Septoplasty and/or inferior turbinoplasty produce significant improvements of the sense of smell*

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Abstract

Background: Patients with septal deviation and/or turbinal hypertrophy may experience olfactory disfunction (OD). The aim of this study was to analyse the effect of septoplasty and/or turbinoplasty on both lateralized and bilateral olfactory function.

Methodology: Prospective study of 47 patients with nasal obstruction secondary to septal deviation and/or turbinal hypertrophy and 20 healthy controls. The Barcelona Olfactory test (BOT-8), a new supraliminal orthonasal subjective olfactometry, was applied 3 times in a row (in each nostril separately and in both simultaneously). The 8 items were applied randomly to minimize the possible risk of learning. The test has not established the minimal clinically important difference (MCID). Anterior rhinomanometry and acoustic rhinometry were performed. All participants self-assessed smell loss and nasal obstruction using a visual analogue scale (VAS) and completed questionnaires for nasal obstruction (Nasal Obstruction Symptom Evaluation, NOSE) and for quality of life (QoL), using disease-specific (SinoNasal Outcome Test-22, SNOT-22) and generic (Short Form-12 Health Survey, SF-12) questionnaires. Nasal measurements and questionnaires were performed preoperatively and 12 months after surgery.

Results: Before surgery, patients reported worse VAS on smell loss and on nasal obstruction compared to controls. Patients scored lower BOT-8 than controls. Lateralized preoperative olfactory function showed that all BOT-8 characteristics were lower at the narrow side than the wider one. Smell function and QoL improved significantly one year after surgery.

Conclusions: Nasal septal deviation and turbinal hypertrophy lead to an olfactory impairment on the obstructed nostril. Nasal surgery provides a positive outcome on olfactory function, as well as on subjective and objective outcomes.

Key words: nasal obstruction, septoplasty, smell, smell test, turbinoplasty

Introduction

A lateralized difference in olfactory function is present in 15% of healthy people and 23.4% of patients presenting with olfactory dysfunction (OD) [1,2]. Studies focusing on the association between intranasal airflow and olfactory function have shown that the structure of the nasal cavity, which determines the pattern of nasal airflow, affects the magnitude of odorant molecules that reach the olfactory epithelium [3].

The most common form of nasal obstruction is mechanical [4] and it could be associated with lateralized OD secondary to decreased nasal airflow. Septum deviation and inferior turbinate hypertrophy are the most prevalent types of nasal mechanical obstruction [4]. A clinically significant nasal septal deviation may be associated with changes in olfactory function, nasal resistance, nasal cycle, and mucociliary clearance [5]. In addition, turbinal hypertrophy is often accompanied by OD since olfactory receptors cannot be adequately reached by odour molecules [6]. Nasal surgery, both septoplasty and turbinoplasty, usually produce an improvement in nasal respiratory airflow. This change in nasal airflow and intranasal volumes improves the transport of air molecules to the olfactory region and seems to be beneficial to the patient's olfactory function [7].

To date, few studies have quantitatively compared the differences between both sides of nasal obstruction [7–9] with differing results. It is important to test olfactory perception in each nasal cavity to evaluate the effect of nasal septal deviation and turbinal hypertrophy on olfactory function and thus be able to assess the impact of septoplasty and turbinal surgery on smell function and quality of life (QoL).

We hypothesized that septal deviation and turbinal hypertrophy may lead to OD secondary to reduction of nasal airflow, and this OD may improve after surgery.

The main objective of this study was to investigate olfactory function in patients with septal deviation and/or turbinal hypertrophy and evaluate the effect of surgical therapy (septoplasty and/or turbinoplasty) on both lateralized and bilateral olfactory function. The secondary aim was to determine the changes in nasal airflow, nasal volumes, mucociliary transport, and patients' QoL before and after nasal surgery.

Materials and methods

Study population and design

A prospective observational study was conducted between May 2016 and July 2020 in a tertiary care centre (Hospital Clínic, Barcelona, Spain). The present study received approval from the clinical research ethics committee (HCB/2015/0053). Informed consent was obtained from all the enrolled participants.

Patients aged from 18 to 65 years with symptomatic nasal obstruction due to nasal septal deviation and/or turbinal hypertrophy without response to medical treatment (intranasal corticosteroids for 3 months), candidates for surgical treatment, were included. The age of the group was selected to be representative of the population with nasal obstruction secondary to these pathologies, further considering that young people is not a representative sample of the patients visited with these diagnoses. And supported by literature that demonstrates olfactory function decline markedly after the age of sixty-five [10].

The diagnosis of septal deviation and turbinal hypertrophy was established based on clinical examination with anterior rhinoscopy and nasal endoscopy. Exclusion criteria included pregnancy, allergic rhinitis, chronic rhinosinusitis with or without nasal polyps, previous nasal surgery, septal perforation, and sinonasal malignancies. Patients were also excluded if they suffered known post-viral or post-traumatic hyposmia or any neurological or systematic diseases associated with decreased smell perception. Skin prick allergy testing completed the clinical investigation to identify participants that met the exclusion criteria.

Healthy individuals without nasal obstruction who had neither septal deviation nor turbinal hypertrophy were recruited as controls. Nasal measurements and questionnaires were performed preoperatively and 12 months after surgery.

Nasal outcomes

Subjective evaluation of nasal symptoms

A visual analogue scale (VAS), ranging from 0 to 10cm, was used to assess the severity of smell loss (0, normal smell; 10, total smell loss) and nasal obstruction (0, no obstruction; 10, fully obstructed).

Nasal endoscopy

Nasal examination was carried out with a 0-degree nasal endoscope. According to the side of nasal obstruction, the nasal cavities were divided into narrow (more obstructed) and wide side. Septal deformity was categorized as obstruction of less than or more than 50% of the nostril. Turbinate size was categorized by Camacho´s classification [11]: grade I, 0%–25% of airway space; grade II, 26%–50%: grade III, 51%– 75%; and grade IV, 76%–100%. Then the participants were regrouped as follows: obstruction up to 50% or more than 50% of the nostril. After initial evaluation, the nostrils were classified into narrow nostril (>50% obstruction due to septal deviation o turbinal hypertrophy) and wide nostril.

Barcelona Olfactory Test (BOT-8)

The olfactory function was determined by the BOT-8 [12]. This olfactory test is a supraliminal orthonasal subjective test validated in Spanish population. It contains 8 odorants to study smell detection, memory/recognition, and identification.

The smell test was always performed in the same room. A quiet, noise isolated, well-ventilated room, with controlled humidity and temperature (21-23ºC). The smell test, like the rest of the tests, was always performed by the same two investigators. Olfactory tests were performed for each nostril separately (while the other nasal airway was obstructed) and for both nostrils (birhinal olfaction). Testing started at the narrower side.

The different odours were presented in randomized order using semi-solid state odorants contained in glass jars and placed about 3 cm below the nostrils for 3-5 seconds, with a latency of 30 seconds between odorants. Test were done with unforced nasal inspiration. Eight odorants were used: banana, chocolate, lemon, rose, coffee, onion, mint and vinegar.

Participants were asked to answer Yes or No to the following questions: 1) Can you smell anything? (detection); 2) Do you remember having smelt it before? (memory/recognition); and 3) Which of these 4 odorants is correct? (forced-choice identification). The score was calculated independently for detection, memory, and identification as a percentage, with 8/8 (100%) being

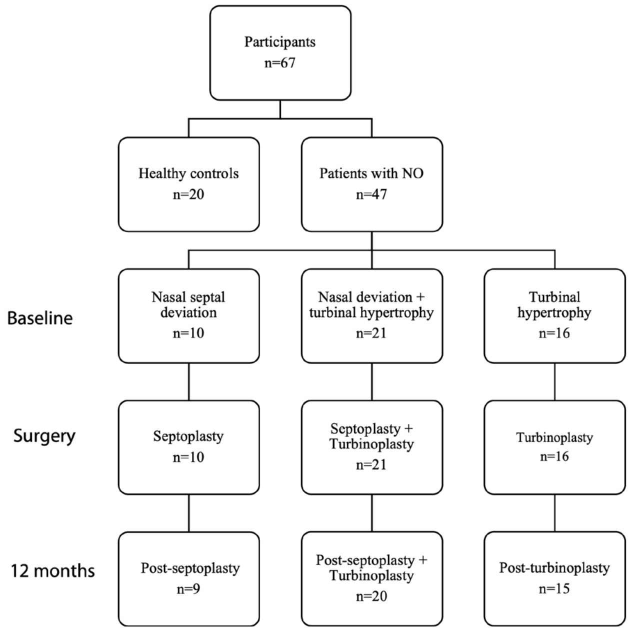

Figure 1. Diagram shows patient flow (NO, nasal obstruction).

the maximum score. The cut-off point for anosmia is ≤37.5% and for hyposmia is ≤75%.

Anterior rhinomanometry

All participants underwent active anterior rhinomanometry (Rhinospir Pro, Sibelmed, Barcelona, Spain). Nasal flow was measured on each side with and without decongestants. Using a facial mask, one of the nostrils was sealed hermetically with an adhesive transparent tape, crossed by a plastic tube which was used for recording the pressure variations, whereas the flow was measured free field through a connection with the mask. The value of nasal airflow at 150 Pa was taken for all assessments of nasal airflow. Decongestion was obtained by using a spray containing 0.5% xylometazoline hydrochloride in both nasal cavities 10 minutes before obtaining the measurements.

Acoustic rhinometry

Acoustic rhinometry (SRE2000, Rhinometrics, Lynch, Denmark) was performed for under standardized form. Minimal cross-sectional area 1 (MCA1) and volume 1 (Vol 1) were measured from each nostril. MCA 1 represented the region coinciding with the nasal valve (0.4 - 2.2cm). Vol 1 described the nasal cavity within the nasal valve region.

Mucociliary clearance

Mucociliary clearance was measured using Saccharin Clearance Time (SCT) [13]. Patients were asked to sit with minimal head extension, and not to speak, sniff, sneeze, or cough. A quarter tablet of saccharin was placed 0.5cm behind the anterior end of the inferior turbinate. Patients were asked to swallow every 60 seconds. The time between placement of the tablet and perception of the sweet taste of saccharin was noted. A normal SCT time is determined to be up to 20 minutes [14].

Disease-specific and overall QoL questionnaires

NOSE

NOSE is a five-item, disease-specific questionnaire for the measurement of nasal obstruction [15]. Each item is scored from zero to four. The sum of scores is multiplied by five, resulting in a final score that ranges from 0 (no symptoms) to 100 (severe nasal obstruction). Participants filled the Spanish-validated version [16].

SNOT-22

The Spanish version of SNOT-22 is a health-related questionnaire in which patients grade 22 different symptoms related to both nasal and general health, and physical and emotional status on a scale from 0 (no symptoms) to 5 (severe symptoms) [17].

SF-12

The Spanish version of SF-12 [18] is a self-reported outcome measure assessing the impact of health on an individual's everyday life. It is often used as a generic QoL questionnaire. The SF-12 uses eight domains: limitations in physical activities, limitations in social activities, limitations in usual role activities, bodily pain, general mental health, limitations in usual role activities, vitality, and general health perception. These domains are then summarized by physical and mental aspects. It is scored from 0 (lowest) to 100 (greatest) impact in QoL.

Surgical procedure

All surgical procedures were performed by two senior surgeons (IA and CL). Depending on the type of obstruction, the following surgeries were performed: septoplasty, turbinoplasty, or septoplasty plus turbinoplasty. Septoplasty was performed according to Cottle technique. Silicone splints were fixed on the nasal septum to prevent septal hematoma and synechiae for 2 weeks. Surgery was completed by intranasal packing for 48 hours. Macrolide antibiotics were prescribed for 3 days. Partial turbinoplasty was performed with Heymann nasal scissors. The resection started at the head of the turbinate and continued to its tail. The turbinoplasty ended with cauterization of the surgical bed with bipolar electrocautery. No silastic or no intranasal packing was used. After the surgical procedure, the surgeon rated his own sense of satisfaction with the surgery. It was measured with a VAS ranging from 0cm (not compliant) to 10cm (fully compliant).

Statistical analysis

Continuous variables were analysed with means and standard deviation (SD), categorical variables with frequency (n) and percentages (%). We used T-Student and Chi-square tests

Table 1. Baseline characteristics of patients and healthy control subjects.

Characteristics	Control group (n=20)	Patient group (n=47)	p-value
Age, years; mean (SD)	38.2 (10.9)	37.4 (12.7)	0.779
Sex, female; n (%)	6 (30)	15 (32)	1.000
VAS (0-10 cm); mean (SD)			
Loss of smell	1.6 (1.8)	3.4 (2.3)	<0.001
Nasal obstruction	1.0 (1.3)	7.0 (1.9)	<0.001
BOT-8 (0-100), mean (SD)			
Smell detection	100.0 (0.0)	97.3 (6.4)	0.006
Smell recognition/memory	95.0 (11.0)	91.5 (16.3)	0.310
Smell dentification	92.8 (10.5)	84.6 (16.3)	0.019
Anterior Rhinomanometry (cm^3/sec), mean (SD)			
Baseline nasal airflow	806.0 (207.0)	647.0 (263.0)	0.020
Post-vaconstriction nasal airflow	962.0 (214.0)	893.0 (351.0)	0.344
Acoustic rhinometry; mean (SD)			
MCA 1 (cm^2)	0.4 (0.2)	0.3 (0.2)	0.002
Volume 1 (cm^3)	7.6 (2.3)	5.6 (2.5)	0.003
Saccharin test (minutes); mean (SD)	6.5 (4.10)	8.4 (4.1)	0.096
NOSE (0-100); mean (SD)	11.0 (8.8)	68.9 (18.0)	<0.001
SNOT-22 (0-110); mean (SD)	12.8 (13.0)	40.3 (18.7)	<0.001
SF-12 physical summary (0-100); mean (SD)	93.1 (7.6)	73.4 (20.4)	<0.001
SF-12 emotional summary (0-100); mean (SD)	87.4 (12.6)	74.9 (15.6)	<0.001

SD: standard deviation, VAS: visual analog scale, BOT-8: Barcelona Olfactory Test, MCA1: Minimal cross-sectional area 1, NOSE: Nasal Obstruction Symptom Evaluation, SNOT-22: SinoNasal Outcome Test-22, SF-12: Short Form-12 Health Survey.

for comparing the control group versus the patient group at baseline time. Baseline olfactory assessment and objective nasal measurements between wide and narrow side, and subjective and objective measurements preoperatively versus one year after surgery, were analysed using a mixed-effect model for repeated measures (MMRM) with patients as a random-effect factor. The correlation of olfactory scores and nasal objective measurements was assessed using Pearson's correlation coefficient. All analyses have been conducted using R, version 4.0.0. The significance level was set as $p<0.05$.

Results

From the 67 participants enrolled in the study, 47 corresponded to patients and 20 to healthy controls (Figure 1). The patient group included 32 men (68%) and 15 women (32%), with a mean age of 37.4 ± 12.7 years (ranged from 18 to 65 years old). The control group included 14 men (70%) and 6 women (30%), with a mean age of 38.2 ± 10.9 years (ranged from 25 to 57 years old) (Table 1). There were no significant differences between age and gender of the patient and control groups. Forty-four patients completed the 12-month follow-up (one patient did not attend the last control visit, one moved to another city, and the last one had a smell loss due to covid infection) (Figure 1).

Regarding the preoperative olfactory function, patients presented a worse rated olfactory function measured by VAS compared to controls. Besides, they presented lower olfactory scores (smell detection, memory/recognition, and identification) on BOT-8 compared to controls. Detection and identification reached statistical significance (Table 1).

With respect to nasal obstruction, patients had higher subjective nasal obstruction (VAS), lower nasal patency (MCA1, Vol 1) as well as lower nasal airflow compared to controls (Table 1). The values of the anterior rhinomanometry and acoustic rhinometry of treatment subgroup can be seen in Table 2.

Patients had longer SCT than controls without a statistically significant difference. Additionally, the patient group had significant severe nasal obstruction measured by the questionnaire (higher NOSE scores) and worse QoL (measured by SNOT-22 and SF-12 test) than controls (Table 1). At baseline, there were no significant correlations between subjective (smell loss and nasal obstruction VAS) and nasal objective measurements.

The analysis of lateralized preoperative olfactory function in patient group, showed that all BOT-8 characteristics (smell detection, memory/recognition, and identification) were lower at

Table 2. Airway measurements in the three treatment subgroups.

	Septoplasty (n=10)	Turbinoplasty (n=16)	S + T (n=21)	p overall
Anterior Rhinomanometry (cm3/sec), mean (SD)				
Baseline nasal airflow	725 (195)	587 (235)	681 (322)	0.408
Post-vaconstriction nasal airflow	921 (290)	852 (393)	917 (360)	0.843
Acoustic rhinometry; mean (SD)				
MCA 1 (cm^2)	0.32 (0.14)	0.30 (0.13)	0.27 (0.24)	0.802
Volume 1 (cm^3)	6.94 (2.30)	5.43 (1.78)	5.01 (2.90)	0.131

SD: standard deviation, MCA1: Minimal cross-sectional area 1, S+D: septoplasty + turbinoplasty.

Table 3. Comparison of baseline olfactory assesment and objective nasal measurements between wide and narrow sides.

Tests	Wide side	Narrow side	p-value
BOT-8 (0-100); mean (SD)			
Smell detection	94.4 (10.4)	85.1 (23.4)	0.006
Smell recognition/memory	77.4 (21.9)	70.5 (31.5)	0.065
Smell identification	72.9 (19.0)	67.6 (26.2)	0.126
Anterior Rhinomanometry (cm^3/sec), mean (SD)			
Baseline nasal airflow	359.7 (176.0)	288.5 (176.0)	0.056
Post-vaconstriction nasal airflow	478.4 (199.0)	414.7 (202.0)	0.037
Acoustic rhinometry; mean (SD)			
MCA 1 (cm^2)	0.4 (0.3)	0.2 (0.1)	0.032
Volume 1 (cm^3)	6.6 (3.1)	4.6 (2.9)	< 0.001

SD: standard deviation, BOT-8: Barcelona Olfactory Test, MCA1: Minimal cross-sectional area 1.

the narrow side than the wider one (Table 3), indicating a worse olfactory function in the obstructed nostril. When we evaluate the other objective nasal measurements, the anterior rhinomanometry showed significant lower nasal airflow after but not before vasoconstrictor in the narrow nostril. The MCA1 and the Vol 1 were significantly lower on the narrower nostril.

One year after surgery patients had a better subjective rating of smell loss and nasal obstruction, both statistically significant (Table 4). The postoperative quantitative assessment of patients' unilateral and bilateral olfactory function revealed a significant improvement in all olfactory scores of BOT-8 (detection, memory, and identification) (Table 4). Prior to surgery, 64% (n=30) of patients were normosmic, 34% (n=16) were hyposmic and 2% (n=1) was anosmic, whereas postoperative results indicated that 88% (n=38) of patients were normosmic, 12% (n=5) were hyposmic and there were no anosmic patients. No patient presented impairment of their olfactory function.

There was a unilateral and bilateral improvement in patients' MCA, Vol1 and nasal airflow values, indicating that there was a significant nasal patency increase one year after surgery ($p < 0.05$ for all parameters) (Table 4).

Regarding to QoL, patients showed an improvement of the NOSE test, nasal QoL (SNOT-22) and SF-12. The NOSE difference before and after surgery was 50.3 (68.9 to 18.6), which demonstrates a significant clinical improvement of nasal obstruction symptoms.

One year after surgery, there were no significant correlations between subjective (smell loss and nasal obstruction VAS) and nasal objective measurements. After the surgical procedure, the mean VAS score of satisfaction of the surgeon with the procedure was 8.2 ± 1.6cm. No complications during surgery or 1 year follow-up were observed.

Discussion

The main findings of our study were:

1) Sense of smell measured by VAS and BOT-8, were significantly worse in patients with septal deviation and/or turbinal hypertrophy than healthy control.

2) Smell test score was lower on the narrower nasal cavity.

3) Nasal surgery (septoplasty and/or inferior turbinate surgery) produced significant improvements in the sense of smell.

4) Nasal surgery improved subjective (VAS, NOSE) and objective (rhinomanometry, acoustic rhinometry) nasal function, mucociliary function (SCT), and quality of life (SNOT-22 and SF-12).

Table 4. Subjective and objective nasal measurements of the patients (preoperative and 1 year after surgery).

Characteristics		Pre-operative (n=47)	Post-operative (n=44)	p-value
VAS (0-10 cm); mean (SD)				
Loss of smell		3.4 (2.3)	0.5 (0.7)	<0.001
Nasal obstruction		7.0 (1.9)	1.5 (2.2)	<0.001
BOT-8 (0-100), mean (SD)				
Smell detection	Narrow side	85.1 (23.4)	98.5 (4.9)	<0.001
	Wide side	94.4 (10.4)	98.8 (4.6)	0.041
	Bilateral	97.3 (6.4)	100.0 (0.0)	0.006
Smell recognition/memory	Narrow side	70.5 (31.5)	93.0 (13.4)	<0.001
	Wide side	77.4 (21.9)	93.9 (11.0)	0.041
	Bilateral	91.5 (16.3)	98.8 (3.7)	0.005
Smell dentification	Narrow side	67.6 (26.2)	84.6 (20.0)	<0.001
	Wide side	72.9 (19.0)	85.2 (18.6)	0.041
	Bilateral	84.6 (16.3)	91.9 (14.1)	0.001
Anterior Rhinomanometry (cm^3/sec), mean (SD)				
Baseline nasal airflow	Narrow side	288.5 (176.0)	512.6 (168.6)	<0.001
	Wide side	359.7 (176.0)	504.3 (166.6)	0.041
	Bilateral	647.0 (263.0)	1017.0 (294.0)	<0.001
Post-vaconstriction nasal airflow	Narrow side	414.7 (202.0)	567.6 (217.8)	<0.001
	Wide side	478.4 (199.0)	603.1 (201.3)	0.001
	Bilateral	893.0 (351.0)	1171.0 (376.0)	<0.001
Acoustic rhinometry; mean (SD)				
MCA 1 (cm^2)	Narrow side	0.2 (0.1)	0.5 (0.3)	< 0.001
	Wide side	0.4 (0.3)	0.5 (0.2)	0.010
	Bilateral	0.3 (0.2)	0.4 (0.2)	0.010
Volume 1 (cm^3)	Narrow side	4.6 (2.9)	9.0 (3.8)	< 0.001
	Wide side	6.6 (3.1)	9.4 (3.8)	< 0.001
	Bilateral	5.6 (2.5)	8.0 (3.6)	0.002
Saccharin test (minutes); mean (SD)		8.4 (4.1)	5.7 (3.1)	< 0.001
NOSE (0-100); mean (SD)		68.9 (18.0)	18.6 (19.2)	< 0.001
SNOT-22 (0-110); mean (SD)		40.3 (18.7)	10.9 (12.8)	< 0.001
SF-12 physical summary (0-100); mean (SD)		73.4 (20.4)	87.5 (15.2)	< 0.001
SF-12 emotional summary (0-100); mean (SD)		74.9 (15.6)	81.8 (21.8)	0.070

SD: standard deviation, VAS: visual analog scale, BOT-8: Barcelona Olfactory Test, MCA1: Minimal cross-sectional area 1, NOSE: Nasal Obstruction Symptom Evaluation, SNOT-22: SinoNasal Outcome Test-22, SF-12: Short Form-12 Health Survey

Using VAS and smell test, the authors demonstrated that bilateral smell scores of the patient´s group preoperatively were significantly lower than the control group. Our findings are in line with the only study that has investigated the presence of lateralized olfaction in patients who underwent septoplasty/turbinal surgery, including a control group [7]. Valsamidis et al [7] studied 60 patients' candidates for septoplasty and turbinoplasty with radiofrequency. They reported a higher smell loss at VAS and a decreased bilateral olfactory function (Sniffin' sticks) in the patients' group compared to the controls.

When nasal obstruction was preoperatively analysed in both groups, the observation demonstrated that septal deviation and turbinal hypertrophy caused nasal obstruction using subjective (VAS, SNOT-22, and NOSE) and objective (MCA1, VOL 1) assessments. These preoperative findings mean that despite nasal obstruction being the leading symptom in patients with nasal septal deviation, olfactory dysfunction is also common.

With reference to lateralized nasal function prior to surgery, our

Table 5. Olfaction in patients with nasal septal deviation and/or turbinal hypertrophy treated with septoplasty ± turbinate surgery.

Study	n	Olfactory test	Lateralized olfactory assesment	Type of surgery	FU	Pre-operative olfaction	Post-operative olfaction
Damm et al. 2003 (25)	30	SST (OT, OD, OI)	Yes (OT)	SP, IT	4mo	7% were anosmic; 60% hyposmic and 33% normosmic	0% were anosmic; 20% hyposmic and 80% normosmic. Significant improvement of OT (5%), OD (70%), OI (80%) scores, albeit modest in OT
Pfaar et al. 2004 (9)	25	SST (OT, OD, OI)	Yes	SP	4mo, 9mo	80% normosmics, 20% hyposmics, Narrow side: OT worse	No OT side-difference postop. No change of overall olfactory function
Pade et al. 2008 (32)	150	SST (OI)	No	SP	4mo	Mean identification score of 12.3 (2.3)	Mean identification score of 12.8 (2.0). Improvement: 13%; no change: 81%; decrease: 7%
Philpott et al. 2008 (40)	30	COT	No	SP	12mo	OT reduced, OI good, SR: 46.7% reduced olfaction	Improvement in olfaction (COT), mainly in OT
Garzaro et al. 2010 (6)	40	SST	No	IT	2mo	5% were anosmic, 82% hyposmic and 12% normosmic.	2% were anosmic, 12% hyposmic and 85% normosmic. The means of preoperative OT, OD OI and the overall TDI score improved significantly postoperatively.
Fyrmpas et al. 2012 (8)	30	12 SST (OI)	Yes	SP ± IT	2mo	20% lateralized olfaction	13% lateralized olfaction, decrease of subjective hyposmia
Schriever et al. 2013 (41)	44	SST (OI)	No	SP, IT	12mo	Mean identification score of 12.1 (3.7)	Mean identification score of 12.6 (2.5). No significant change in identification score
Dengiz et al. 2015 (42)	53	BSIT	No	SRP	4wk, 12wk	Mean preoperative score of 10.1 (1.3)	Change in mean BSIT score was not significant at 4wk, but became significant at 12wk postoperatively
Gupta et al. 2015 (21)	37	CCCRC (OT, OI, COS)	Yes	SP	4wk	VAS – COS and SFNQ – COS (obstructed side) correlated	Improvement of SR and COS for the obstructed side. Improvement of smell in 70.6%
Berkiten et al. 2016 (31)	50	CCCRC (OT, OI)	Yes	SP	6wk	Mean score of 3.8 (0.9)	Statistically significant improvement
Dalgic et al. 2016 (29)	39	SST (OT, OD, OI)	No	SP (ts,m)	1wk, 3mo	Mean composite score of hyposmia (29.6 group A (ts); 29.5 group B (m))	OT, OD and OI scores increased significantly at 3mo
Kilicaslan et al. 2016 (30)	37	CCCRC (OT, OI)	No	SP, IT	1wk, 6wk, 6mo, 1yr	2.7% had moderate hyposmia, 10.8% mild hyposmia, and 86.5% normosmia	Total olfaction worsened at 1wk, was the same as pre-op after 3wk, and improved after 6mo and 1yr. By 6mo all patients had become normosmic.
Randhawa et al. 2016 (43)	43	SST (OD)	No	SRP	12wk	NR	Significant change in SST score. 58% improved, 35% remained the same, 7% worsened
Choi et al. 2016 (44)	5	BTT	Yes	SP	6mo	NR	Improved birhinal BTT
Haytoglu et. al 2017 (45)	116	BSIT	No	SP	1mo, 3mo	Mean preoperative scores of 8.8 (1.2) in smokers and 8.6 (1.2) in non-smokers. No differences between smoking habit	BSIT scores worsened at 1mo, but improved above baseline at 3mo in both smokers and non-smokers
Turk et al. 2017 (28)	30	SST (OT, OD, OI)	No	SP	6wk	33.3% of patients were normosmic, 60.0% hyposmic, and 6.7% anosmic	Significant improvement in SST scores. 63.3% of patients were normosmic, 36.7% hyposmic, and none anosmic 6wk after surgery.

Study	n	Olfactory test	Lateralized olfactory assesment	Type of surgery	FU	Pre-operative olfaction	Post-operative olfaction
Aydogdu et al. 2019 [27]	39	CCCRC	Yes	SP	8wk	Mean preoperative scores of 3.0 (0.6) and 2.9 (0.5) for conventional and extracorporeal septoplasties, respectively	Significant improvement. No differences between surgical techniques
Kokubo et al. 2019 [46]	34	UPSIT	No	SRP	4wk, 12wk	79.4% of patients had normosmia, 14.7% mild hyposmia, and 5.9% moderate hyposmia	76.5% of patients had normosmia, 20.6% mild hyposmia, and 2.9% moderate hyposmia. No change in USPIT score after 4wk nor 12wk postoperatively
Valsamidis et al. 2019 [7]	60/25 controls	SST (OT, OD, OI)	Yes	SP, IT	6mo	31.7% were normosmic and 68.3% had olfactory deficits. Significantly lower scores than controls in all SST sub-tests	Significantly improved olfactory function, but still worse than controls
Mackers et al. (current)	47 patients/20 controls	BOT-8	Yes	SP, IT	12mo	Lower scores than controls in BOT-8 parameters. Narrow side: BOT-8 worse than wide nostril.	Significantly improved olfactory function.

n: number of patients; FU: follow-up, mo: months, wk:weeks, yr: years; SP: septoplasty; SRP: septorhinoplasty; IT: surgery of the inferior turbinate; SST: Sniffin' Sticks Test; UPSIT: University of Pennsylvania Smell Identification Test; BTT: Butanol Threshold Test; BSIT: Brief Smell Identification Test; CCCRC: Connecticut Chemosensory Clinical Research Center test; BOT-8: Barcelona olfactory test; OI:Olfactory identification; OT: Olfactory threshold; OD: olfactory discrimination; COT: Combined Olfactory Test; COS: combined olfactory score; SFNQ: Short form nasal questionnaire; SR: Subjective report; VAS: visual analog scale; ts: transseptal sutures; m: merocele packing; NR: Not Reported.

study showed a difference in olfactory function, including odour detection, memory, and identification between the two nostrils. These findings are consistent with those described in the literature [7–9,19–21]. The same results were found in measurement of nasal volume, MCA1 and nasal airflow when the narrow nostril was compared with the wider one.

Despite that few patients complain about unilateral olfactory loss, we believe it is important to assess lateralized olfactory function. In fact, significant side differences of odour perception have been described in 15% of healthy subjects [1]. Welge-Lusen et al. [2], evaluated patients with olfactory disorders due to different etiologies using the extended "Sniffin' Sticks" test battery applied to each nostril separately. They found a differences of six or more points in the TDI-score between the right and left nostrils in 23.4% of patients. Gudziol et al. [22] provide an additional strong reason for lateralized olfactory function testing. They studied, using "Sniffin' Sticks", 35 normosmic individuals with side differences (difference group) and 58 subjects who did not demonstrate side differences (control group). Re-test were done on average 4.6 years after baseline investigations. Olfactory testing at follow-up indicated lower olfactory function in the "difference group" than in the "control group". These results suggest that individuals with side differences of olfactory function are at risk to develop bilateral olfactory loss within 4.5 years. Thus, the degree of lateralized smell function could be an indicator for future smell loss.

It seems reasonable to think that the nasal airway patency is critical to determine the odorant transport that reach the olfactory mucosa, with the consequent changes in olfactory function. The association between the intranasal airflow and olfactory function have shown that the structure of the nasal cavity, which has a significant effect on intranasal airflow, is affecting olfactory function [3,19,23,24].

Zhao et al. [3] developed a method to convert nasal CT scans from an individual patient into a 3-D numerical nasal model that can be used to predict air flow and odorant transport, which may ultimately determine olfactory sensitivity. Their results suggest that anatomical changes in the olfactory region (upper meatus below the cribriform plate) and the nasal valve region will strongly affect airflow patterns and odorant transport through the olfactory region, with subsequent effects on olfactory function.

Previous studies demonstrated that nostrils transmit the odour molecules present in the air to the olfactory neuroepithelium areas which are located on the superior nasal septum, the cribriform plate region, and the superior turbinate, with a variable surface area [25]. During sniffing and snoring, turbulence airflow occurs, and odour molecules are directed to the mucosa of the

olfactory area by diffusion [5].
Another important parameter to mention, is how the sniffing behavior affects the abundance of odorants transferred to the olfactory cleft and in turn influences odor perception. In this field of research, Beauchamp et al. [26] studied using a spectrometer with an odorant pulse delivery olfactometer, the intranasal odorant concentrations of butane-2,3-dione at the interior naris and the olfactory cleft. They concluded that the highest concentrations at both areas in the nose were observed during normal sniffing, with the lowest concentrations correlating with periods of forced sniffs.
Regarding the effect of septal dysmorphia and turbinate hypertrophy on smell function, previous investigations have found that septal deviation results in decreased olfactory function at the obstructed nasal side (Table 5). Concerning the isolated effect of turbinate hypertrophy on smell, the published literature is limited. As demonstrated in radiological and clinical studies, the volume around the inferior turbinates is correlated with olfactory function [6]. Garzaro et al. [6] studied smell function in 40 patients with turbinal hypertrophy candidates to turbinal surgery, using TDI score (Table 5).
Nasal surgery produces a change in nasal respiratory airflow, which many patients experience as an improvement. This change of nasal respiratory airflow also seems to be beneficial to the patient's olfactory abilities [9]. In the current study, septoplasty and/or turbinoplasty, produce significant improvements in the sense of smell. One year after surgery, the detection, memory, and identification of the narrower nostril showed an improvement compared to baseline. Patients also reported an improvement on the BOT-8 score at the wider nostril. Even the difference between obstructed and non-obstructed sides disappeared at 12 months. Our results suggest that septoplasty and inferior turbinate surgery provide excellent results in terms of subjective measures and objective assessment of both olfactory function and nasal airflow. These results are in line with previous studies that report that nasal septoplasty is associated with a decrease in nasal resistance, and increased nasal patency leads to an improvement in smell function [7]. Previous studies evaluating olfaction before and after surgery presented controversial results (Table 5). Most of them showing an improved smell perception [7,21,25,27–31], others reported no significant changes [9,32], and even some showed temporary smell impairment [30].
Another important finding was that NOSE, SNOT-22, and SF-12 questionnaires, showed significant improvement one year after surgery. The minimal clinically important difference (MCID) has been previously assessed as 19.4 for NOSE [33] and in 8.9 for SNOT-22 [17]. In our study, the score difference between patient groups pre- and post-surgery was -50.3 for NOSE and -29.4 for SNOT-22, which demonstrates a significant clinical improvement of nasal and general symptoms. Previous findings have also confirmed that a preoperative high NOSE score predicted a greater improvement of NOSE score after surgery [15]. Another study demonstrated that nasal obstruction symptoms' severity rather than olfactory function was a prognostic factor of patients' general QoL improvement after septoplasty [34].
Although the subjective and objective variables presented a significant improvement 12 months after surgery, the study was not able to demonstrate a positive correlation between VAS loss of smell and BOT-8, nor between VAS nasal obstruction and nasal patency. We didn't find either a correlation between nasal patency and smell function.
The order in which the VAS of smell and olfactometry were perform could act as a determining factor in the correlation of both variables. Landis et al. [35] found that when VAS preceded measurements of olfactory function, there was no significant correlation between the two parameters. However, VAS of smell correlated significantly with ratings of nasal airway patency. This last correlation could not be demonstrated in our study probably to patients were more aware of the degree of nasal obstruction than of the olfactory deficit. This lack of correlation between objective and subjective parameters is an aspect that could be improved by designing a study that evaluates the subjective parameters (mainly nasal obstruction) of each nostril separately, both in the narrow and the wider one.
An ongoing discussion among rhinologists is whether it is reasonable to routinely perform objective measurements of nasal patency before and after surgery. The main argument against it is a huge discrepancy in results [36]. Gungor et al. [37] did not find correlations between VAS and acoustic rhinometry during the nasal cycle and Yepes-Nuñez et al. [38] found that symptom score correlated weakly with acoustic rhinometry (Vol0-6 and MCSA).
Regarding mucociliary transport measured by the saccharin test, this improved one year after surgery. Although the turbinoplasty technique may be a more aggressive technique than the submucosa one, with greater complications and with a greater decrease in the efficiency of mucociliary transport (39), our patients did not present complications due to this procedure, and even the function ciliary improved in all surgery groups one year after the intervention.
To our knowledge this is the first long-term (12 months), prospective and controlled study that investigate the presence of lateralized olfaction in patients who underwent septoplasty and/or turbinoplasty.
The present study indicates that surgical changes in the nasal pathways may change olfactory function and, consecutively, may have a considerable impact on the patient's QoL. Besides, we score the surgeon satisfaction during the surgery to avoid human bias on the results. Both main surgeons had high VAS satisfaction score.
The limitations of our study were: 1st) The sample size did not allow a specific analysis on the sense of smell between the three groups of surgical techniques (septoplasty, turbinoplasty, or

combined surgery), being unable to demonstrate differences between these three types of surgery (it was not designed to test that hypothesis due to insufficient sample size and statistical power to detect a difference). 2nd) no imaging methods (MRI, CT scan) were used to evaluate the size of olfactory bulb and nasal air pathways after surgery; and 3rd) We used a psychophysical test in sequence, preoperative and one year after surgery. The authors are aware that repetitive application of an 8-item odor identification test 3 times in a row can be accompanied by learning effects. In order to reduce bias, all odors were applied to each nostril in a randomized order and no feedback regarding test results were provided to patients until completion of the testing one year after surgery. Despite this, the authors cannot rule out a certain degree of learning.

Conclusion

Nasal septal deviation and turbinal hypertrophy may lead to an olfactory impairment on the obstructed nostril while septoplasty and/or turbinoplasty may provide a positive outcome on olfactory function. Surgery was also effective to improve subjective and objective measurements of nasal function. Nasal obstruction has a negative impact on QoL while septoplasty and/or turbinoplasty improved QoL at the level of healthy population; this improvement remaining one year after surgery. These results provide further insight into the effects of such surgical procedures on olfaction and serve as a reference for the surgeon when prospectively counselling patients.

Authorship contribution

Conceptualization: PM, IA and JM; methodology, PM, AN, CL and IA; formal analysis, PM, MJR-L; data curation, PM, MJR-L; writing—original draft preparation: PM; writing—review and editing: PM, MJR-L, AN, CL, IA, JM; supervision, IA and JM; project administration, IA and JM. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

Joaquim Mullol has received research grants from AstraZeneca, Genentech, GSK, Viatris/MEDA Pharma, Novartis, Regeneron, Sanofi-Genzyme and Noucor/Uriach Group; consulting fees from Sanofi-Genzyme and Noucor/Uriach Group and attended speaker bureaus and/or advisory boards for AstraZeneca, Genentech, GSK, Glenmark, Menarini, Mitsubishi-Tanabe Pharma, MSD, Viatris/MEDA Pharma, Novartis, Proctor & Gamble, Regeneron Pharmaceuticals Inc., Sanofi-Genzyme, UCB Pharma, and Noucor/Uriach Group. Isam Alobid has received honoraria for consultancy and conferences from Viatris, Roche, Sanofi, GSK, MSD, Menarini, Salvat and Novartis.

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