Objective nasal airflow measures in relation to subjective nasal obstruction, trigeminal function, and olfaction in patients with chronic rhinosinusitis

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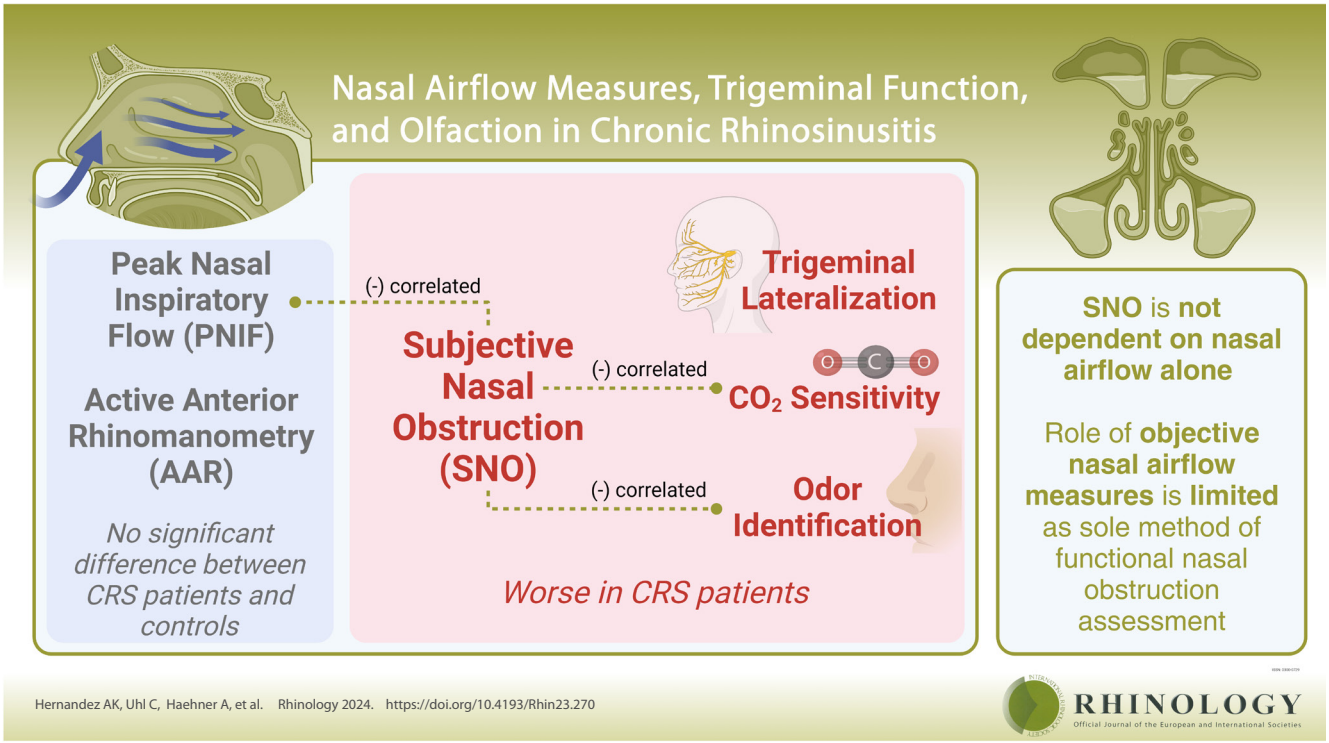

Abstract

Background: This study aimed to determine how nasal airflow measures and trigeminal function vary among patients with chronic rhinosinusitis (CRS) versus healthy controls and whether these measures are correlated with subjective nasal obstruction (SNO), olfactory function, and CRS control.

Methodology: Participants included CRS patients and healthy controls. After a structured medical history, nasal airflow (peak nasal inspiratory flow [PNIF]; active anterior rhinomanometry [AAR]), trigeminal function (trigeminal lateralization test, CO_2 sensitivity), and olfactory ("Sniffin' Sticks" odor identification test) tests were performed. SNO ratings were also obtained.

Results: Sixty-nine participants were included (37 men, 32 women, mean age 51 years). There was no significant difference for objective nasal airflow between patients and controls, but CRS patients had worse SNO, trigeminal function, and olfaction compared to controls. SNO, but not objective nasal airflow tests, was negatively correlated with CO_2 sensitivity and odor identification.

Conclusion: The perception of nasal obstruction does not only depend on nasal airflow, but may also be modulated by trigeminal function and other factors. Thus, the role of objective nasal airflow measures as a sole method of functional nasal obstruction assessment in CRS remains limited.

Key words: nasal obstruction, sinusitis, nasal polyps, trigeminal nerve, rhinomanometry

Introduction

Chronic rhinosinusitis (CRS) affects 5-12% of the general population [1]. The presence of nasal obstruction and loss of smell are common symptoms that are associated with decreased quality of life (QoL) in patients [1–3]. Although fewer studies have focused on trigeminal function in CRS, there is evidence to support impairment in these patients [4–9].

Various studies have investigated nasal airflow [10–12], trigeminal function, and olfaction in CRS, but often only in isolation or in pairs. To our knowledge, only one study investigated these three parameters in CRS patients. Saliba et al. [7] performed nasal airflow, trigeminal, and olfactory tests in CRS patients without nasal polyps (CRSsNP). They found no significant differences in objective nasal airflow (measured using peak nasal inspiratory flow [PNIF]) and olfactory measures between patients and controls in their study. However, CRS patients reported worse subjective nasal obstruction and had decreased trigeminal sensation, and trigeminal sensation was proposed to modulate the sensation of nasal obstruction [7]. The sample size in their study was quite low, with only 14 CRS patients included.

Despite evidence showing a relationship between CRS and trigeminal function [5–9,13,14], as well as olfactory sensitivity and nasal airflow [1,15–17], complete psychophysical or objective tests for these parameters are more likely to be performed only during specialist consultations. Although anatomic nasal patency may be determined through nasal endoscopy, the European Position Paper on Rhinosinusitis and Nasal Polyps 2020 (EPOS 2020) guidelines made no explicit recommendations for objective nasal airflow testing (PNIF; active anterior rhinomanometry, AAR; or acoustic rhinometry) in CRS [1]. Moreover, the same guidelines did not elaborate on recommendations for trigeminal testing in CRS (1). Objective evaluation of nasal airflow may require instruments or equipment [18] that are not as easily accessible when compared to simply asking patients to give ratings or answer questionnaires. Furthermore, nasal obstruction in CRS has been hypothesized to be associated with decreased trigeminal function [7,9]. It is of interest to know the relationship between trigeminal function and nasal airflow and whether the former may be used to predict the latter among CRS patients.

Our study aimed to determine how nasal airflow and trigeminal function measurements vary between patients with chronic rhinosinusitis (CRS) and healthy controls and whether these measures correlate with subjective nasal obstruction (SNO), olfaction and disease severity.

Materials and methods

This cross-sectional study was approved by the Institutional Review Board of the University Hospital Dresden and was conducted according to the principles in the Declaration of Helsinki. All participants provided their written informed consent.

Participants

The study included adults (≥18 years), diagnosed with CRS based on the EPOS 2020 guidelines and admitted for surgery (CRS patients) and patients who consulted for non-nasal complaints (controls) at the University Hospital Dresden. Structured medical history was taken, including age, gender, previous nasal surgery (including the number and types of previous nasal surgeries), and rescue medications (intranasal corticosteroids ± biologics). CRS control (disease severity) and SNO ratings (see below) were also obtained.

CRS control score

To better understand the degree of disease severity among the CRS patients, we opted to estimate disease control using the following variables based on the EPOS 2020 guidelines on CRS control [1]: 1) Nasal symptom count (based on scores from items 1 [nasal obstruction], 3 [rhinorrhea], 10 [smell loss], 12 [facial pain/pressure], and 13 [sleep problems] of the Sinonasal Outcome Test-20 German Adapted Version [SNOT-20 GAV], where a score of ≥3 (moderate problem) would correspond to 1 point for each item; 2) Nasal polyp scores (Lildholdt or Lund Kennedy, taken bilaterally), where scores ≥2 would correspond to diseased mucosa, also corresponding to 1 point; 3) Rescue medications currently used, where one needed (at least) 1 course of rescue treatment (intranasal corticosteroids [mometasone or budesonide], biologics or both) corresponding also to 1 point. A sum of ≥3 out of the 7 variables was considered as uncontrolled CRS. Greater than 1 but <3 was considered as partly controlled CRS and 0 was controlled CRS.

Subjective nasal obstruction rating

Based on the work by Piccirillo et al. [19], a validated German translation of the 20-item Sinonasal Outcome Test [20] was administered to participants. This included items about rhinologic symptoms and overall QoL. Participants were instructed to rate each symptom from 0 (no problem) to 5 (problem as bad as it can be), to better illustrate the severity of the symptoms. Only the ratings for question 1 (SNO) were used in the analysis.

The following measures were also determined: PNIF and AAR (before and difference after decongestion; nasal airflow), trigeminal lateralization test and CO_2 sensitivity (trigeminal function), "Sniffin' Sticks" odor identification test (olfaction).

Peak Nasal Inspiratory Flow

Peak nasal inspiratory flow (PNIF) is a measure of nasal airflow (in l/min) using an inspiratory flow meter (Order number 3109750; Clement Clarke Int. Ltd., Harlow, UK). The test was done twice,

with each participant asked to inhale deeply through both nostrils with their mouths closed each time. The higher value of the two attempts was recorded.

Active Anterior Rhinomanometry

Active anterior rhinomanometry (AAR) measures nasal airway resistance from airflow and pressure readings. Using the Rhino-Sys system (Happersberger Otopront GmbH, Hohenstein, Germany), a probe was secured over one of the nostrils while the nose and mouth were covered with a mask attached to the device. Measurements (in ml/s) were done according to manufacturer recommendations and correspond to the total volume of air through the left and right nasal cavities during the inspiratory phase of the respiratory cycle at a trans-nasal pressure difference of 150 Pa) before decongestion (AAR B Before Decongestion with Xylometazoline hydrochloride), after decongestion (AAR B After Decongestion) and the difference between after and before decongestion (AAR B Change) were included in the analyses.

Nasal cycle

To control for the impact of the nasal cycle, all measurements of nasal airflow were noted as the sum of scores for both nostrils. A previous study by Gungor [21] found no correlation between VAS ratings for nasal patency and the nasal volumes or cross sectional areas during the nasal cycle and that the sum of the left and right volumes and areas were quite constant. Thus, the same method was applied in this study.

Trigeminal Lateralization Test

Using 2 squeezable polypropylene bottles pressed simultaneously using a device [22], puffs of air were delivered into both nostrils. One bottle contained 10 ml of 99% Eucalyptol (order number C80601; Sigma Aldrich, Taufkirchen, Germany) while the other bottle contained only air. Participants were asked to identify which side of the nose was presented with Eucalyptol (total of 20 presentations with randomized selection of stimulated nostril, interstimulus interval: 20 s). The sum of correct lateralizations comprised the score (highest: 20).

CO_2 sensitivity

Participants were presented with 100% CO_2 in both nostrils (airflow: 200 ml/min) using a nasal cannula and were asked to press a button when the stimulus was perceived. Until then, the stimulus duration increased by 100 ms steps at an interval of 8 s. Maximum stimulus duration was 2000 ms. A "CO_2 threshold" corresponded to the duration where participants were able to perceive the stimulus and was determined using a staircase method with seven turning points. For statistical analysis, the scores were multiplied by -1 for ease of interpretation and were subsequently referred to as "CO_2 Sensitivity", with a lower number corresponding to worse function.

"Sniffin' Sticks" 16-item Odor Identification Test

In the "Sniffin' Sticks" odor identification test (Burghart Messtechnik, Holm, Germany [23,24]), devices similar to felt tip pens filled with common odors were presented to participants at a distance of approximately 2 cm in front of both nostrils. They were asked to identify the odor from a selection of 4 verbal descriptors. The sum of correct answers comprised the score, ranging from 0 to 16 (highest).

Data collection and statistical analysis

Patient records were assigned codes and anonymized. Data were analyzed using SPSS software (Version 28.0; IBM Corp., Armonk, NY, USA). Independent sample t-test, Pearson's r correlation, chi-square test, and Fisher's exact test were used in the analysis of the data, with a p-value of <0.05 considered as significant.

Results

Sixty-nine participants were included (37 men, 32 women; age 28 to 76 years, mean 51 years). There were no significant differences in age, but there was a significant association between gender and group (patient/control group, $\chi_{(1,69)}=4.05$, $p=0.04$); and between previous surgery and group, with more patients having previous nasal surgery (Fisher's exact test, $p<0.001$); between asthma and group, with more controls not having asthma (Fisher's exact test, $p<0.001$). Means, medians, and frequencies are shown in Table 1.

Group differences for objective nasal airflow and trigeminal measures

There were no significant differences in PNIF and AAR measurements in CRS patients and controls. However, CRS patients had worse SNO ratings ($t_{64}=3.55$, $p<0.001$), lower trigeminal lateralization scores ($t_{67}=2.07$, $p=0.04$), decreased CO_2 sensitivity ($t_{56.96}=4.45$, $p<0.001$), and lower odor identification scores ($t_{48.46}=6.25$, $p<0.001$) compared to controls.

Correlation between the different objective nasal airflow measures and SNO

PNIF was positively correlated with AAR B After Decongestion ($r_{62}=0.28$, $p=0.03$), but not with AAR B Before Decongestion or AAR B Change. AAR B Before Decongestion was positively correlated with AAR B After ($r_{63}=0.77$, $p<0.001$) and negatively correlated with AAR B Change ($r_{63}=-0.47$, $p<0.001$). SNO ratings were negatively correlated with PNIF ($r_{65}=-0.26$, $p=0.04$) but were not correlated with AAR (Figure 1).

Correlation of nasal airflow measures with trigeminal function and olfaction

PNIF and AAR were not correlated with trigeminal and olfactory

Table 1. Means, medians, and frequencies of clinicodemographic variables.

	Frequency (n, %)			Mean (SD)			p-value
Variables	**With CRS**	**Without CRS**	**Total**	**With CRS**	**Without CRS**	**Total**	
Clinical-demographic							
Age				54.4 (13.1)	47.9 (14.0)	51.4 (13.8)	0.05
Gender							
Men	24 (34.8%)	13 (18.8%)	37 (53.6%)				0.04*
Women	13 (18.8%)	19 (27.5%)	32 (46.4%)				
Groups	37 (53.6%)	32 (46.4%)	69 (100%)				
Asthma							
Yes	19 (27.5%)	2 (2.9%)	21 (30.4%)				<0.001*
No	18 (26.1%)	30 (43.5%)	48 (69.6%)				
Previous Nasal Surgery							
Yes	37 (53.6%)	3 (4.3%)	40 (58.0%)				
Endoscopic Sinus Surgery (ESS)	17 (24.6%)	0 (0%)	17 (24.6%)				
Septoplasty	4 (5.8%)	3 (4.3%)	7 (10.1%)	1.8 (1.4)	0 (0)+	1.0 (1.3)	<0.001*
ESS and Septoplasty	5 (7.2%)	0 (0%)	5 (7.2%)				
Unknown or others	4 (5.8%)	0 (0%)	4 (5.8%)				
No	7 (10.1%)	29 (42.0%)	36 (52.2%)				
Rescue Medications							
INCS	20 (29.0%)	0 (0%)	20 (29.0%)				
Mometasone	19	0	19				
Budesonide	1	0	1				
INCS + Omalizumab	1 (1.4%)	0 (0%)	1 (1.4%)				<0.001*
None	16 (23.2%)	32 (46.4%)	48 (69.6%)				
CRS Control Score							
Uncontrolled	23 (62.2%)						
Partly Controlled	12 (32.4%)			3.53 (0.9)			
Controlled	0 (0%)						
Unknown	2 (5.4%)						
Nasal Airflow							
PNIF				124.7 (51.4)	125.6 (46.8)	125.1 (48.9)	0.94
AAR B Before Decongestion				832.4 (456.7)	801.4 (487.8)	817.1 (468.7)	0.80
AAR B After Decongestion				984.3 (443.1)	994.9 (404.5)	989.5 (421.1)	0.92
AAR B Change				151.9 (312.2)	193.6 (304.3)	172.4 (306.6)	0.59
Trigeminal							
Trigeminal Lateralization				15.7 (2.8)	17.2 (3.0)	16.4 (3.0)	0.04*
CO_2 Sensitivity				-1648.4 (448.0)	-1076.5 (596.3)	-1383.2 (592.4)	<0.001*
Olfactory							
Odor Identification				9.1 (3.5)	13.1 (1.4)	10.9 (3.4)	<0.001*
Quality of Life							
Subjective Nasal Obstruction Rating				2.0 (1.3)	1.0 (0.9)	1.5 (1.2)	<0.001*

INCS: Intranasal corticosteroids; PNIF: peak nasal inspiratory flow, AAR: rhinomanometry, B: bilateral, Change: difference between after and before decongestion; CO_2: Carbon dioxide; * statistically significant, $p<0.05$; + Variable was not normally distributed based on skewness and kurtosis [58], thus data was reported as Median (IQR: Interquartile Range).

function. However, SNO ratings were negatively correlated with CO_2 sensitivity (r_{66}=-0.34, p=0.01) but not with trigeminal lateralization (Figure 1). In addition, SNO was also negatively correlated with odor identification (r_{63}=-0.38, p=0.002), and positively correlated with CRS control (r_{34}=0.64, p<0.001) scores, as well as the number of previous surgeries (r_{66}=0.33, p=0.01).

Exploratory subgroup analyses (Figure 2)

Mild nasal obstruction versus severe nasal obstruction (SNO ratings)

When looking at participants who rated nasal obstruction as less problematic (0 to 1, n=36) versus very problematic (4 to 5, n=5), those who reported severe nasal obstruction had lower

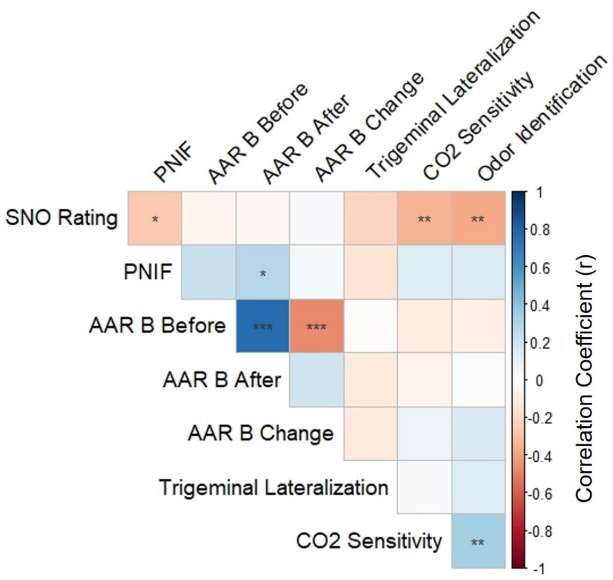

Figure 1. Correlations between subjective nasal obstruction ratings, objective nasal airflow, trigeminal function, and olfactory tests. Box colors correspond to direction and strength of correlation (blue: positive correlation, red: negative correlation, darker colors denote stronger correlation); * p < 0.05, ** p < 0.01, *** p < 0.001; SNO Rating: Sinonasal Outcome Test-20 German Adapted Version Question 1 [Nasal Obstruction] Rating, PNIF: peak nasal inspiratory flow, AAR: rhinomanometry, B: bilateral, Before: before decongestion, After: after decongestion, Change: difference between after and before decongestion; CO_2: Carbon dioxide.

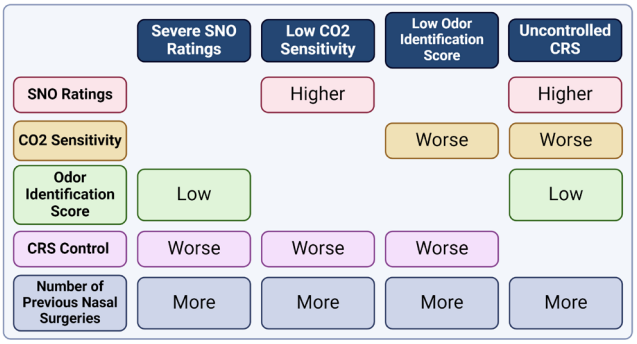

Figure 2. Exploratory subgroup analyses. SNO: subjective nasal obstruction; CO_2: Carbon dioxide; CRS: chronic rhinosinusitis; Severe SNO rating: ≥4; Low CO_2 sensitivity: <-1556ms, Low odor identification score: ≤10, Uncontrolled CRS: ≥3 points in the CRS control score; results of trigeminal lateralization subgroup analysis was not included in the figure due to non-statistically significant findings.

odor identification scores (t_{38}=2.86, p=0.01), worse CRS control (t_{36}=6.46, p<0.001) and more previous surgeries (t_{39}=2.35, p=0.02). There were no significant differences for any of the objective nasal airflow measures or trigeminal function tests between these groups.

Low vs. normal trigeminal lateralization scores

When comparing participants' trigeminal lateralization scores and dividing them based on the cut-off of <15 as low, ≥15 as normal [25], there were no significant differences for any of the objective nasal airflow measures, SNO ratings, CO_2 sensitivity, odor identification scores, CRS control scores, or number of previous surgeries.

Low vs. normal CO_2 sensitivity

Based on a previous publication [26], CO_2 threshold values greater than the 90th percentile (1556 ms, n=99) in their sample indicated poor CO_2 sensitivity and this was used to classify the participants into 2 groups (<-1556 as low, ≥-1556 as normal). There were no significant differences for any of the nasal airflow measures or for trigeminal lateralization between the groups. Those with low CO_2 sensitivity had higher SNO ratings (t_{64}=3.17, p=0.002), lower odor identification scores (t_{64}=2.62, p=0.01), and more previous surgeries (t_{67}=2.02, p=0.047).

Low vs. normal odor identification score

Odor identification scores are regarded to be low if ≤10 [24]. There were no significant differences for any of the nasal airflow measures or for trigeminal lateralization between the groups. However, those with low odor identification scores had worse CO_2 sensitivity ($t_{49.72}$=2.60, p=0.01), and more previous nasal surgeries ($t_{24.77}$=3.89, p<0.001).

Uncontrolled versus partly controlled CRS

Only 12 patients had partly controlled CRS, 23 had uncontrolled CRS, while 2 had unknown control status. Those with uncontrolled CRS had lower PNIF ($t_{13.24}$=2.42, p=0.03), higher SNO ratings ($t_{35.71}$=4.16, p<0.001), and lower odor identification ($t_{30.1}$=4.84, p<0.001) scores. However, there were no significant differences for AAR, trigeminal function measures, and number of previous nasal surgeries.

Severe nasal obstruction patients: described

Only 5 patients rated their nasal obstruction as 4. None of the patients rated their nasal obstruction as 5. Three patients had low PNIF (<120 [27]), 4 had low AAR Before (taking the mean of measurements for both sides of the nose, (normal: ≥700 [28,29]), 1 had a low trigeminal lateralization (<15 [25]) score, 4 had low CO_2 sensitivity (low: <-1556 [26]), 3 had low odor identification (low: ≤10 [24]), all had uncontrolled CRS, 4 were women, 4 had asthma, all had at least 1 previous surgery with 3 having had previous nasal polyp surgery.

Discussion

Nasal airflow, trigeminal function, and olfaction may all be af-

fected in CRS. However, this study supports the following key findings: 1) objective nasal airflow measurements were not different between CRS patients and controls, while trigeminal function was decreased in CRS patients; 2) objective nasal airflow measures were not correlated with trigeminal or olfactory tests, while SNO ratings were correlated with more variables, including PNIF, CO_2 sensitivity, odor identification, CRS control score, and number of previous nasal surgeries.

Nasal obstruction is a core symptom of CRS [1] and may be assessed using patient reported outcome measures (PROM, i.e. SNOT-22 [30], a more recent version of SNOT-20 GAV) and objective measures (PNIF, AAR, and acoustic rhinometry) in the clinical setting [31]. SNOT-22 has been routinely used in to assess CRS patients' quality of life and the outcome of surgical intervention. Although it has been regarded as the highest quality validated PROM in adult CRS patients [32], the definitive role of objective nasal airflow measures in CRS remains unclear [1], especially as these tests may inherently have limitations (see below) and are often reserved for use in research settings [31].

PNIF measures the maximum volume of nasal airflow during deep inspiration. AAR was used to measure the total volume of air through the left and right nasal cavities taken on 2 separate measurements and not as a measure of nasal resistance at 150 Pa, as what other published studies have done. According to a study by Vogt et al., the application of the parameter of 150 Pa in resistance computations is physically and mathematically incorrect when applied to an unsteady airstream that quickly changes velocity and direction due to the irregular nasal anatomy [33]. When AAR is performed with nasal decongestion, this allows the investigation of anatomic structures related to nasal resistance, but may dampen the influence of mucosal changes as is experienced in daily nasal breathing. Accurate measurement of both tests depends on an airtight seal around a mask placed over the nose and mouth, tight lip closure, avoidance of nasal vestibular collapse (PNIF) or alteration of nasal opening when pressure probe is secured (AAR), good pulmonary function, and patient cooperation for maximal inspiratory effort. PNIF measurements are highly reproducible and testing is quick and easy to perform using portable and inexpensive equipment [34]. However, the unnatural breathing pattern (deep and rapid inhalation) may not parallel physiologic breathing. On the other hand, conditions for AAR testing (humidity, temperature, comfortable seating, positioning, etc.) must be standardized [35] and a computer is required to operate the equipment, making transportation around a clinic or hospital impractical [34].

To the best of our knowledge, our study is the first to compare 2 objective nasal airflow measures in a sample of CRS patients and controls. Previous studies have found a negative correlation between SNO ratings and PNIF [11,27,36] but not AAR [28,37,38], but many of these studies did not include CRS patients [39]. The lack of correlation between these objective nasal airflow measures may indicate that the conduct of testing (PNIF: maximal inspiration in normal birhinal breathing; AAR: normal monorhinal breathing, also influenced by effort) may affect participants' test performance. Although measures to reduce nasal cycle influence were attempted, only after nasal decongestion do AAR measures correlate with PNIF. Decongestion typically results to a nasal airflow increase of approximately 20% [29,40], possibly explaining how AAR B After Decongestion could be correlated to PNIF performed at maximal inhalation. This shows that the influence of the nasal mucosa and the nasal cycle on objective nasal airflow measures should not be underestimated.

Although both PNIF and AAR measure nasal airflow volume, it is also likely that the volume of air going through the nose may not be the most significant factor, nor the best measure to approximate the perception of SNO. Similar to what was highlighted in a letter by Nivatvongs et al. [41], the relationship between subjective symptoms and physiological variables is complex and may help explain the lack of correlations with objective nasal airflow measures and more correlations with SNO. Physiologic abnormalities, as in objective tests of nasal airflow or psychophysical trigeminal function, help explain only one aspect of the complete understanding of symptom burden and quality of life, where patient factors such as previous experience, cultural expectations, age, socio-economic status, and co-morbidities may interact and contribute to the subjective perception of disease and its severity [41]. The multifactorial nature of an individual's perception of nasal obstruction is evident in our findings through the correlation of SNO ratings with measures of nasal airflow, trigeminal and olfactory function, and disease severity (CRS control and number of previous nasal surgeries).

We hypothesize that subjective nasal obstruction may be modulated by: 1) volume of nasal airflow; 2) trigeminal dysfunction; 3) location of obstruction; 4) mucosal heat exchange, and 5) increased work of breathing – among others.

Volume of nasal airflow

Physiologic breathing involves nasal airflow of up to 500 ml/s [42]. Increased physical activity may increase required airflow up to >1 liter, requiring supplementation with mouth breathing [42]. When the nose is obstructed in CRS due to mucosal changes (nasal polyps), or increased nasal secretions and the physiologic volume of nasal airflow is not achieved, this may contribute to the perception of nasal obstruction.

Trigeminal dysfunction

CRS patients have been found to have decreased trigeminal

function [5–9, 43–45] but the exact mechanism on how it relates to nasal obstruction is unknown. However, mucosal cooling [46,47], TRP channel activation leading to a cascade of proinflammatory cytokine release [48–50], and a reduction in TRPM8 sensitivity [7,9,51], as well as post-surgical dysfunction after functional nasal surgery [45] have been proposed to explain the perception of nasal obstruction in CRS.

Location of obstruction

The nasal valve is the narrowest area of the nasal airway [52] and any compromise to the structural support of the valve or the adjacent structures (nasal septum, upper lateral cartilages, inferior turbinate), or an anatomic obstruction in this area is likely to result in the perception of nasal obstruction [42,53].

Mucosal heat exchange

A study by Zhao et al. found that when air temperature was constant, humidity of inspired air modulates the perception of unilateral nasal patency. Instead of static air temperature, it was related to the interaction between an individual's nasal anatomy and the inspired airflow, where varying mucosal heat loss would result in different experiences of nasal patency [47]. Mucosal changes in CRS can lead to alterations in viable surface area for effective for heat exchange [22].

Increased work of breathing

It was proposed by Vogt et al., that the sensation of force required for the work of nasal breathing follows the logarithmic scale of Weber-Fechner, where subjective sensation is proportional to the logarithm of the original force required for nasal breathing [33]. The nasal cavity also has the ability to compensate to ensure adequate airflow is achieved. When resistance is higher despite the absence of physical activity, the required effort for nasal breathing increases until additional mouth breathing or total mouth breathing is required to achieve adequate airflow [42]. This provides additional signals that nasal obstruction is present.

Information related to trigeminal stimulation passes through the trigeminal nucleus, brainstem, and to cortical areas [54] that are shared with the olfactory system [55]. A previous study by Chao et al. showed that olfactory (phenyl ethyl alcohol, PEA) and mixed olfactory-trigeminal (menthol) stimuli mediated the perception of nasal patency and those with better olfaction reported greater nasal patency after PEA exposure [56]. Although it has been hypothesized that cognitive processes, specifically related to emotion, may contribute to the perception of nasal obstruction in empty nose syndrome [54], it is unknown to what degree central processing and integration of sensory information influences this perception. The correlations between SNO, trigeminal and olfactory function appear to be in support of some interaction between these senses. In CRS patients complaining of nasal obstruction but having unremarkable nasal endoscopic findings, it is important to include a trigeminal function test in the assessment of nasal obstruction.

The similarity in the qualities of the 5 patients with severe SNO ratings affirms that SNO is multifactorial and may be more distinct in severe disease. Trigeminal function or nasal airflow tests should not be used in isolation to evaluate nasal obstruction. Although PNIF may be more practical for routine clinical use; and CO_2 sensitivity, through the CO_2 threshold test, may be a more specific trigeminal test (compared to trigeminal lateralization that also has an olfactory component and has not been validated to account for adaptation [57]), our findings emphasize the importance of performing both subjective and objective measures and correlating the findings from each when assessing nasal obstruction.

Limitations of the study relate to sample composition, with most CRS patients having previous nasal surgery. Future studies may explore these interactions in a larger sample of patients with heterogeneous distribution of previous nasal surgery and severity of disease.

Conclusion

The perception of nasal obstruction does not appear to depend solely on nasal airflow. Trigeminal function, location of obstruction, mucosal heat exchange, as well as increased work of breathing, among other patient factors, may contribute to one's perception of nasal obstruction; thus, the role of objective nasal airflow measures as a sole method of assessment of nasal obstruction in CRS remains limited and would benefit from additional information from trigeminal function tests and SNO ratings.

Authorship contribution

AKH: data analysis, writing, review, and editing; CU: conceptualization, data collection, review, and editing. AH: conceptualization, supervision, review, and editing. MC: conceptualization, supervision, review, and editing. TH: conceptualization, supervision, review, and editing.

Conflict of interest

The authors do not have any conflict of interest to declare.

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