Improvement in minimal cross-sectional area and nasal cavity volume occurs in different areas after septoplasty and radiofrequency therapy of inferior turbinates

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Title

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ABSTRACT

Purpose: Septoplasty and radiofrequency therapy for inferior turbinate hypertrophy (RFIT) are common techniques used to improve nasal patency. Our aim was to compare nasal geometry and function using acoustic rhinometry (AR) and peak nasal inspiratory flow (PNIF) in three patients groups undergoing surgery for nasal obstruction, and to investigate if the improvement in minimal-cross-sectional-area (MCA) and nasal-cavity-volume (NCV) occurred in different nasal cavity areas in the groups. Finally, we evaluated the correlation between the objective measurements and the patients' assessment of nasal obstruction (SNO).

Methods: This prospective, observational study investigated 148 patients pre-operatively and 6 months post-operatively. Fifty patients underwent septoplasty (group 1), 51 underwent septoplasty combined with RFIT (group 2), and 47 underwent RFIT alone (group 3). The minimal-cross-sectional-area (MCA) and nasal-cavity-volume (NCV) were measured at two distances (MCA/NCV$_{0\text{-}3.0}$ and MCA/NCV$_{3\text{-}5.2}$), in addition to measuring PNIF and SNO.

Results: Pre-operatively, groups 1 and 2 had narrower MCA$_{0\text{-}3.0}$ on one side than group 3 [0.31± 0.14 and 0.31± 0.14] versus [0.40 ± 0.16] cm^2. Post-operatively, total MCA$_{0\text{-}3.0}$ and MCA/NCV$_{3\text{-}5.2}$ increased in group 1. In group 2, MCA/NCV$_{0\text{-}3.0}$ at the narrow side and total MCA/NCV$_{3\text{-}5.2}$ increased, while total MCA/NCV$_{3\text{-}5.2}$ increased in group 3. PNIF improved from 106 ± 49 l/min to 150 ± 57 l/min post-operatively. We found a correlation between increased MCA and NCV and less SNO in the septoplasty group ($p<0.01$).

Conclusion: Surgery produced an improvement in MCA and NCV in all groups. The improvement occurred in different areas of the nasal cavity in the patient groups. Both anterior and posterior areas increased in the septoplasty groups while only the posterior area increased in the RFIT group. PNIF improved in all three patient groups, indicating that surgery produced an improvement in nasal patency.

Key words: Nasal obstruction, acoustic rhinometry, septoplasty, radiofrequency therapy of inferior turbinates and peak nasal inspiratory flow.

INTRODUCTION

Patients with symptoms of nasal obstruction frequently consult an otorhinolaryngologist [1]. Sustained nasal obstruction may have structural causes such as deviation of the nasal septum or inferior turbinate hypertrophy (ITH) [2], but chronic diseases such as chronic rhinosinusitis and allergic rhinitis may also cause nasal congestion and reduced nasal airflow [3,4]. The sensation of subjective nasal obstruction is difficult to evaluate by clinical examination and can be misleading [5]; it is not only a question of nasal resistance, but the occurrence of turbulence is also important [6]. As subjective and objective measurements often do not correlate well [7], it is recommended also to use objective methods in the pre-operative nasal evaluation to avoid unnecessary operations and to improve post-operative patient satisfaction [8]. Acoustic rhinometry (AR), rhinomanometry, and peak nasal inspiratory flow (PNIF) are currently the most used objective tests. AR is a static measure of nasal dimensions such as minimal cross-sectional area (MCA in cm^2) and cavity volumes (NCV in cm^3) and may give information about the site of the obstruction [9]. PNIF measures the maximal inspiratory airflow (l/min) [8,10].

Since the cross-sectional areas of the nasal cavity increases in the anteroposterior direction [11], with the nasal valve being the narrowest area of the nasal cavity [12], cross-sectional cavity measurements should be assessed both anteriorly and posteriorly. In addition, small changes in nasal patency can also affect the total airway resistance and, thereby, the total respiratory function [13]

Septoplasty and radiofrequency therapy of the inferior turbinate (RFIT) are common surgeries performed to relieve nasal obstruction [14,15]. Studies have shown moderate to excellent results [16,17], but unsatisfactory results have also been published recently [18]. Some suggest that patient selection for septoplasty should depend on the actual nasal obstruction complaints, a present septal deformation on anterior rhinoscopy, and a critical value of the minimal cross- sectional area (MCA) at the narrow side of ≤ 0.40 cm^2 [19,20]. Patient selection for turbinate surgery is often based on the effects of decongestion on nasal resistance, but also AR test results have also been used [21].

Nevertheless, there is no clear consensus on the optimal surgical method, optimal selection of patients, or expected improvement in symptoms [22-24]. Continuous evaluation of surgical indications and outcomes is necessary. Objective evidence may be more important than the opinions of experienced surgeons, and lately, information from medical quality registers increases the possibility to explore surgical outcomes [8].

The primary aim of this study was to compare pre- and post-operative AR and PNIF in three patient groups: 1) those who underwent septoplasty alone; 2) those who underwent septoplasty combined with RFIT and 3) those who underwent RFIT only. In addition, we investigated if the improvement in minimal cross-sectional area (MCA) and nasal-cavity volume (NCV) occurred in different cavity areas in the groups.

MATERIALS AND METHODS

Ethics, consent, and permissions

This longitudinal, prospective observational registry study was conducted during the period from January 2012 to April 2015 and was approved by the Committee for Medical Research Ethics in Norway, 2015-367/REK NORD. All patients signed a written consent prior to study inclusion.

Materials

All patients were referred to the Otorhinolaryngology Department at St Olav`s University Hospital by general practitioners, private otorhinolaryngologists, or local hospitals in the region. All patients were examined at the outpatient clinic by consultants or registrars. The diagnosis was based on anterior rhinoscopy and nasal endoscopy combined in conjunction with patients` symptoms and was classified according to the International Classification of Diseases (ICD-10) codes J34.2 (septum deviation) and J34.3 (ITH). The patients were asked to participate in the study when there was indication for septoplasty, septoplasty in combination with RFIT, or RFIT alone.

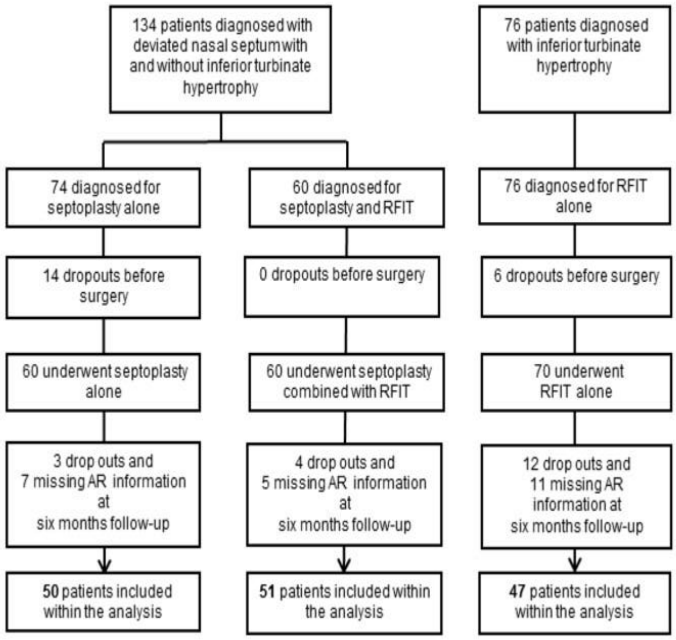
Inclusion criteria consisted of a deviated septum, a deviated septum in combination with ITH, or ITH alone with presenting symptoms of chronic nasal obstruction. The patients had symptoms lasting at least 3 months, and the symptoms were still persistent after medical management.

Exclusion criteria were age < 18 years, difficulty in interpreting the questionnaires due to language- or cognitive problems, pregnancy, ongoing cancer treatment, granulomatosis with polyangiitis, cystic fibrosis, Kartagener syndrome, Sarcoidosis, or primary ciliary dyskinesia. Patients with comorbidities as allergy, asthma, sleep apnea, and previous septal or turbinate surgery were also included in this study. Patients could not have used any topical decongestant 12 hours prior to the assessments, and the assessments were obtained without decongestion of the nasal mucosa pre-operatively (baseline) and 6 months post-operatively.

We included 210 patients. Due to withdrawals (before surgery) and loss of follow-up and incomplete data, the total sample of the study was 148 (70.5%) patients. Fifty patients underwent septoplasty, 51 patients underwent septoplasty combined with RFIT, and 47 patients underwent RFIT alone.

Figure 1 Flow chart

N= 210



Acoustic rhinometry (AR)

AR was performed to measure the MCA and NCV. AR utilizes a sonic echo technique and all measurements were made with an acoustic rhinometer (Rhinometrics SRE2100, Rhinoscan version 2.5, built 3.2.5.0; Interacoustics, Minneapolis, MN, USA). Recordings were performed according to published protocols [25]. Specially trained nurses performed the AR with the patients in sitting position using a handheld probe and a nose adaptor. Sufficient contact between the adaptor and the nose was secured using contact gel, and the average of three satisfactory recordings during a breath hold was obtained.

The rhinometer calculated the MCA and NCV in each nasal cavity in two areas of the nose. The most anterior area, which usually covers the area of the nasal valve and the head of the inferior turbinate [11], was defined as 0–3.0 cm from the nostrils and included MCA/NCV$_{0\text{-}3.0}$ [26]. The posterior area, which covers the area and volumes posterior of the head of the inferior turbinate, involving the turbinated area (inferior, middle and superior turbinate) was defined 3–

5.2 cm from the nostrils and included $MCA/NCV_{3\text{-}5.2}$[26]. NCV from 0–5.2 cm was also calculated ($NCV_{0\text{-}5.2}$).

Due to the variations represented by the nasal cycle, the sum of the two averages of left and right cavity was divided by 2 to obtain the total mean MCA ($cm^{2)}$ and NCV (cm^3) for each distance (total: $MCA_{0\text{-}3.0,}$ $MCA_{3\text{-}5.2,}$ $NCV_{0\text{-}3.0}$ and $NCV_{3\text{-}5.2}$). In addition, we identified the preoperatively narrow and wide side of $MCA_{0\text{-}3.0,}$ $MCA_{3\text{-}5.2,}$ $NCV_{0\text{-}3.0}$ and $NCV_{3\text{-}5.2.}$

Peak nasal inspiratory flow (PNIF)

The maximal nasal inspiratory flow was measured using a portable PNIF meter (In-check DIAL and In-check NASAL; Clement Clarke International, Harlow, Essex, UK), using a size appropriated facial mask. The mean of three approved PNIF measures was recorded with the subjects in a sitting position and the head held in a level position. Maximum flow registration was limited to respectively 120 l/min in the period 01.01.2012 –18.06.2013 and 370 l/min in the period 19.06.2013 – 31.12.2015. Patients with values of exactly 120 l/min before the date of changing flowmeter were excluded from the analysis.

Subjective nasal obstruction (SNO)

The patients' perception of subjective nasal obstruction was indicated on 100 mm visual analog scale (VAS) where 0 mm represents no nasal obstruction and 100 mm represents nasal obstruction "as troublesome as possible" [27,28].

Comorbidity, smoking and previous nasal surgery

Patients were asked if they had allergy, asthma or sleep apnea, and smoking status.

Information of previous nasal surgery was obtained from the patients' medical records.

Surgery

Septoplasty was performed as traditional intranasal cartilage-preserving septoplasty.

Septoplasty combined with RFIT was performed with the CelonProBreath® bipolar coagulation electrode (Celon AG medical instruments 2003 Rheinstrasse 8, D-14513 Teltow/Berlin, Germany). The power setting was 15 watts and exposure time ranged from 5 to 15 seconds with varying applications in each turbinate.

RFIT alone was done with the Sutter system BM-780 II (Sutter medizintechnik GMBH Tullastrasse 87, 79108 Freiburg, Germany) AutoRF setting, power adjustment 2; exposure time ranged from 5 to 9 seconds in each application. The number of applications in each turbinate was assessed by the surgeon.

No treatment allocation or randomization was done. The procedures were performed by 14 different surgeons: six consultants and eight senior registrars at St Olavs Hospital. The nasal packing was removed by a nurse at the outpatient clinic or by the patients themselves. The plates were taken out by the surgeon 1 week after surgery.

Six months after surgery, the objective measurements were repeated at the outpatient clinic.

Statistics

We used PASW Statistics, version 23 for Windows (SPSS Inc. Chicago, Illinois) for statistical analysis. The mean value ± SD was used to describe MCA, NCV and PNIF. Categorical and ordinal variables were analyzed with the Pearson Chi-square test or Fisher exact test depending on sample size. All data were not normally distributed. For comparative analyses of continuous variables we used the Mann-Whitney and Wilcoxon signed ranked test. Spearman’s rank correlation coefficient was used for analysis of statistical dependence between MCA, NCV, and PNIF and the self-report measure SNO. Due to multiple testing pvalues ≤ 0.01 were considered statistically significant.

RESULTS

The baseline characteristics did not differ with respect to demographic or medical characteristics, except for group 1 which had more men than group 3 *($p < 0.01$)* (Table 1).

Table 1 Demographic and medical characteristics before surgery

	Group 1, n= 50	Group 2, n = 51	Group 3, n = 47
Mean age, years (range)	36.6 (18–67)	38.6 (18–64)	38.9 (18–66)
Sex (m/f)	42/8	38/13	28/19
Height, m (range)	1.80 (1.57–1.96)	1.78 (1.59–1.93)	1.75 (1.60–1.91)
Mean BMI, kg/m² (SD)	26.0 ± 4.31	27.9 ± 4.84	27.3 ± 4.67
Daily smokers, n (%)	3 (6.0)	7 (13.7)	5 (10.9)
Allergy, n (%)	23 (46.9)	21 (41.2)	18 (40.0)
Asthma, n (%)	6 (12.0)	9 (17.6)	8 (17.4)
Sleep apnea, n (%)	7 (14.6)	12 (25.5)	11 (24.4)
Revision cases, n (%)	11 (22.0)	7 (13.7)	9 (19.6)

Group 1, septoplasty; group 2, septoplasty combined with radiofrequency therapy (RFIT); group 3, RFIT. BMI, body mass index. Revision cases, patients having prior surgery of septoplasty, septoplasty combined with RFIT or RFIT alone.

Surgical procedures and post-operative care

Patient group 1) *septoplasty:* The mean duration of surgery was 73 ± 28 minutes. Of these patients, 10 patients had local anesthesia, 42 patients had a silastic plate bilaterally for support and to prevent post-operative adhesions, and 33 patients had a nasal packing for 2 days to prevent bleeding and hematoma of the septum.

Patient group 2) *septoplasty combined with RFIT:* The mean duration of surgery was 72 ± 32 minutes. Of these patients, 11 patients had local anesthesia, 39 patients had a post-operative silastic plate bilaterally, and 40 patients had a nasal packing for 2 days.

Patient group 3) *RFIT:* The mean duration of surgery was 13 ± 7 minutes and 46/47 had surgery under local anesthesia.

AR before and after surgery

Rhinometric data at baseline and 6 months post-operative are presented in Table 2.

At baseline, there were no significant differences in AR values between the patient groups *($p \geq 0.08$),* except in groups 1 and 2 in which $MCA_{0\text{-}3.0}$ at the narrow side was smaller than in group 3 *($p < 0.01$)*. After surgery, group 1 had a significant increase in total $MCA_{0\text{-}3.0}$ (Figure 2), whereas only $MCA/NCV_{0\text{-}3.0}$ at the narrow side increased in group 2. All groups had a significant increase in the total $MCA/NCV_{3\text{-}5.2}$ (Figure 3). The pre- and post-operative changes or the post-operative values were not different between groups *($p \geq 0.07$)*, except for the postoperative total $MCA_{3\text{-}5.2}$, which was smaller in group 1 compared to group 3 *($p < 0.01$)*.

PNIF before and after surgery

PNIF values at baseline and 6 months post-operatively are presented in Table 2 and Figure 4. Eleven patients lacked pre- or post-operative measurements. These patients were equally distributed among the groups. Pre-operatively, there were no significant differences in PNIF among the patient groups *($p \geq 0.33$)*. PNIF improved significantly in all groups, and the improvement was not different among groups *($p > 0.07$)*.

See table 2 and figure 2-4 at the end of the article

Correlation between objective and subjective measurements

Pre- or post-operatively, no significant correlations were found between AR or PNIF measurements and SNO in the three patient groups, except for in group 1 post-operatively. $MCA_{3\text{-}5.2}$, $NCV_{3\text{-}5.2}$, and $NCV_{0\text{-}5.2}$ showed a moderate negative correlation with SNO (*r= -.38, -.45, -.44, $p < 0.01$*) (Data not shown).

Comorbidity, smoking, and previous surgery

In this study, some of the patients had comorbidities such as allergies, asthma, and sleep apnea. Some were daily smokers, and some had a history of the previous septal or turbinate surgery. There was no significant difference in the distribution of these conditions among the groups.

Sub-analysis showed that patients with pre-operative allergies had significant smaller total $NCV_{3\text{-}5.2}$ compared to patients without allergy *($p \leq 0.01$)*, with a mean of 2.49 ± 0.95 cm^3 versus 3.00 ± 1.32 cm^3. Post-operatively, these patients had significantly smaller $MCA_{0\text{-}3.0}$ at the narrow side compared to patients without allergies *($p \leq 0.01$)*, with a mean of 0.41 ± 0.15 cm^2 versus 0.49 ± 0.16 cm^2.

Variables, as asthma, smoking and previous surgery, had no significant influence on AR or PNIF *($p \geq 0.05$) (d*ata not shown).

DISCUSSION

This study demonstrates that MCA and NCV improved in different nasal-cavity areas in the three patient groups after surgery. In the nasal cavity, septoplasty increased the total anterior MCA and the total posterior MCA and NCV, whereas septoplasty combined with RFIT increased the narrow side of MCA and the NCV anteriorly, in addition to the total MCA and NCV posteriorly. RFIT increased the total posterior MCA and NCV. PNIF improved in all patient groups.

In our study, the patient groups had a pre-operative similar mean total $MCA_{0\text{-}3.0}$ between 0.45 and 0.48 cm^2. The $MCA_{0\text{-}3.0}$ at the narrow side was between 0.31 and 0.40 cm^2. The $MCA_{0\text{-}3.0}$ at the narrow side was significantly smaller in groups 1 and 2 compared to group 3, indicating that the septoplasty groups had a smaller $MCA_{0\text{-}3.0}$ at the narrow side than the ITH group. Our study reports pre-operative $MCA_{0\text{-}3.0}$ values smaller than Thorstensen and Moxness, who reported a mean MCA of respectively 0.52 and 0.55 cm^2 in control groups of healthy individuals [29, 30]. These study populations were of similar ethnicity as ours, and the AR equipment was identical.

Pre-operatively, the location of the $MCA_{0\text{-}3.0}$ in the patient groups was between 1.77 and 1.95 cm from the nostrils, which is similar to other studies reporting that the narrowest part of the nasal cavity is usually situated within a distance of 30 mm from the nares [6,11]. We note that the MCA in our patient groups was located somewhat more anteriorly in the nasal cavity compared to patients with normal nasal patency, indicating that the cause of obstruction in our patients was mainly located in the very anterior part of the nasal cavity.

After surgery, patients with septoplasty had an increase in the total $MCA_{0\text{-}3.0}$ and total $MCA/NCV_{3\text{-}5.2}$, whereas $NCV_{0\text{-}3.0}$ only increased at the narrow side. The increase in MCA is supported by findings from other studies [20,31,32]. Patients with septoplasty combined with RFIT had an increased $MCA/NCV_{0\text{-}3.0}$ at the narrow side but no change in the total $MCA/NCV_{0\text{-}3.0}$. In any case, we might assume that the surgery led to a more even airflow in both nasal cavities, which is indicated by the improvement of PNIF. Therefore, our findings seem to confirm that both septoplasty and septoplasty combined with RFIT caused an increase in the nasal patency both in the anterior and posterior parts of the nasal cavity. We note that the post-operative $MCA_{3\text{-}5.2}$ was smaller in the septoplasty group than in the RFIT group.

A critical pre-operative value of MCA at the narrow side $\leq$0.40 cm^2 is suggested to be of importance for successful septal surgery [20,19]. In the groups of patients with septoplasty and septoplasty combined with RFIT, 74% and 80% of the patients, respectively, had an anterior MCA ≤0.40 cm^2 at the narrow side, but only 53% was observed in the RFIT group. This may explain the increase in MCA that occurred in the anterior part in the septoplasty groups but not in the RFIT group.

In the groups receiving septoplasty combined with RFIT and receiving RFIT only there was an improvement in the total MCA and NCV only in the posterior part of the nose. This indicates that RFIT caused an increase in the area and volume posteriorly, which may be expected since the main part of the inferior turbinates are located more posteriorly in the nasal cavity. Clement et al. [6] and Grymer et al. [11] also found that the most reactive area in decongestion of nasal mucosa is located at 3.3 and 4.0 cm, respectively, from the nostrils. Our results are partly supported by other studies using RFIT, in which it was found that an improvement in nasal-cavity volumes occurred at 2 to5 cm from the nostrils [15], although the differences in location for the NCV measurements makes this comparison difficult.

Post-operative MCA and NCV in the anterior part of the nose in our patient groups were still smaller than for the healthy controls in Moxness` and Thorstensen`s studies [30,29]. Surprisingly, MCA and NCV in the posterior part of the nose were larger in our patient groups, except for the $NCV_{3\text{-}5.2}$ and $NCV_{0\text{-}5.2}$ in the septoplasty group which still remained smaller after surgery [29,30]. The reason for the post-operative differences may be due to anatomical features. We can speculate that the patients have a narrower aperture piriformis than the controls, but other reasons such as different distribution of gender or other unknown characteristics of the control groups may explain the differences [5].

PNIF improved in all three groups, indicating that the surgery improved the nasal patency. Our results may confirm that small changes in nasal patency after surgery affect total airway resistance as seen in the PNIF improvement. PNIF may therefore be a useful tool for postoperative evaluation of surgical effects. The postoperative PNIF values in our groups are in line with reference values from subjects with no reported subjective nasal obstruction [33]. Earlier studies have shown significant improvement of SNO after septoplasty and RFIT [34]. In this study we found a significant negative correlation between MCA and NCV and SNO postoperatively in the patients who underwent septoplasty. Increased MCA and NCV were associated with less symptoms of SNO. Our results are partially supported by other studies that found significant correlations between subjective nasal obstruction and AR measurements after septal surgery [32].

Neither AR or PNIF measurements can be separated from patients’ symptoms, nor can the surgeon’s pre- and post-operative assessments. However, these objective tests can be of major importance before referring patients for surgery, especially if the surgeon has doubts about the surgical outcome.

Our sub analysis included all patients demonstrating that patients with pre-operative allergies had smaller posterior NCV and less improvement in post-operative NCV compared to non-allergic patients. A study from Karazanis et al. involving septoplasty patients using rhinomanometry supported our findings regarding allergic patients [35]. This underlines the importance of allergy treatment pre- and post-operatively to nasal surgery with a specific focus on nasal mucosa. Pre-operatively, patients with sleep apnea had smaller posterior MCA at the narrow side compared to patients without sleep apnea, which is supported by similar findings in Moxness` study [30]. This should underline the importance of paying attention to possible coinciding factors in patients with nasal obstruction.

The major strength of this study was the prospective design and comparison of three surgical techniques. This study had some limitations. The patients were not randomized to treatment groups, and we did not perform AR measurements after decongestion, because we wanted the present study to reflect daily practice in an outpatient clinic.

We used two different devices for RFIT, and one could argue that this might have influenced our results. The Celon ProBreath® was used on the patients who underwent septoplasty combined with RFIT and the Sutter system BM-780 II was used on patients who underwent only RFIT. This was due to varying availability to the devices at our clinic. A review comparing different surgical techniques for bilateral ITH reduction reported no significant difference in subjective nasal obstruction using either microdebrider-assisted turbinoplasty or multiple types of radiofrequency devices [36].

The surgery improved MCA and NCV in all groups. Improvements occurred in different areas of the nasal cavity. Both anterior and posterior areas increased in the septoplasty groups, whereas only the posterior area increased in the RFIT group. PNIF improved in all three patient groups, indicating that surgery produced an improvement in nasal patency. In addition, a correlation between increased nasal areas and volumes and less symptoms of nasal obstruction was found in the septoplasty group.

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Authorship Contribution

AHN: Study design, data collection, statistical analysis, and paper drafting, WMT: Study design, data collection, statistical analysis, and paper drafting. ASH: Study design, statistical analysis, and paper drafting. SN: Data collection and paper drafting. VB: Study design, data collection, statistical analysis, and paper drafting

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the regional research committee and with the Helsinki declaration.

Conflicts of Interest The authors declare that there is no conflict of interest.

The research involved only human participants. Informed consent was obtained from each participant.

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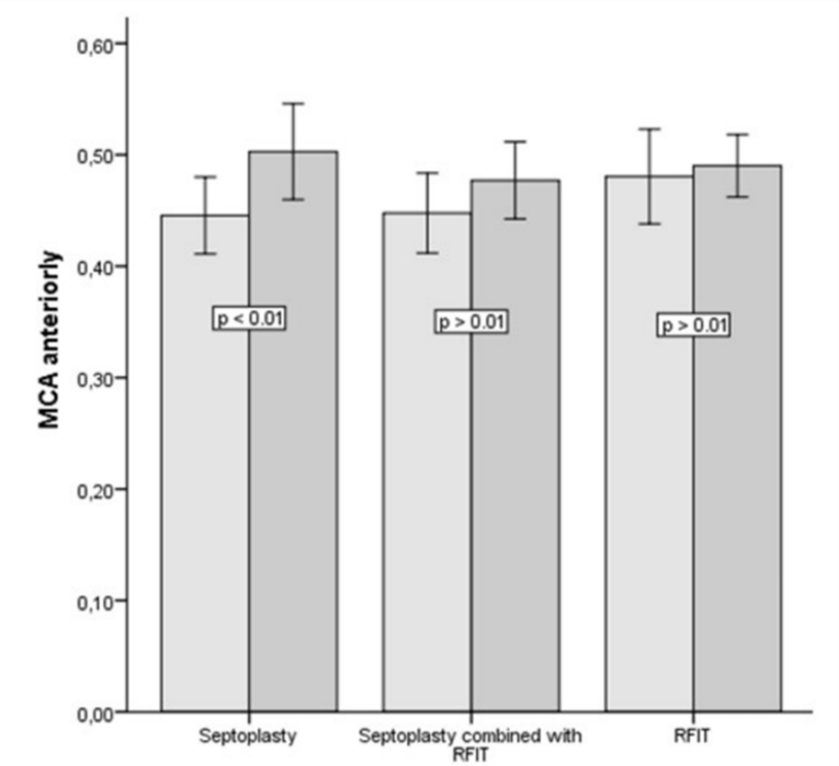
Table 2 AR and PNIF before and 6 months after surgery

	Group 1 n = 50			Group 2 n = 51			Group 3 n = 47		
	Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*
MCA_{0-3} tot	0.45 ± 0.12	0.50 ± 0.15	*0.005**	0.45 ± 0.13	0.48 ± 0.12	*0.034*	0.48 ± 0.15	0.49 ± 0.10	*0.672*
Distance	1.89 ± 0.63	1.89 ± 0.56	*0.808*	1.95 ± 0.57	1.77 ± 0.53	*0.137*	1.77 ± 0.71	1.64 ± 0.54	*0.211*
MCA_{0-3} ns	0.31 ± 0.14	0.47 ± 0.18	*0.000**	0.31 ± 0.14	0.42 ± 0.16	*0.000**	0.40 ± 0.16	0.44 ± 0.13	*0.100*
MCA_{0-3} ws	0.58 ± 0.17	0.53 ± 0.18	*0.031*	0.58 ± 0.17	0.53 ± 0.17	*0.037*	0.56 ± 0.15	0.54 ± 0.14	*0.364*
NCV_{0-3} tot	2.38 ± 0.43	2.49 ± 0.56	*0.024*	2.40 ± 0.44	2.46 ± 0.43	*0.307*	2.47 ± 0.47	2.48 ± 0.37	*0.857*
NCV_{0-3} ns	2.05 ± 0.46	2.37 ± 0.66	*0.000**	2.06 ± 0.43	2.31 ± 0.46	*0.001**	2.21 ± 0.46	2.30 ± 0.46	*0.346*
NCV_{0-3} ws	2.70 ± 0.56	2.61 ± 0.66	*0.376*	2.74 ± 0.58	2.61 ± 0.56	*0.095*	2.72 ± 0.56	2.66 ± 0.49	*0.312*
$MCA_{3-5.2}$ tot	0.71 ± 0.27	0.98 ± 0.40	*0.000**	0.75 ± 0.29	1.07 ± 0.41	*0.000**	0.83 ± 0.37	1.15 ± 0.30	*0.000**
Distance	3.44 ± 0.35	3.45 ± 0.40	*0.832*	3.44 ± 0.36	3.40 ± 0.42	*0.205*	3.57 ± 0.47	3.59 ± 0.58	*0.936*
$MCA_{3-5.2}$ ns	0.47 ± 0.24	0.98 ± 0.52	*0.000**	0.50 ± 0.28	1.06 ± 0.57	*0.000**	0.58 ± 0.30	1.13 ± 0.41	*0.000**
$MCA_{3-5.2}$ ws	0.95 ±0.40	0.97 ± 0.43	*0.699*	0.99 ± 0.41	1.08 ± 0.45	*0.157*	1.08 ± 0.58	1.16 ± 0.38	*0.149*
$NCV_{3-5.2}$ tot	2.78 ± 1.24	3.56 ± 1.52	*0.001**	2.74 ± 1.17	3.72 ± 1.19	*0.000**	2.75 ± 1.19	3.72 ± 1.07	*0.000**
$NCV_{3-5.2}$ ns	2.02 ± 1.24	3.60 ± 1.88	*0.000*	2.06 ± 1.13	3.64 ± 1.56	*0.000**	2.07 ± 1.07	3.79 ± 1.36	*0.000**
$NCV_{3-5.2}$ ws	3.52 ± 1.50	3.52 ± 1.71	*0.874*	3.41 ± 1.38	3.80 ± 1.53	*0.202*	3.44 ± 1.59	3.64 ± 1.35	*0.242*
$NCV_{0-5.2}$ tot	5.15 ± 1.45	6.05 ± 2.00	*0.002**	5.14 ± 1.49	6.18 ± 1.50	*0.000**	5.22 ± 1.53	6.20 ± 1.28	*0.002**
PNIF(n=137)	107.2 ± 53.5	146.6 ± 57.4	*0.000**	109.9 ± 47.1	146.1 ± 53.5	*0.000**	100.5 ± 46.3	156.7 ± 61.1	*0.000**

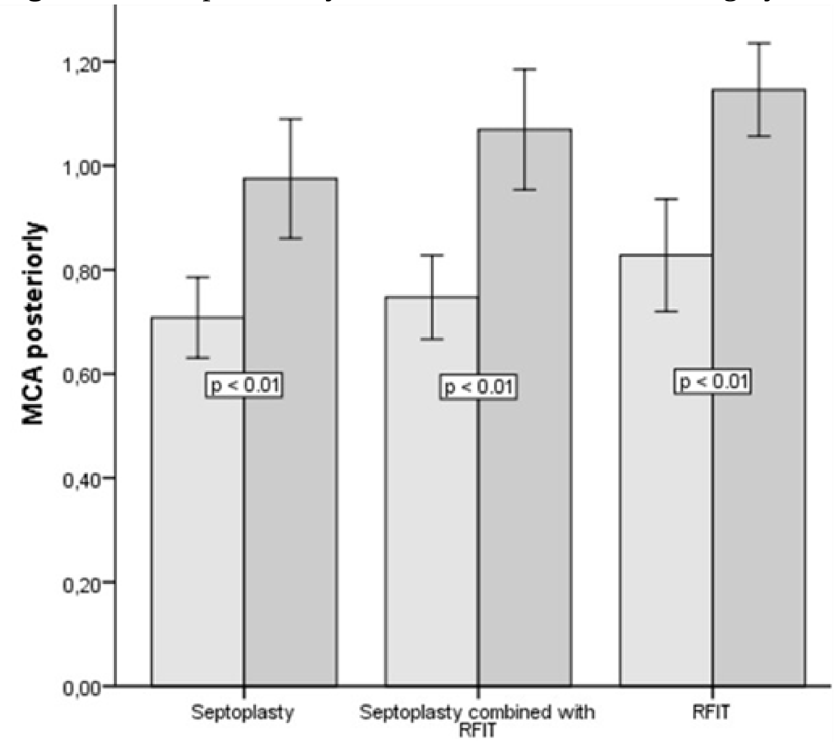
Group 1, septoplasty; group 2, septoplasty combined with RFIT; group 3, RFIT. MCA, minimal cross-sectional area; NCV, nasal cavity volume; tot, mean value of both sides; ns, narrow side; ws, wide side. PNIF recordings from 137 patients; group 1, 45 patients; group 2, 44 patients; group 3, 48 patients. Data are presented as mean with standard deviation. *P-values ≤ 0.01** are considered statistical significant.

Figure 2 MCA anteriorly before and 6 months after surgery



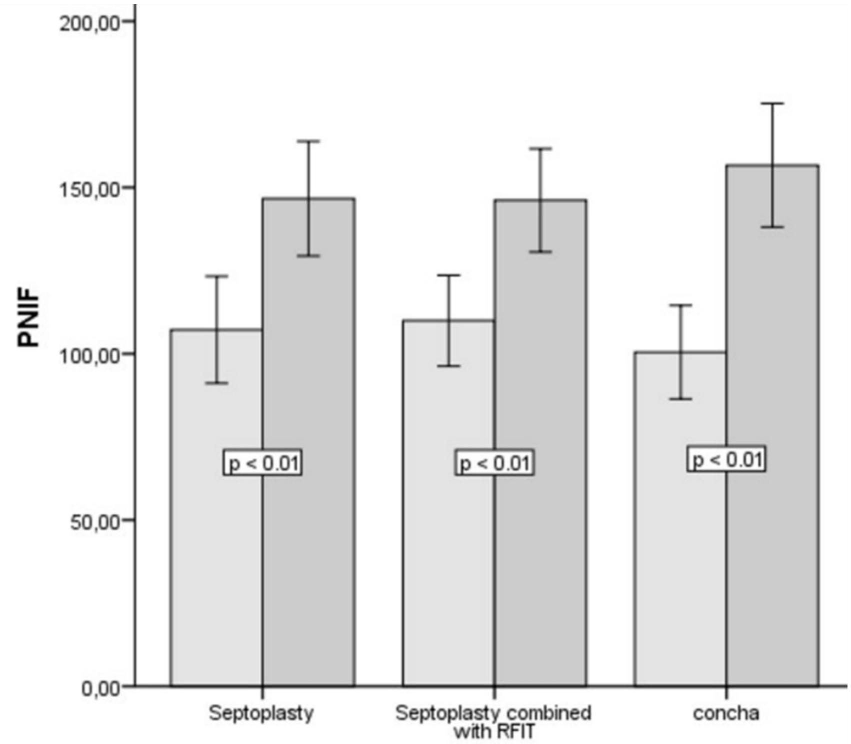
Mean total $MCA_{0-3.0}$: minimal cross-sectional area (cm^2) 0–3.0 cm from nostrils. RFIT: radiofrequency therapy. Error Bars: 95% CI. Light grey bar: pre-operative, dark grey bar: post-operative.

Figure 3 MCA posteriorly before and 6 months after surgery



Mean total $MCA_{3-5.2}$: minimal cross-sectional area (cm^2) 3–5.2 cm from nostrils. RFIT: radiofrequency therapy. Error Bars: 95% CI. Light grey bar: pre-operative, dark grey bar: post-operative.

Figure 4 PNIF before and 6 months after surgery



Mean PNIF: peak nasal inspiratory flow in l/minutes. RFIT: radiofrequency therapy.
Error Bars: 95% CI. Light grey bar: pre-operative, darker grey bar: post-operative.