences of qualitative parameters between groups. Spearman's (ρ) correlation coefficients were calculated to determine the strength of the correlations between objective nasal patency measurements and nasalence scores. Univariate linear regression analysis was used for the evaluation of any potential association between the likelihood of clinically significant improvement for VHI score and patients' demographic and clinical characteristics. Clinically significant improvement for each QoL questionnaire was defined as a change of ≥1/2 SD of the baseline score [29]. Odd ratios (OR) and 95% confidence intervals (CI) were estimated as the measure of association between clinically significant improvement for subjective evaluation of patients' voice and all potential prognostic factors. In agreement with other studies, we used as criteria to measure the differences in nasalence and VHI scores, the median postoperative TNR, TMCSA, TVOL, NOSE score, and SAST values. The patients were divided into two groups for five criteria above and below median value for the five following parameters: a) TNR (total nasal resistance), b and c) TMCSA and TVOL (nasal patency), d) NOSE score (obstruction symptoms) and e) SAST values (stress levels). The analysis of the nasalance and VHI scores was based on the comparison between these two groups. A p value of less than 0.05 was determined as the statistical significance level.

Results

The patients' subgroup comprised from 34 males (56%) and 26 females (44%), with a mean age of 32.98 ±11.98 years, and a mean Body Mass Index (BMI) of 25.6±3.2 kg/m^2. The control subgroup included 13 males (52%) and 12 females (48%), with a mean age of 29 ±8.87 years, and a mean BMI of 24.1±2.5 kg/m^2. Twenty participants in the patients' subgroup (33.33%) and 10 in the controls' subgroup (40%) were smokers. Regarding the socio-economic status, in the patients' subgroup 23% had low, 40% medium and 37% high socio-economic status and in controls 25% had low, 35% medium and 40% high socio-economic status. There were no statistically significant differences between the two groups in the age, and BMI ($p>0.05$, for both Mann- Whitney *U* test), gender, smoking habits and socio-economic status ($p>0.05$, for all three, Chi Square test).

Regarding the preoperative nasalance scores, patients presented lower scores (nasalance score for oral, nasal and oronasal text) compared to controls. These differences were statistically significant for the nasalance score for nasal and oronasal text ($p=0.01$ and $p=0.04$ respectively). Patients were found to have statistically significantly higher nasal resistance (TNR) and statistically significantly lower nasal patency (lower TMCSA, TVOL values) compared to controls ($p<0.001$ for all the parameters as demonstrated in Table 1). The patients' group had higher VHI scores (total, functional, physical and emotional) compared to the control group, but the differences were statistically significant only for the VHI total and the VHI physical score ($p<0.05$ for both variables). Six months after surgery there was an improvement in all nasalance scores. The change in nasalance score for the nasal text was statistical significant ($p=0.04$). In the patients' group there was significant decrease in nasal resistance and increase in nasal patency and statistically significant improvement in

TNR, TMCSA and TVOL (p<0.001 for all parameters – Table 1). All the patients' VHI scores were improved, but only the improvement in the VHI physical score was statistically significant (p=0.033). Postoperatively, there were no statistically significant differences between the controls and the patients in nasal patency (TNR, TMCSA and TVOL), nasalance and VHI. Patients had higher TNR, lower TMCSA and TVOL values as well as worse nasalance and VHI scores than the controls, but all the differences were not statistically significant (p<0.05 for all the parameters – Table 1). Correlation analysis between nasalance scores and nasal objective measurements revealed a statistically significant correlation only between the baseline and the postoperative nasalance score for the nasal text and the total nasal cavity volume (TVOL) – Graph 1.

Comparisons among above and below criteria groups (presented in detail in the statistical analysis section) revealed that patients with lower nasal resistance and higher nasal patency (higher TMCSA and TVOL values) had higher nasalance scores (for oral, nasal and oronasal text) scores and lower VHI scores than patients with higher nasal resistance and lower nasal patency. However, only differences in nasalance scores for nasal text were statistically significant (p<0.05 – Table 2). Furthermore, patients with milder nasal obstruction symptoms had statistically significantly higher nasalance scores for nasal text (p=0.012) and lower VHI scores (p=0.02) than patients with more severe nasal symptoms. VHI scores were statistically significantly lower for the patient group with lower stress levels (p=0.008) compared to the patient group with higher scores in the SAST questionnaire (Table 2).

Among the patients' cohort, clinically significant improvement was observed in 25 patients (41.67%) for subjective evaluation of their voice (VHI score). The incidence of clinically significant improvement of VHI score in relation to patients' demographics and disease characteristics was further analyzed (Table 3). In univariate linear regression analysis (Table 3), it was found that the likelihood of clinically significant improvement of VHI score was significantly associated only with clinically significant improvement of patients' nasal obstruction symptoms (NOSE score) (OR:2.32, 95% CI:1.08 – 5.15, p.=0.041) and psychological status (SAST score) (OR:3.06, 95% CI:1.15 – 7.04, p.=0.038 - Table 3).

Discussion

The nasal cavity and paranasal sinuses have been considered to play an important role in shaping the resonant characteristics of the voice. Nasal airway resistance can influence nasality [22]. Nasal resistance, nasal cavity volume and nasal resonance are mainly dependent on the size and structure of the internal nasal cavity and are significantly affected by the size of the nasal turbinates apart from the presence of a septal deviation. [4]. A decrease in nasal airway patency due to septal deviation and hypertrophy of the nasal turbinates may result in an increase of the resistance to nasal airflow and sound transmission. This indicates that nasal obstruction caused by nasal septal deviation and nasal turbinates enlargement may also create enough impedance, reducing or even preventing sound from entering via the nasopharynx, even when the velopharyngeal region is open during speech [1, 30]. Therefore, hyponasality may be present in patients with nasal obstruction symptoms [22]. Nasalance scores for nasal and oronasal text were significantly lower in our patients' group compared to healthy controls, in accordance with the study of Hernandez – Garcia et al. [14] who also reported reduced nasality in patients with septal deviation.

Septoplasty in combination with turbinate surgery primarily leads to improvement of nasal patency but also has the potential to influence voice by altering the resonant characteristics of the vocal tract [12]. A reduction in the mucosal surface and widening of nasal passages following septoplasty and reduction of the inferior turbinate hypertrophy would be expected to result in a decrease in nasal airway resistance and an increase in nasal cavity volume [1, 22, 31]. Consequently, these changes may decrease acoustic damping and increase acoustic coupling with the paranasal sinuses and therefore increase nasal acoustic energy and nasalance [1, 30]. In the present study, a significant decrease in total nasal resistance and a significant increase in nasal minimal cross-sectional area and nasal cavity volume were noted six months after surgery. Additionally, an increase in nasalance scores for oral, nasal and oronasal texts six months after surgery was found. However, nasalance changes only for the nasal text reached statistical significance. Nasalance scores showed non-significant differences between patients postoperatively and controls. It is worth comparing the results in the present study with the results by other researchers who evaluated nasalance after septoplasty in different time points. Hernandez – Garcia et al. [14] and Amer et al. [15] reported a significant increase in nasalance two and four weeks after septoplasty respectively that resolved after three months. Similarly, Kim et al. [8] also found an increase in nasalance a month after surgery, but a decrease to the preoperative values at six months postoperatively. Regarding the contribution of turbinate surgery in voice nasality, Vishak et al. reported a significant increase in nasalance one month after turbinectomy which was transient, as it resolved in five months after surgery [32]. The increase of nasalance in the first month after the operation is attributed to the widened nasal passages mainly due to the inferior turbinate hypertrophy reduction as well as the removal of the deviated part of the nasal septum. The increased nasal cavity size results in a decreased acoustic damping leading to an intensification of the nasal acoustic energy. Additionally, the widening of the nasal passages usually reaches its maximum one month after surgery, enhancing nasal resonance and leading to increased nasalance. [33]. Reduction of the nasality in the long term may be due to the decrease of crusts and subsequently the normalization of the nasal septum's and nasal turbinates' mucosa, mucosal vibration and dampening function. With time, the size of the nasal cavities tends to decrease slightly again, leading to decreased nasalance [15]. Interestingly, the nasalance scores only for the nasal text remained significantly changed six months after septoplasty and turbinate reduction, due to the fact that vocal reproduction of the nasal text requires higher contribution of the nasal tract than the oral and oronasal text [22].

Nasal septoplasty and nasal turbinate reduction can affect nasalance scores by increasing nasal cavity volumes and/or decreasing nasal airway resistance, leading to an increase in nasal acoustic energy [30]. However, the relationship between nasal resistance, nasal cross-sectional areas, nasal cavity volumes and nasalance before and after surgical correction of septal deviation and turbinate reduction has never been evaluated before. In the present study, the effects of septoplasty and turbinate surgery on nasal resistance, nasal cross-sectional areas, and nasal cavity volumes and nasalance were investigated, in order to determine the association between subsequent changes in nasal measurements and nasalance. By using anterior rhinomanometry, acoustic rhinometry and nasometry, it was examined whether changes in nasal measures resulted in increased nasalance scores. The results of the present study showed that both preoperatively and six months after surgery no significant correlation was found between changes in nasal measures and nasalance scores for oral and oronasal text. Additionally, despite the fact that nasalance scores for oral and oronasal text were higher in patients with lower total nasal resistance, higher total minimal nasal cross-sectional area and total nasal cavity volume than patients with worse results in nasal measures, these differences were not statistically significant. These findings are consistent with results from previous studies who investigated the relationship between changes of nasalance and nasal cavity volume following nasal decongestant administration [22, 34] or functional endoscopic sinus surgery [35] and nasal cross-sectional areas in normal adult speakers [36, 37] that did not demonstrate any strong relationship between these parameters. In contrast to the results of the present study, Williams et al. [38] demonstrated a significant inverse correlation between changes in nasalance and high nasal airway resistance in healthy volunteers and in patients suffering from symptoms of acute rhinitis after the application of a topical nasal decongestant. A likely explanation for this finding is that nasal measures may not be sensitive predictors of changes in nasalance scores and other additional factors, such as the function of the soft palate, the oral cavity and lips, also contribute to nasalance alterations [38]. Subsequently, the changes in nasal airway resistance, minimal cross-sectional area and nasal cavity volume due to septal deviation and inferior turbinate enlargement found in the present study that would otherwise result in more significant changes in nasalance, are probably compensated by subtle alterations in palatal function. Furthermore, Litzaw et al. [37] noted that nasal acoustic energy is affected by the overall shape and volume of the nasal cavity. Resonant characteristics (nasality) of voice recordings for the nasal text, where the nasal component of speech is more significant, are mainly modified by the anatomy of the nasal airway. On the contrary, production of the oral and oronasal text is more dependent on the shape of the oral cavity and lips and the position of the soft palate than the structure of the nasal cavity [38]. This would explain the significant correlation found between total nasal volume and nasometry measures only for the nasal passage in our study.

Voice disorders may have a negative impact on patients' social life and self-esteem because individuals with speech problems are usually stereotyped as less pleasant and less intelligent than people with normal speech [39]. Therefore, patients' self-evaluation of voice quality was an important treatment outcome measure in the present study. In line with several studies, VHI-30 [27, 28] was used as a tool to assess the impact of hyponasal speech on patients' quality of life. The present study showed that patients with septal deviation had higher VHI scores (total and physical) than healthy individuals, indicating that the presence of hyponasal speech has a negative impact on their daily life and the subjective evaluation of their voice quality. Previous reports of Mora et al. [1] and Atan et al. [9] demonstrated significant reductions in VHI scores one month after septoplasty, while Apaydin et al. [17] found statistically significant decrease in VHI scores at one and three months after surgery compared to the preoperative period. Similarly, Celik et al. [13], who used VHI-10 questionnaire (a shorter version of VHI-30) [40] in patients who underwent septophinoplasty with spreader grafts, reported a significant decrease in VHI scores one to three months after septoplasty. The present study does not support these arguments as six months after surgery total VHI scores were lower than the baseline scores, but the difference did not reach statistical significance. Analysis of the three subscales of the questionnaire separately revealed a statistically significant change in the physical component after surgery. Differences in VHI scores between patients and controls were not significant six months after septoplasty and turbinate reduction. In accordance with the results of the present study, Behrman et al. [41] noticed no statistically significant reduction in VHI scores in patients with septal deviation one to three months after surgery. Similarly, Liapi et al. [7] and Celik et al. [13] reported no significant changes related to patients' voice nasality one to three months after septoplasty. These findings indicate that patients who undergo septoplasty and turbinate reduction may notice improvement of their hyponasal voice after surgery but these changes do not significantly alter their functional abilities and emotional status. Additionally, daily life of patients with nasal septal deviation is probably not affected in the same degree by voice quality as other voice-impaired patients.

To the best our knowledge this is the first study that attempts to investigate potential predictive factors associated with clinically significant improvement of the patients' subjective evaluation of voice after septoplasty and turbinate reduction. It was demonstrated that the improvement of nasal obstruction symptoms and stress levels were the two parameters significantly related to clinically significant improvement of patients' VHI scores. Specifically, patients with a clinically significant nasal obstruction improvement and resolution of anxiety symptoms were almost 2.32 and 3.06 times more likely to experience clinically significant improvement of subjective assessment of their voice respectively. Regarding the body mass index it was hypothesized that the presence of a narrow retropalatal space may affect air escape into the nose and nasal resonance. This narrow airway space was considered to be more common in patients with higher body mass index. That is why comparisons were performed between patients with higher and lower body mass index regarding the postoperative changes in subjective evaluation of voice performance (VHI scores). However, the results of the present study indicated that the body mass index did not show any significant correlation with nasalance and consequently with patients' voice performance. This concurs with a previous study which mentioned that nasalance measurements were not correlated with patients' obesity [42]. Six months after surgery patients with milder nasal obstruction symptoms and lower stress levels self-rated their voice quality significantly higher than patients with more severe nasal and anxiety symptoms. This is possibly explained by the fact that the sensation of breathing better and psychological profile may highly contribute to patients' perception of voice quality. Additionally, it has been supported that severity of nasal obstruction symptoms and stress levels are prognostic factors for the quality of life and personal benefit of patients after septoplasty [43]. Consequently, these findings indicate that nasal obstruction symptom resolution and improvement of psychological status after septoplasty and turbinate reduction mainly affect patients' perceptual improvement of voice performance and the impact of speech quality on their daily life.

The present study investigated the changes in voice nasality after septoplasty and turbinate reduction. Nasometry was performed for objective quantification of nasalance and validated questionnaires were used for subjective assessment of patients' voice performance and its impact on their quality of life before and after surgery. Previously, only a few studies used both nasometry and subjective reports to evaluate changes in nasality after septal surgery. There were numerous methodological differences between these studies including different languages for the texts used for nasometry measurements, different instruments for subjective evaluation of voice (Table 4) and different normal values for nasalance scores (Table 5). Additionally, in the previous studies there were various limitations, including small sample size, limited follow-up period, lack of a control group and utilization of non-validated questionnaires. The present study compared values of nasalance and VHI scores between patients and healthy controls. In addition, the presented data were obtained during the later postoperative period (six months after surgery), when the nasal mucosa is normalized, in comparison to the vast majority of the previous studies. Another strength of the present study was the use of rhinomanometry and acoustic rhinometry to enable objective measurement of the change in nasal airway resistance, nasal minimal cross-sectional areas and nasal cavity volume after septoplasty and turbinate reduction, in order to determine their relative contribution to the alterations in nasalance. Our findings may be clinically relevant for special patient groups with concerns about the effects of nasal septoplasty and turbinate hypertrophy reduction on their vocal characteristics, such as singers and professional speakers. Further studies on a larger patient series investigating the effect of septum deviation types on resonant characteristics of voice would increase existing knowledge on this subject.

Conclusion

Hyponasality is a distinct vocal feature related to nasal obstruction caused by nasal septal deviation and nasal turbinate hypertrophy. Nasal septoplasty and turbinate hypertrophy reduction can alter the resonant characteristics of the vocal tract and produce an increase in nasality, but these changes were not significant in the long term. Nasalance scores for nasal text were significantly correlated to total nasal cavity volume. However, no significant relationship was found between changes in total nasal resistance, total minimal cross sectional areas, volumetric change of the nasal cavity and nasalance scores for oral and oronasal text, indicating that nasalance may be more affected by other factors. According to the patients' VHI scores, voice changes after septoplasty and turbinate reduction are perceived by the patients, but do not seem to significantly interfere with the patients' daily activities and affect their emotional status. Additionally, improvement of both nasal obstruction and anxiety symptoms appear to significantly affect patients' subjective evaluation of voice performance after surgery and its impact on their quality of life. Although postoperative changes in nasality of spoken Greek, as represented by the oro-nasal text, were not significant, specialists should counsel patients, particularly professional voice users, regarding the possible effects of this commonly performed surgical procedure on voice.

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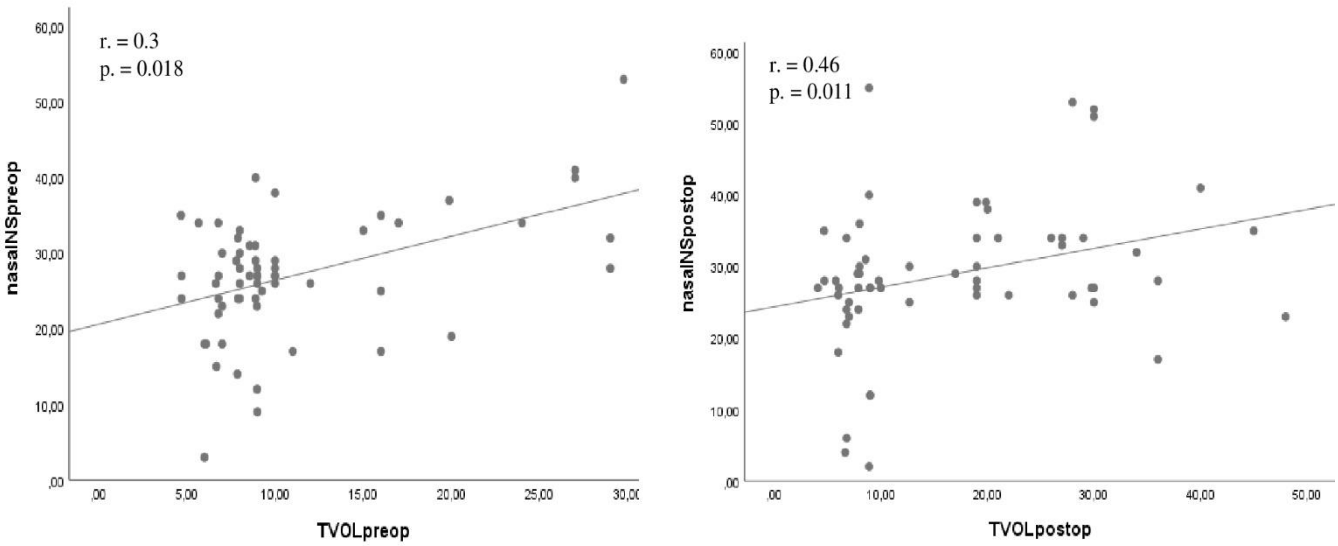
Graph



Graph 1. Correlation between Nasalence Scores (NS) for nasal text and total nasal cavity volume (TVOL) pre- and postoperatively

Table

Table 1. Nasal measurements, nasalance scores and subjective evaluation of voice in the controls and the patients' group (preoperatively and 6 months after surgery)

	Control	Patient group		p. value
		preop	postop	
TNR	0.14 (0.07)	0.41 (0.26) *	0.17 (0.1)	< 0.001
TMCSA	0.85 (0.21)	0.37 (0.19) *	0.73 (0.21)	< 0.001
TVOL	18.68 (6.7)	11.05 (6.46) *	16.93 (11.44)	< 0.001
Nasalance score				
Oral text	12.5 (4.8)	11.7 (5.2)	12.34 (4)	0.078
Nasal text	42.7 (7.8)	38.4 (10.78)*	43.4 (9.12)	0.04
Oronasal text	29 (9.2)	24.85 (9.33)*	26.3 (10)	0.08
VHI (total)	6.7 (3.52)	9.01 (4.98)*	7.83 (4.43)	0.086
VHI (functional)	1.42 (2.77)	1.7 (3.11)	1.69 (1.9)	0.95
VHI (physical)	3.88 (3.68)	5.8 (1.88) *	4.64 (4.19)	0.033
VHI (emotional)	1.4 (3.09)	1.51 (2.07)	1.5 (2.83)	0.98

Data are expressed as mean values (standard deviation, SD)
TNR: Total Nasal Resistance, TMCSA: Total Minimal Cross-Sectional Area, TVOL: Total Volume (nasal), VHI: Voice Handicap Index, preop: preoperatively, postop: postoperatively
* Statistically significant difference compared to control group
p. values refer to comparison between pre- and post-treatment scores – Wilcoxon Signed Rank test for paired samples

Table 2. Comparison of postoperative nasalance and VHI scores between the above and the below the criteria groups: criterion A (median value of postoperative TNR), criterion B (median value of postoperative TMCSA), criterion C (median value of postoperative TVOL), criterion D (median value of postoperative NOSE score) and criterion E (median value of postoperative SAST score)

	Criterion A			Criterion B		
	Above (N=29)	Below (N=31)	p value	Above (N=28)	Below (N=32)	p value
NS (oronasal text)	25±7.55	27±10.22	0.14	26.76±6.4	25.6±8.9	0.1
NS (nasal text)	35.4±6.8	39±10.7	0.036	39.3±7.08	35.6±4.5	0.041
VHI	8.01±2.65	6.99±3.28	0.2	7.2±2.1	7.98±3.54	0.19
	Criterion C			Criterion D		
	Above (N=29)	Below (N=31)	p value	Above (N=28)	Below (N=32)	p value
NS (oronasal text)	26.8±9.34	24.8±11.02	0.076	23.89±9	26.5±10.1	0.061
NS (nasal text)	40.23±8.01	36±5.11	0.04	34.3±9.2	41±6.69	0.012
VHI	7.18±1.2	8±3.04	0.083	8.64±2.44	5.1±1.33	0.02
	Criterion E					
	Above (N=29)	Below (N=31)	p value			
VHI	9.32±2.05	4.22±1.9	0.008			

Data are expressed as mean values (standard deviation), N:number of patients
TNR: Total Nasal Resistance, TMCSA: Total Minimal Cross-Sectional Area, TVOL: Total Volume (nasal), NS: Nasalance Score, VHI: Voice Handicap Index, NOSE: Nasal Obstruction Symptom Evaluation, SAST: Short Anxiety Screening Test
p. value – Mann Whitney U test for independent samples

Table 3. Clinically significant improvement of Voice Handicap Index in relation to patients' demographic and clinical characteristics

	Clinically improved VHI (N, %)	OR (95% CI)	p value
Age			0.44
≤ 30 years	11 (24%)	Ref.	
> 30 years	14 (32%)	1.16 (0.54 – 2.01)	
Sex			0.56
Males	13 (38.8%)	Ref.	
Females	12 (26.4%)	0.98 (0.34 – 2.29)	
Smoking			0.25
No	15(42.8%)	Ref.	
Yes	10 (37%)	0.78 (0.22 – 2.87)	
BMI			0.1
≤ 25 kg/m^2	12	Ref.	
> 25 kg/m^2	13	1.09 (0.36 – 3.01)	
Socio-economic status			0.13
Low	5 (17.6%)	Ref.	
Medium	9 (29%)	1.45 (0.16 – 3.07)	
High	11 (43.1%)	1.79 (0.52 – 4.98)	
Clinically improved NOSE			0.041
No	9 (23%)	Ref.	
Yes	16 (59%)	2.32 (1.08 – 5.15)	
Clinically improved SAST			
No	9 (21%)	Ref.	0.038
Yes	16 (62%)	3.06 (1.15 – 7.04)	

Data are expressed as number of patients (N) and percentages (%). OR: odds ratio, CI: confidence intervals, p values: univariate linear regression.
BMI: Body Mass Index (kg/m^2), VHI: Voice Handicap Index, NOSE: Nasal Obstruction Symptom Evaluation, SAST: Short Anxiety Screening Test

Table 4. Nasalance changes in patients with nasal septal deviation treated with septoplasty

Studies	n	Voice assessment	Nasometry	Pre-operative assessment	FU	Post-operative assessment
Present study	60p/25c	Nasometry VHI-30	Language: Greek Text: oral (100% oral sounds); nasal (23.1% nasals); oronasal (8.6% nasals and 91.3% oral sounds)	Nasometry: Lower nasalance scores in patients Controls: oronasal text: 29±9.2; nasal: 42.7±7.8; oral:12.5±4.8 Patients: oronasal text: 24.85±9.33; nasal: 38.4±10.78 oral:11.7±5.2 VHI (total): patients worse scores (9.01±4.98) than controls (6.7±3.52)	6m	Nasometry: increase in nasalance scores (nasal text) Patients postop: Oronasal text:26.3±10; nasal:43.4±9.12; oral:12.34 ±4 Significant increase for VHI-physical subscale No significant differences for nasalance and VHI between patients and controls
Hernandez-Garcia et al [14], 2017	31p/27c	Nasometry Subjective: NQ (patients), GRBAS (researcher)	Language: Spanish Text – not reported Spanish vowels (/a/, /e/, /i/, /o/, /u/)	Nasometry: lower nasalance scores in patients, subjective: worse GRBAS and NQ scores for patients	2w, 3m	Nasometry: 2w increase in nasalance scores –3m return to preop values Subjective improvement in GRBAS and NQ scores (2w, 3m)
Amer et al [15], 2017	25 p	Nasometry Subjective: APA (researchers)	Language: Arabic Text: Oral, nasal sentence	Nasometry: Nasalance score 8±4 (oral) - 44±5 (nasal) Subjective APA: 36% hyponasal speech	1m, 3m	Nasometry: improvement in nasalance scores at 1m 17±5 (oral) - 55±6 (nasal). No significant change in nasalance scores at 3m 9±3 (oral) - 46±3 (nasal) APA: 1m, 3m (20%) hyponasal speech
Kim et al [8], 2015	25 p	Nasometry	Language: Korean Text: Voiced sounds Nasal consonant Plosive consonant–vowel combinations Nasal consonant–vowel combinations hypernasality sentence - nasal consonant ratio of 65.6 % and mean nasalance - 50 %. Hyponasality sentence - nasal consonant ratio 0 % - mean nasalance - 14 %	Nasometry Nasalance scores hyponasality passage 13.1±5.4 Hypernasality 49.1±12.7 They reported normal nasalance scores: 54.7% in a typical Korean nasal sentence 61.1% in an English nasal sentence	1m, 2m, 3m, 4m, 5m, 6m	Nasometry improvement in nasalance scores at 1m (hyponasality sentence 27±8.9 – hypernasality sentence 68.6±4.2) , 2m,3m and 4m. No significant change in nasalance scores at 5m for hypernasality sentence (hypernasality sentence 50±4.2 – hyponasality sentence 15.6±5.3), no changes for both sentences at 6m (hypernasality sentence 49.5±8.3 – hyponasality sentence 13.6±6.3)
Mora et al [1],	20 p/40 c	Subjective:		Subjective:	1m	Subjective

2009		VHI-30, Mirror fogging test – Gutzmann test (researchers)	(-)	VHI (patients) - 78		improvement in VHI (26 for patients) mirror- fogging and Gutzmann test scores
Atan et al [9], 2016	43 p	Subjective: VHI-30	(-)	VHI-30: 1.53 ±2 in total	1m	Improvement in VHI-30: 0.69 ±1.43 (total)
Apaydin et al [17], 2019	42 p	Subjective: VHI-30	(-)	VHI-30: 26.1 ±26.2	1m, 3m	Improvement in VHI score at 1m (14.2±19.3) and at 3m (9.8 ±13)
Celik et al [13], 2012	20 p	Subjective: VHI-10 and patients' SR	(-)	VHI-10: 9.44 ±6.1 75% of patients reported hyponasality	1-3m	Improvement in VHI score: 5.1 ±3.94 25% of patients reported hyponasality
Liapi et al [7], 2015	15 p /19 c	Subjective: NQ (patients)	(-)	Patients perceived that their voice sounded as if they had a blocked nose and as though the sound was coming through their nose significantly more often than controls.	4w	Unchanged symptoms (regarding nasality) compared to controls However half of patients felt that their voice had changed after surgery – (87.5%) thought that this change was positive
Gulec et al [10], 2016	33 p /30 c	Subjective: Patient reported single questions about voice change	(-)	(-)	1m, 3m	Subjective voice change improvement: 36%, no change: 61%, negative change: 6%
Subramaniam et al [12], 2015	15p/ 30 c	Nasometry	Language: Tulu, Kannada e.t.c. Text: sustained vowels /a/, /i/, /u/ and sustained consonants /m/ and /n/, oral sentence, nasal sentence and passage reading.	Nasometry lower nasalance scores in patients for nasal sentence and passage Controls: Oral sentence: 14.34±4.85; nasal sentence: 34.53±12.87; passage: 29.87±5.29 Patients - Oral: sentence 11.47±3.27, nasal sentence: 42.10±12.78, passage: 21.64±3.03	1m	Nasometry: No increase for all nasalance scores in patients postop Significant differences for nasalance scores (nasal sentence – passage) between patients postop and controls
Karakurt et al.[18], 2020	69p	Subjective: VHI-30	(-)	VHI-30 (total): 12 ±8 for patients with severe NSD		Significant improvement in VHI total scores (10±2.85) only for patients with severe NSD
Only statistically significant changes are included n: number of patients, p:patients, c:controls, FU: follow-up, m: months, w: weeks, postop:postoperatively, preop:preoperatively, NSD: Nasal Septum Deviation All operations were septoplasty except study [15] (septorhinoplasty) and study [17] (septoplasty and turbinoplasty).						

VHI:Voice Handicap Index, GRBAS: Grade, Roughness, Breathiness, Asthenia, Strain , NQ: Nasality Questionnaire with custom made research questions targeting nasality - nasal function, APA: Auditory Perceptual Assessment – custom made evaluation of speech by the researchers including type and degree of nasality, consonant precision, compensatory articulatory mechanisms, audible nasal emission of air and overall intelligibility of speech,
SR: Subjective report regarding nasality during speech
Gutzmann test: the subjects were asked to produce a series of *a* and *i* sounds alternately with the nares held open and closed. A change in vowel quality with the nares closed was indicative of hypernasality

Table 5. Nasalance (%) Norms according to different studies – languages

Studies	Nasalance scores		
	Oral	Nasal	Oronasal
Hernandez-Garcia et al [16], 2017 Spanish (controls' scores)			17.13 ± 6.24
Okalidou et al[23], 2011 Greek	12.4 ± 4.8	42 ± 7.8	25.5 ± 5.4
Kim et al [10], 2015 Korean		54.7	
Van der Weijer & Slis[44], 1991, Northern Dutch	11.7 ±4.4	52.3 ±7.0	31.9 ±5.1
Litzaw & Dalston[45], 1992, Northern American English	16.0 ±7.3	65.4 ±5.8	36.0 ±6.1
Van Lierde, et al.[46], 2001 Flemish	10.1 ±5.5	55.8 ±6.1	33.8 ±5.5
Kavanagh et al.[47], 1994 Canadian French	13.4 ±6.5	65.4 ±5.8	37.1 ±5.7
Subramaniam et al [14], 2015 Tulu (controls' scores)	14.34±4.85	34.53±12.87	29.87±5.29
Present study Greek (controls' scores)	12.5 ± 4.8	42.7 ± 7.8	29± 9.2