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Volumetric Computed Tomography Analysis of the Olfactory Cleft in Patients with Chronic Rhinosinusitis

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Abstract

Background—Commonly used computed tomography (CT) staging systems for chronic rhinosinusitis (CRS) focus on the sinuses and do not quantify disease in the olfactory cleft. The goal of the current study was to determine whether precise measurements of olfactory cleft opacification better correlate with olfaction in patients with CRS.

Methods—Olfaction was assessed using the 40-item Smell Identification Test (SIT-40) before and after sinus surgery in adult patients. Olfactory cleft opacification was quantified precisely using three-dimensional, computerized volumetric analysis, as well as via a semi-quantitative Likert scale estimations at predetermined anatomic sites. Sinus opacification was also quantified using the Lund-Mackay staging system.

Results—The overall cohort (n=199) included 89 (44.7%) patients with CRS with nasal polyposis (CRSwNP) and 110 (55.3%) with CRS without nasal polyposis (CRSSNP). The olfactory cleft opacified volume correlated with objective olfaction as determined by the SIT-40 ($R_s = -0.461$; $p < 0.001$). The correlation was significantly stronger in the CRSwNP subgroup ($R_s = -0.573$; $p < 0.001$), whereas no appreciable correlation was found in the CRSSNP group ($R_s = -0.141$; $p = 0.141$). Correlations between sinus-specific Lund-Mackay CT scoring and SIT-40 scores were weaker in the CRSwNP ($R_s = -0.377$; $p < 0.001$) subgroup but stronger in the CRSSNP ($R_s = -0.225$; $p = 0.018$) group when compared to olfactory cleft correlations. Greater intra-class correlations (ICC) were found between quantitative volumetric measures of olfactory cleft opacification (ICC=0.844; $p < 0.001$) as compared with semi-quantitative Likert grading (ICC=0.627; $p < 0.001$).

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Conclusions—Quantitative measures of olfactory cleft opacification correlate with objective olfaction, with the strongest correlations seen in patients with nasal polyps.

Keywords

sinusitis; tomography scanners; x-ray computed; smell; cone-beam computed tomography

INTRODUCTION

Chronic rhinosinusitis (CRS) affects 10-15% of the United States population and is one of the most common causes of impaired olfaction.^{1,2} Olfactory loss is considered a defining feature of CRS and can be found in 40-80% of patients.³⁻⁵ Although olfactory dysfunction is highly prevalent in patients with CRS, very little is known about its immunopathology and current clinical staging of CRS using recommended CT and endoscopy systems does not highly correlate with olfactory dysfunction.^{4,6} As a result, impaired olfaction is often overlooked clinically and remains one of the most troubling and difficult features of the disease to treat.

Olfactory dysfunction in CRS likely results from the mucosal inflammation present in all forms of CRS. Mucosal inflammation, whether it causes mucosal swelling or polyp formation, could affect olfaction by physically impeding airflow and delivery of odorants to an otherwise unaffected olfactory epithelium. Alternatively, inflammatory-mediated damage to the olfactory epithelium itself could impair olfaction directly despite adequate delivery of odorants.⁷⁻¹¹ Computed tomography (CT) scan is the primary imaging study used to identify mucosal inflammation in CRS. However, commonly used CT staging systems for CRS focus on the sinuses specifically and do not quantify disease in the olfactory cleft.¹² The end result is that these sinus-specific CT staging systems may not be highly predictive of olfactory loss.

With these limitations in mind, Chang et al. graded opacification of the olfactory cleft using a semi-quantitative grading system.⁶ They found that olfactory cleft opacification was more predictive of objective olfactory function than sinus-specific opacification as graded by the Lund-Mackay scoring system. Since that time, advances in imaging analysis have allowed the exact degree of opacification to be quantified, permitting more precision as compared with systems which require subjective assessments of opacification.^{13,14} The goal of the current study was to determine whether precise measurements of olfactory cleft opacification better correlate with objective olfactory function in patients with CRS (with and without nasal polyps) than sinus-specific staging systems. Secondary goals were to compare precise, computer generated quantitative measures of olfactory cleft opacification with easier to perform semi-quantitative methods, with respect to predictive power and inter-rater reliability.

MATERIALS & METHODS

Study Population

Adult (>18 years) patients with CRS were recruited from rhinology clinics at Oregon Health and Sciences University (OHSU, Portland, OR), as part of an on-going prospective cohort study which has been previously reported.¹⁵ Each patient fulfilled diagnostic criteria for CRS according to Clinical Practice Guideline of the American Academy of Otolaryngology-Head and Neck Surgery.⁵ Each study participant self-selected endoscopic sinus surgery (ESS) for treatment of recalcitrant symptoms associated with CRS. Using standardized questionnaires, preoperative characteristics related to demographics and medical comorbidities were collected for each patient, including the presence of septal deviation, nasal polyposis, asthma, acetylsalicylic acid (ASA) sensitivity, allergic rhinitis, depression, diabetes mellitus, tobacco use, oral steroid dependency, and a history of previous sinus surgery. High resolution CT scans were obtained on each patient during the course of routine clinical care and prior to sinus surgery in all instances. All CT scans were evaluated by the enrolling physician and the degree of sinus opacification was scored using the Lund-Mackay staging system, with the reviewer blinded to other study data.¹² Nasal endoscopy was performed on each patient and those with visible polyps were classified as CRS with nasal polyposis (CRSwNP) and those without visible polyps as CRS without polyps (CRSSNP). Nasal endoscopy exams were scored semi-quantitatively using the Lund-Kennedy staging system.¹⁶ Each patient completed two surveys of sinus-specific quality-of-life (QOL): the Rhinosinusitis Disability Index (RSDI) and the Chronic Sinusitis Survey (CSS).^{17,18} Objective olfactory function was quantified using the 40-item Smell Identification Test (SIT-40, Sensonics Inc., Haddon Heights, NJ, USA).¹⁹ The SIT-40 is a validated, forced choice, “scratch and sniff” test utilizing microencapsulated odorant strips (score: 0–40, lower scores in patients with greater loss of smell). All study participants with a preoperative SIT-40 score less than 6 were removed from the cohort due to probable malingering. Objective olfactory scores were collected preoperatively and again after ESS, at least 6 months postoperatively. For this cohort, the extent of sinus surgery was dictated by the treating surgeon based on clinical presentation, nasal endoscopic examination, and CT findings. In general, all sinuses impacted on imaging were surgically opened. Polyps were moved throughout the sinuses up to the boundaries of the olfactory cleft, but tissue was not surgically removed from the olfactory cleft proper as outlined below. This study was approved in advance by the Institutional Review Boards at OHSU and MUSC and all subjects provided written, informed consent in English.

Olfactory Cleft Radiologic Evaluations

Three-dimensional volumetric analysis—Volumetric analysis of CT images was also performed using the Mayo Clinic Analyze 12.0 software (Biomedical Imaging Resource, Mayo Clinic, Rochester, MN) utilizing equally spaced coronal images. The olfactory cleft was considered to be a 3-dimensional (3-D) space that started at the anterior most olfactory filament (the anterior plane of middle turbinate) and ended just anterior to the face of the sphenoid sinus.^{20,21} The lateral boundary of the olfactory cleft was the attachment of the middle and/or superior turbinates. The roof of the olfactory cleft was the cribriform plate and the floor was an imaginary line drawn 1 cm inferior to the cribriform. These boundaries

generated a roughly “rectangular” volume (**Figure 1**). A block of CT image data (multiple slices) is composed of individual cubes called voxels. A process called segmentation defined which voxels belonged to the olfactory cleft 3-D space. Segmentation was done manually by two authors who were blinded to each other’s segmentations as well as all other study data including olfactory function. Each voxel had a measure of attenuation (measured in Hounsfield units [HU]; for reference, water has an HU of 0). To assess the olfactory cleft, the range –1,024 to –500 HU was used for air and values above this range were considered to represent opacification. The software allowed calculation of the total volume of the segmented 3-D olfactory cleft space, as well as the volume of air within that space. The percent opacification was defined as $[1 - (\text{total volume of air} / \text{total volume of olfactory cleft})]$ multiplied by 100.

Two-dimensional cross sectional analysis—Three coronal plane sections of the olfactory cleft were demarcated; anterior, middle, and posterior [ie 2-dimensional (2-D) planes]. The anterior section was the coronal plane at the anterior limit of the olfactory cleft. The middle section was the coronal plane of the posterior globe. The posterior section was the coronal plane just anterior to the face of the sphenoid. First, the percentage of the olfactory cleft that was opacified was graded on a “semi-quantitative” 0-3 Likert scale (0= ‘0-24%’, 1= ‘25-49%’, 2= ‘50-74%’, 3= ‘75-100%’ opacification). Then “quantitative” analysis was done using Analyze 12.0 software to determine the exact percent of opacification for each of the demarcated coronal olfactory cleft sections (**Figures 2-3**). After completion of all radiographic grading, a second reviewer repeated the grading for a randomly selected subset of 20 patients. The second reviewer was blinded to the all other study data, including segmented regions and results of the initial reviewer and measures of olfaction.

Statistical Analysis

Statistical analyses were performed using a commercially available software application (SPSS v.22, IBM Corporation, Armonk, NY, USA). Descriptive statistics are reported using means [standard deviation], frequency, and range where appropriate. Graphical analysis evaluated linear trends between continuous study variables. Two-sided independent t-tests or Mann Whitney U tests were used to compare mean total opacification between preoperative characteristics. Spearman’s rank correlation coefficients (R_s) were used to evaluate non-parametric correlations between study variables. Agreement between rater pairings for both semi-quantitative and quantitative CT scoring methods was assessed using two-way random intra-class correlation coefficients (ICC) at the 0.050 level of significance.

RESULTS

Study Cohort

The overall cohort included 199 patients with CRS, of which 89 (44.7%) were CRSwNP and 110 (55.3%) were CRSsNP. Demographics, medical comorbidities, and measures of disease severity are summarized in **Table 1**. The average SIT-40 score was 27.1[10.1], ranging from 6-39. Average CT scores of the olfactory cleft are shown in **Table 2**, including quantitative and semi-quantitative measures. The 3-D olfactory cleft opacification (volumetric analysis)

averaged 75.4%, ranging from 45.1-100.0%. Quantitative 2-D cross sectional analyses of anterior, middle and posterior sections were 73.3%, 76.0%, and 78.7 %, respectively. Semi-quantitative scores averaged 0.93, 1.45, and 1.62 for the anterior, middle, and posterior sections respectively (range 0-3).

Three-dimensional Volumetric Analysis

Average 3-D volumetric percent opacification of the olfactory cleft was evaluated with respect to demographic factors, medical comorbidities, and overall sinus-specific disease severity measures. The overall percent opacification was significantly greater in patients with nasal polyps (82.1% vs 70.0%; $p<0.001$), as well as those with asthma or aspirin sensitivity ($p<0.001$ for both). There was no difference in olfactory cleft opacification based on gender, race, previous sinus surgery, allergic rhinitis, or history of diabetes mellitus (**Table 3**). Of note, those who actively smoke tobacco products had less olfactory cleft opacification (64.4% vs 76.0%; $p=0.004$), and this association persisted after controlling for polyp status. As expected, there was significant correlation between olfactory cleft opacified volume and sinus-specific Lund-Mackay CT scores ($R_s=0.429$; $p<0.001$) and Lund Kennedy endoscopy grades ($R_s=0.353$; $p<0.001$). There was no appreciable or significant correlation between olfactory cleft opacification and sinus-specific QOL on either the RSDI or CSS instruments.

The olfactory cleft opacified volume was found to significantly correlate with objective olfaction as determined by the SIT-40 ($R_s=-0.461$; $p<0.001$). When examining subgroups, the correlation was significantly stronger in the CRSwNP subgroup ($R_s=-0.573$; $p<0.001$), whereas no appreciable correlation was found in the CRSsNP group ($R_s=-0.141$; $p=0.141$) (**Figure 4**). When examining all CRS patients together, the correlation between olfactory cleft opacification and SIT-40 scores was not meaningfully different than the correlation seen between sinus-specific Lund Mackay CT scoring and SIT-40 scores ($R_s=0.490$; $p<0.001$). However, notable differences were seen when subgroups with and without polyps were examined. Interestingly, when examining subgroups, correlations between sinus-specific Lund-Mackay CT scoring and SIT 40 scores became noticeably weaker in both the CRSwNP ($R_s=-0.377$; $p<0.001$) and the CRSsNP ($R_s=-0.225$; $p=0.018$) subgroups (**Figure 5**). Therefore, although olfactory cleft opacification and sinus-specific Lund-Mackay scores correlate with olfaction similarly in CRS patients overall, total olfactory cleft-opacification is the superior predictor in patients with polyps whereas sinus-specific scores are more predictive in those without polyps.

The ability of total olfactory cleft percent opacification to predict change in SIT-40 scores after surgery was examined. In all patients with CRS, there was a weak correlation between baseline olfactory cleft opacification and change in SIT-40 scores after surgery ($R_s=0.254$; $p=0.002$). Once again, a stronger, significant correlation was found in the CRSwNP subgroup ($R_s=0.300$; $p=0.011$), wherein a greater degree of baseline olfactory cleft opacification predicted more improvement after surgery. However, no appreciable correlation was found in the CRSsNP subgroup ($R_s=-0.050$; $p=0.682$), such that the degree of olfactory cleft opacification at baseline did not inform the likelihood of olfaction improving after surgery. The degree of baseline sinus opacification as measured by the

Lund-Mackay score did not predict improvement in olfaction after surgery for CRSwNP ($R_s=0.183$; $p=0.126$) or CRSsNP ($R_s=0.090$; $p=0.459$) groups.

Two-dimensional Cross-sectional Analysis

Correlations between 2-D cross-sectional olfactory cleft opacification and SIT-40 olfaction scores are shown in **Table 4**. For the CRSsNP subgroup, no significant correlation was found for the anterior or middle 2-D sections. However, a weak but significant correlation was found between percent opacification of the posterior plane and SIT-40 scores ($R_s = -0.200$; $p=0.036$). For the CRSwNP subgroup, the strongest correlations were found in the anterior 2-D section ($R_s = -0.625$; $p<0.001$), with strength of correlation decreasing slightly and progressively in the middle ($R_s = -0.547$; $p<0.001$), and then posterior sections ($R_s = -0.436$; $p<0.001$). When comparing quantitative (% opacification) and semi-quantitative (0-3 Likert) scoring systems, there were no substantial differences in correlation coefficients.

Reliability Measures

Intra-rater reliability scores were evaluated for both 3-D volumetric percent opacification and semi-quantitative Likert scores of the olfactory cleft. Greater reliability was seen between the quantitative volumetric measures ($ICC=0.844$; $p<0.001$) as compared with the semi-quantitative Likert grading scheme ($ICC=0.627$; $p<0.001$).

DISCUSSION

Radiographic evidence of mucosal inflammation is a defining feature in the diagnosis of CRS, thus it is logical for CT grading systems to focus on the degree of mucosal thickening and/or opacification in the sinuses specifically. However, the severity of mucosal inflammation in the sinuses may or may not mirror that seen in the olfactory cleft. One can imagine a scenario where pansinusitis exists yet the olfactory cleft is mostly spared. On the contrary, it is not uncommon in the postsurgical setting to see residual polyp disease in the olfactory cleft and relatively clear sinuses.

The hypothesis set forth in this study was that olfactory-specific opacification would more strongly correlate with objective measure of olfaction than a sinus-specific grading system such as the Lund-Mackay. Interestingly, data from this study paints a nuanced picture. When all CRS patients were included together, olfactory-specific CT grading and sinus-specific CT grading systems correlated with objective olfaction to a similar degree. However, when subgroups were examined by polyp status very different findings emerged. Olfactory-specific grading became highly correlated with olfaction in CRSwNP, but did not correlate in CRSsNP. Interestingly, the correlation between sinus-specific Lund-Mackay CT grading and olfaction became weaker in both CRSwNP and CRSsNP subgroups than in that seen in CRS patients overall. This latter finding is somewhat unusual, as one would expect the correlation in CRS overall to be roughly a weighted average of the subgroup correlations. However, it is evident in **Figure 5** that the CRSsNP group is clustered in the region of low Lund-Mackay CT scores and higher SIT scores, and the CRSwNP group is clustered in the higher Lund-Mackay CT scores region but with a range of SIT scores. Putting the two

groups together leads to confounding and makes the sinus-specific grading system appear to correlate with olfaction better than it truly does for any given patient.

Findings from this study agree with those previously published by Chang et al. who found that olfactory cleft CT scores correlate better with objective olfaction than any individual sinus opacification.⁶ In their study, Chang et al. utilized a semi-quantitative grading system (0-4) based on visual inspection, versus the current study which also utilized a fully quantitative, volumetric method to determine olfactory cleft opacification. The most notable difference in findings is that Chang et al. reported a similar degree of correlation in patients regardless of polyp status, whereas the current study noted stronger correlations in those with polyps. The reason for this disagreement is not entirely clear. One other difference in methodology between studies was the Chang et al. study utilized monorhinal olfactory testing and correlated this to the ipsilateral olfactory cleft, whereas the current study administered bilateral testing and considered both olfactory clefts together. The two studies also differ in geographic region, with the former enrolling patients from South Korea and the current from North America.

Improvements in olfaction after sinus surgery are inconsistent and difficult to predict, making it challenging to counsel patients with regard to expectations.^{22,23} In this study, the degree of baseline olfactory cleft opacification did correlate with improvement in SIT-40 scores after surgery in patients with polyps, helping to explain some of the variability in olfactory outcomes. This stands in contrast to Lund-Mackay CT grading which was not predictive in CRSwNP or CRSsNP groups. This study, as designed, was not intended as a surgical outcomes study per se and further investigation is required to understand whether olfactory cleft imaging would contribute to preoperative clinical decision-making. It is perhaps most likely that imaging will be one of several olfactory-specific measures will allow for a more robust predictive model which will aid in future patient counseling with regard to smell after surgery.

The mechanisms of olfactory loss in CRS are understudied, but are typically thought of in terms similar to hearing loss [e.g., either a conductive deficit (airflow restriction) or a neural dysfunction (inflammatory damage to the olfactory-specific epithelium)]. The former might include nasal polyposis or mucosal swelling which block odorant-containing air from reaching the olfactory cleft, whereas the latter might involve deficits in odorant binding, neural propagation, or even irreversible replacement of olfactory epithelium with respiratory epithelium.²⁴ However, these classifications are not likely to be mutually exclusive and instances surely exist where inflammation results in both conductive and neural dysfunction. Interestingly, data from the subgroup analysis suggests that airflow restriction may be more important in CRSwNP, whereas other mechanisms may play a more substantial role in CRSsNP. For example, a strong correlation between olfactory cleft opacification and objective olfaction was found in CRSwNP patients, whereas no such correlation was seen in CRSsNP. Furthermore, in CRSwNP the strongest correlations were found in the anterior-most 2-D section, the location most relevant to airflow. In CRSsNP, the degree of opacification of the anterior-most 2-D section did not correlate with objective olfaction (nor did the overall scores); however, the posterior-most 2-D section did significantly correlate, albeit weakly. It is reasonable to speculate that polyps located anteriorly block airflow and

contribute to olfactory loss, whereas olfactory loss in CRSsNP may be more related to generalized inflammation and mucus production. In a separate cohort of patients, we have previously reported that patient-complaint of nasal discharge was associated with olfactory loss in patients with CRSsNP, suggesting a mechanism other than airflow restriction.²² Certainly, any further discussion of mechanisms based on this data would be speculative without accompanying tissue-level measures.

The quantitative 2-D and 3-D analysis and semi-quantitative (Likert scale) 2-D cross sectional olfactory cleft scoring systems appeared to correlate with SIT-40 olfaction scores to a similar degree. The advantage of the quantitative analysis is that it gives a precise measurement with a high degree of inter-rater reliability. This would be an advantage for research purposes, as findings could be compared across raters, centers, or different studies with relative confidence. The primary disadvantage of the quantitative analysis is the necessity to manually segment each CT scan, which can be quite labor intensive and would certainly not be amenable to routine clinical practice until the process is automated. For individual clinical settings, semi-quantitative scoring at predetermined cross-sectional anatomic sites provides a similar degree of information in a time efficient manner. For patients with nasal polyposis, the degree of olfactory cleft opacification does highly correlate with baseline SIT-40 scores and offers some predictive power with regard to postoperative improvement.

There are a few caveats to consider with regard to this study. The ability to identify odorants was the only objective measure of olfaction used in this analysis. It is possible that measures of olfactory threshold or discrimination may have correlated differently. With this in mind, future studies should consider more broadly evaluating olfactory function and using composite metrics. Additionally, patients were recruited from a tertiary rhinology practice and thus were more likely to have had prior sinus surgery and a relatively high degree of overall sinus disease than what might be seen in a general practice, potentially limiting external generalizability. Lastly, although the basic dimensions of the olfactory cleft are well defined, determining the degree of opacification is not as straightforward as one might think. The middle turbinate may at times be significantly curved and both it and the septum may have varying degrees of mucosal thickness and bony width that could be a result of underlying CRS or may simply represent normal variation. In this study, the manual segmentation included the intervening septum, with the idea that normal variability would be at random and would essentially introduce variation (noise) but not bias results. This explains why none of the patients had a 3-D quantitative opacification score less than 45%. The semi-quantitative (Likert) scoring system is subjective by nature and requires raters to make judgments between normal variation in mucosal/bony width and pathologic changes that are contributing to opacification. Refinement of these techniques may require further understanding of normal olfactory cleft anatomical variation and its impact on olfaction if any.

CONCLUSION

Quantitative measures of olfactory cleft opacification correlate with objective olfaction as measured by the SIT-40 instrument in patients with CRS. The strongest correlation is seen in

patients with nasal polyps, whereas insignificant correlations are seen in patients without polyps, suggesting differing mechanisms may underlie olfactory loss. Further study is required to refine these techniques and understand how measures of olfactory cleft opacification may contribute to overall predictive models of olfactory dysfunction in patients with CRS.

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Figure 1.

3-dimensional (3-D) volume of the olfactory cleft. Orange color shows the segmented 3-D volume of the olfactory cleft, the red shaded area represents the anterior coronal section of the segmented olfactory cleft, and the blue outline is the middle coronal section of the segmented olfactory cleft.

Figure 2.

Segmentation of the olfactory cleft in a patient with chronic rhinosinusitis without nasal polyps; A=anterior (36.9%); B=middle (42.1%); C=posterior (49.5%). The total 3-D volumetric opacification=45.2%.

Figure 3.

Segmentation of the olfactory cleft in a patient with chronic rhinosinusitis with nasal polyps; A=anterior (83.5%); B=middle (52.7%); C=posterior (78.2%). The total 3-D volumetric opacification is 76.3%.

Figure 4.

Linear correlations between olfactory cleft opacified volume and objective SIT-40 olfaction scores in CRSsNP (n=110; $R_s = -0.141$; $p=0.141$) and CRSwNP (n=89; $R_s = -0.573$; $p<0.001$). Lines represent best linear fit. CRSsNP, chronic rhinosinusitis without nasal polyposis; CRSwNP, chronic rhinosinusitis with nasal polyposis; SIT-40, 40-item Smell Identification Test.

Figure 5.

Linear correlations between SIT-40 olfaction scores and sinus-specific Lund-Mackay CT scores in CRSsNP ($n=110$; $R_s = -0.225$; $p=0.018$) and CRSwNP ($n=89$; $R_s = -0.275$; $p=0.009$). Lines represent best linear fit. Solid black line indicates correlation for entire cohort ($R_s = -0.490$; $p<0.001$). CT, computed tomography; CRSsNP, chronic rhinosinusitis without nasal polyposis; CRSwNP, chronic rhinosinusitis with nasal polyposis; SIT-40, 40-item Smell Identification Test.

Table 1

Preoperative characteristics of study cohort (n=199)

Preoperative characteristics:	Mean [SD]	Range	N (%)
Age (years)	48.1 [14.7]	[18 – 79]	
Male			110 (55.3)
Female			89 (44.7)
Septal deviation			57 (28.6)
Nasal polyposis (CRSwNP)			89 (44.7)
Asthma			73 (36.7)
ASA sensitivity			20 (10.1)
Allergic rhinitis			58 (29.1)
Depression			33 (16.6)
Diabetes mellitus			8 (4.0)
Tobacco use			10 (5.0)
Oral steroid dependency			7 (3.5)
Previous sinus surgery			118 (59.3)
Lund-Mackay CT Score	12.9 [6.3]	[1 – 24]	
Nasal Endoscopy Score	7.3 [4.4]	[0 – 20]	
SIT-40 Olfaction Score	27.1 [10.1]	[6 – 39]	
RSDI Physical Score (n=199)	19.4 [7.7]	[1 – 38]	
RSDI Functional Score	15.4 [6.9]	[0 – 34]	
RSDI Emotional Score	13.7 [7.6]	[0 – 39]	
RSDI Total Score	48.5 [19.6]	[3 – 105]	
CSS Symptom Score (n=186)	28.3 [26.8]	[0 – 100]	
CSS Medication Score	51.1 [26.6]	[0 – 100]	
CSS Total Score	39.6 [19.8]	[0 – 96]	

SD, standard deviation; CRSwNP, chronic rhinosinusitis with nasal polyposis; ASA, acetylsalicylic acid; CT, computed tomography; SIT-40, 40-item Smell Identification Test; RSDI, rhinosinusitis disability index; CSS, chronic sinusitis survey.

Table 2

Computed tomography scores of the olfactory cleft (n=199)

3-Dimensional measures:	N (%)	Mean[SD]	Range
Opacified volume (quantitative)%		75.4% [15.4]	[45.1% – 100%]
Total volume (voxels)		1669.3 [614.9]	[21.7 – 4368.2]
2-Dimensional measures:			
Anterior opacification			
Quantitative		73.3% [18.0]	[25.8% – 100%]
Semi-quantitative grade		0.93 [1.24]	
Grade 0: 0-25%	115 (57.8)		
Grade 1: 25-50%	25 (12.6)		
Grade 2: 50-75%	16 (8.0)		
Grade 3: 75-100%	43 (21.6)		
Middle opacification			
Quantitative		76.0% [17.5]	[18.3% – 100%]
Semi-quantitative grade		1.45 [1.17]	
Grade 0: 0-25%	56 (28.1)		
Grade 1: 25-50%	53 (26.6)		
Grade 2: 50-75%	35 (17.6)		
Grade 3: 75-100%	55 (27.6)		
Posterior opacification			
Quantitative		78.7% [16.2]	[27.4% – 100%]
Semi-quantitative grade		1.62 [1.19]	
Grade 0: 0-25%	49 (24.6)		
Grade 1: 25-50%	45 (22.6)		
Grade 2: 50-75%	37 (18.6)		
Grade 3: 75-100%	68 (34.2)		

SD, standard deviation

Table 3

Clinical characteristics and mean olfactory cleft opacified volume (%)

Preoperative Characteristics:	Yes Mean%[SD]	No Mean%[SD]	p-value
Male	76.5%[16.1]	74.0%[14.5]	0.251
Septal deviation	74.5%[13.7]	75.8%[16.1]	0.578
Nasal polyposis (CRSwNP)	82.1%[16.1]	70.0%[12.6]	<0.001
Asthma	80.5%[16.4]	72.5%[14.1]	0.001
ASA sensitivity	88.3%[15.8]	74.0%[14.7]	<0.001
Allergic rhinitis	74.8%[14.4]	75.7%[15.9]	0.738
Depression	72.9%[13.8]	75.9%[15.7]	0.314
Diabetes mellitus	73.1%[14.9]	75.5%[15.5]	0.659
Tobacco use	64.4%[9.7]	76.0%[15.5]	0.004
Oral steroid dependency	83.9%[17.6]	75.1%[15.3]	0.140
Previous sinus surgery	75.9%[16.7]	74.7%[13.4]	0.600

SD, standard deviation; CRSwNP, chronic rhinosinusitis with nasal polyposis; ASA, acetylsalicylic acid

Table 4

Spearman's correlation coefficients (Rs) between olfactory cleft opacification and SIT-40 olfaction scores for each 2-dimensional section: anterior, middle, and posterior. The anterior, middle and posterior "score" represents the semi-quantitative Likert scoring method at that anatomic site. The anterior, middle and posterior "% opacification" represents the quantitative measurement utilizing the Analyze 12.0 software program at the same site.

	SIT-40 Score	
	Rs	p-value
CRSSNP (n=110)		
Anterior Score	-0.120	0.211
Anterior % Opacification	-0.056	0.562
Middle Score	-0.096	0.318
Middle % Opacification	-0.095	0.323
Posterior Score	-0.212	0.026
Posterior % Opacification	-0.200	0.036
CRSwNP (n=89)		
Anterior Score	-0.558	<0.001
Anterior % Opacification	-0.625	<0.001
Middle Score	-0.500	<0.001
Middle % Opacification	-0.547	<0.001
Posterior Score	-0.463	<0.001
Posterior % Opacification	-0.436	<0.001