Comparison of anatomic, physiological, and subjective measures of the nasal airway

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ABSTRACT

Background: *Studies comparing different categories of nasal measures have reported inconsistent results. We sought to compare validated measures of the nasal airway: anatomic (acoustic rhinometry), physiological (nasal peak inspiratory flow), and subjective experience (Nasal Obstruction Symptom Evaluation Scale and a visual analog scale [VAS]).*

Methods: *This prospective cross-sectional study of 290 nonrhinologic patients included upright and supine rhinometry (minimum cross sectional area [MCA] and volume) and flow (mean and maximum) measurements, as well as subjective measures. Associations between measures were evaluated with Spearman correlations and multivariate linear regression, adjusting for age, sex, race, body mass index, and smoking history.*

Results: *Correlations between objective (rhinometry and flow) and subjective categories of nasal measures ranged from -0.16 to 0.03 (mean correlation, -0.07 ± 0.05), with 0 significant correlations of 16 tested. Correlations between anatomic (rhinometry) and physiological (flow) categories ranged from 0.04 to 0.15 (mean correlation, 0.10 ± 0.03), with 0 significant correlations of 16 tested. In contrast, within each category (rhinometry, flow, and subjective), all correlations were significant (13 correlations, all $p < 0.001$) and ranged from 0.62 to 0.99. Of 16 adjusted associations between objective and subjective measures, 14 were not significant ($p > 0.05$); only upright and supine MCAs were significantly associated with the VAS (both, $p < 0.05$).*

Conclusion: *Validated anatomic, physiological, and subjective nasal measures may assess different aspects of the nasal airway and provide complementary information. Future studies should be directed at developing a composite measure including components from all three categories of nasal measurement.*

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There are many methods of measuring the nasal airway but there is no recognized gold standard. Three of these methods can be categorized as anatomic (measuring structural dimensions), physiological (measuring a functional or biological parameter), or subjective (patient-reported perception or experience). Acoustic rhinometry relies on acoustic reflectance to produce an anatomic profile of the cross-sectional area along the length of the nasal cavity.[1] Nasal peak inspiratory flow produces physiological measures of the rate of airflow through the nasal passage on inspiration. These two objective measures have diagnostic sensitivities for nasal obstruction between 80 and 95%[2] and both have been independently validated against other anatomic or functional diagnostic modalities.[3–11] The Nasal Obstruction Symptom Evaluation (NOSE) scale and a nasal obstruction visual analog scale (VAS) are validated and responsive instruments for evaluating patients' subjective experience with nasal obstruction.[12]

It is unclear which of these measures are most important in assessing nasal outcomes. Discordance between objective measures of disease severity and subjective patient self-assessments has been established in other medical conditions including sleep apnea,[13,14] sinusitis,[15] sinus surgery,[16] reflux laryngopharyngitis,[17,18] asthma,[19] and coronary artery disease.[20] It has been argued that objective and subjective evaluations often measure different aspects of disease burden, and in such cases both should be included in the assessment of the disease.[21] Although some studies have established a correlation between objective and subjective measures of nasal obstruction,[22–24] others have not.[25] To investigate the relationship between anatomic, physiological, and subjective measures of the nasal airway, this study compares acoustic rhinometry, nasal peak inspiratory flow, and two subjective measures of nasal obstruction (NOSE and VAS) in a large cohort of nonrhinologic patients.

METHODS

Study Design

A prospective cross-sectional study was conducted to compare anatomic, physiological, and subjective nasal measurements in a cohort of 290 consecutive patients being evaluated for obstructive sleep apnea for the first time. This study was approved by the University of Washington Institutional Review Board.

Participants

Eligible subjects were adults referred for polysomnography at the University of Washington Sleep Laboratory located at Harborview Medical Center in Seattle, WA. Nasal measurements were taken as part of a larger cohort study of patients

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suspected of obstructive sleep apnea, but not yet diagnosed or treated. Inclusion criteria for the parent cohort study included an age of ≥18 years, ability to give informed consent, ability and willingness to complete the study protocol, and fluency in verbal and written English. Patients with a prior diagnosis of nasal malignancy or sleep disorder, no telephone, or plans to move during the 6 months after enrollment were excluded. Patients with prior nasal surgery and those taking nasal medications were not excluded. Questionnaire data, acoustic rhinometry data, nasal flow measurements, and height and weight measurements were all obtained at the sleep laboratory on the evening of each patient's scheduled diagnostic polysomnography. Nasal flow measurements began after 140 patients had already been enrolled, so there are fewer data for these measurements.

Acoustic Rhinometry

Acoustic rhinometry is a noninvasive quantitative method of anatomic assessment that has been independently validated against other anatomic measures such as computed tomography, magnetic resonance imaging, and nasal endoscopy.[3–5,9–11] The acoustic rhinometer (Rhinometrics, Lynge, Denmark) was used to measure the minimum cross-sectional area (MCA) in squared centimeters and volume of the nasal passage in cubic centimeters, measured between 0.5 and 3.5 cm into the nasal airway on each side. Measurements were taken in upright position, and then again after lying in supine position for 10 minutes. A standard operating procedure was followed by trained examiners, with subjects instructed to hold their breath or to breathe gently through the mouth during testing. No topical decongestants or chin or head supports were used.[26–29]

A curve (a profile of the cross-sectional area relative to the distance into the nasal chamber) was captured when the coefficient of variation of the last five readings (automatically updated 20 times per second) was <5%. Three curves from each side of the nose[30] were averaged to give a mean curve for each side and these were then averaged to produce an overall nasal MCA and volume.

Nasal Peak Inspiratory Flow

Nasal peak inspiratory flow is a noninvasive physiological measure that indicates the peak nasal airflow achieved during inspiration and is measured in liters per minute. It is a reliable method of measuring nasal patency[31,32] and has been validated against rhinomanometry and other objective measures of nasal patency.[6–8,33] Patients were instructed in a standardized technique using an In-Check nasal flow meter (Alliance Tech Medical, Inc., Granbury, TX) with a demonstration from trained examiners. Patients held the flow meter mask attachment over the nose and mouth with sufficient force to secure an airtight seal while minimizing distortion of the nasal anatomy. Patients then inspired as forcefully as possible with lips tightly closed.[8] Each flow measurement was taken three times in upright position and again after lying in supine position for 10 minutes. The mean and maximum of the three readings in upright and supine positions were recorded for subsequent analysis.

Subjective Assessment

Two subjective parameters were assessed by questionnaire: (1) the NOSE scale and (2) a nasal obstruction VAS. The NOSE scale is a reliable, validated, and responsive instrument for assessing a patient's subjective experience of nasal obstruction over the previous 4 weeks. It is based on five questions, each rated on an ordinal scale from 0 to 4 and is scored on a scale from 0 to 100.[12] The nasal obstruction VAS is based on a patient's rating of overall nasal obstruction on a linear scale with anchors 0 indicating no obstruction and 100 indicating total obstruction.

Covariates

Age, gender, race, and smoking history were elicited on questionnaire. Height and weight were measured with shoes off at the time of enrollment using the same measurement devices for every subject. Body mass index (BMI) was calculated as kilograms per square meter.

Analyses

Among the descriptive data presented, differences between means in upright and supine positions were tested with a paired *t*-test. Bivariate associations between all nasal parameters were calculated with Spearman correlations, because normal distributions required of Pearson correlations were not observed for all parameters. In the case of comparisons between the two subjective parameters or between any two objective parameters, one would expect a positive correlation (*i.e.*, improvement in both variables or worsening in both variables). However, in a comparison between either subjective measurement and any objective parameter, one would expect a negative correlation (*e.g.*, an increase in NOSE scale indicating worse subjective nasal obstruction and a decrease in MCA indicating a smaller airway). To summarize correlations consistently, we used the absolute value of the correlation coefficient and assigned a negative value for correlations in the unexpected direction and a positive value for correlations in the expected direction. This sample has >95% power to detect a correlation of 0.30 at the two-tailed significance level of 0.05.

Multivariable linear regression analysis was used to test for significant associations while adjusting for age, gender, race, BMI, and smoking history. Each model contained a subjective nasal measure as the continuous dependent variable, an objective nasal measure as the continuous independent effect variable, and the adjustment variables. Age was categorized into 10-year intervals (<30, 30–39, 40–49, 50–59, and ≥60 years); race was grouped into white, black, and other (including Asian, Native American, and Native Hawaiian/Pacific Islander); BMI was categorized according to clinical categories (≤20, 21–25, 26–30, 31–35, and >35 kg/m^2); and smoking history was dichotomized as ever smoked or never smoked. Hispanic ethnicity was not included in the model because of a large proportion of unknown or missing data when patients declined to identify their ethnicity. Ninety-five percent confidence intervals and p values based on the coefficient t-test were calculated using the Huber/White/sandwich estimator of variance to relax the assumption of normal distributions in the model parameters, which is found in classic linear regression models.

Multiple logistic regression models were developed to confirm the linear regression analyses by nonparametric means. Subjective measures were dichotomized at their median as the dependent binary variable in each model. The objective nasal measures and adjustment variables were entered as described previously. All data were analyzed with Stata/SE 9.0 software (Stata Corp., College Station, TX). A value of $p < 0.05$ was considered statistically significant.

RESULTS

On average, the sample population was middle aged and obese, and a majority were men, white, and had smoked cigarettes sometime in the past (Table 1). The mean nasal MCA and nasal volume were within a normal range[34–36] (Table 2) with significantly smaller values in the supine than in the upright position (both, $p < 0.05$). Similarly, the mean and maximum nasal peak inspiratory flow was significantly less in the supine position (both, $p < 0.05$). The NOSE scale and nasal obstruction VAS yielded similar mean ratings of nasal obstruction on their respective scales between 0 and 100.

The correlations between different measurement categories were all small and not statistically significant. Of the 16 correlations between subjective and objective (rhinometry and flow) categories of nasal measures, there were 14 correlations in the expected negative direction (88%); however, none was statistically significant and none had a magnitude >0.16 (Table 3). The mean correlation between subjective and objective nasal measures was -0.07 ± 0.05. Figures 1 and 2 depict examples of the poor correlation between the NOSE scale and two objective parameters.

Of the 16 correlations between the anatomic (acoustic rhinometry) and physiological (nasal flow) categories of nasal measures, all were in the expected positive direction, but none were statistically significant, and none were >0.15 in magnitude. The mean correlation between rhinometry and nasal flow was 0.10 ± 0.03.

In contrast, the correlations within measurement categories were all statistically significant and highly positive (Table 3). Of the six correlations between the various rhinometry parameters, all were statistically significant and highly positive

Table 1 **Sample characteristics ($n = 290$)**

Patient Demographics	*n* (%)	Mean ± SD	Median (Range)
Age (yr)	268 (92)	47 ± 12	47 (21, 78)
BMI (kg/m^2)	269 (93)	35 ± 10	34 (18, 83)
Gender			
Male	159 (55)		
Female	131 (45)		
Race			
White	207 (71)		
Black	28 (10)		
Other*	29 (10)		
Unknown	26 (9)		
Cigarette use ever	91 (58)		

**Includes Asian, Native American, Native Hawaiian/Pacific Islander. Hispanic ethnicity was not presented because of missing data.*

Table 2 **Nasal measurements ($n = 290$)**

Variable	*n* (%)	Mean ± SD*		Median (Range)	
		Upright	Supine	Upright	Supine
Anatomic measures (acoustic rhinometry)					
MCA (cm^2)	283 (98)	0.47 ± 0.15	0.39 ± 0.13	0.43 (0.07, 0.92)	0.39 (0.05, 0.84)
Volume (cm^3)	283 (98)	2.36 ± 0.66	2.14 ± 0.62	2.16 (0.87, 4.84)	2.13 (0.53, 5.49)
Physiological measures (nasal peak inspiratory flow)					
Mean (L/min)	156 (54)	98 ± 38	89 ± 36	97 (10, 230)	90 (13, 180)
Maximum (L/min)	156 (54)	106 ± 41	97 ± 38	100 (10, 240)	100 (20, 200)
Subjective measures					
NOSE scale	270 (93)	41 ± 25		40 (0, 100)	
VAS (%)	288 (99)	38 ± 30		35 (0, 100)	

** Differences between mean measurements taken in upright and supine positions are significant ($p < 0.05$, paired t-test) for all anatomic and physiological measures.*

Table 3 **Spearman correlation analysis**

	Acoustic Rhinometry				**Nasal Peak Inspiratory Flow**				**Subjective**	
	Upright		**Supine**		**Upright**		**Supine**			
	MCA	**Volume**	**MCA**	**Volume**	**Mean**	**Max**	**Mean**	**Max**	**NOSE**	**VAS**
Acoustic rhinometry										
Upright										
MCA	1.00									
Volume	0.80*	1.00								
	283									
Supine										
MCA	0.79*	0.70*	1.00							
	282	282								
Volume	0.62*	0.79*	0.78*	1.00						
	282	282	283							
Nasal flow										
Upright										
Mean	**0.09**	**0.03**	**0.08**	**0.08**	1.00					
	151	**151**	**152**	**152**						
Maximum	**0.07**	**0.00**	**0.05**	**0.04**	0.98*	1.00				
	151	**151**	**152**	**152**	157					
Supine										
Mean	**0.13**	**0.09**	**0.14**	**0.13**	0.88*	0.87*	1.00			
	151	**151**	**151**	**151**	156	156				
Maximum	**0.15**	**0.10**	**0.14**	**0.12**	0.86*	0.85*	0.99*	1.00		
	151	**151**	**151**	**151**	156	156	156			
Subjective										
NOSE	***−0.06***	***−0.05***	***−0.05***	***−0.12***	***−0.08***	***−0.08***	***−0.16***	***−0.14***	1.00	
	263	***263***	***263***	***263***	***143***	***143***	***142***	***142***		
VAS	***−0.10***	***−0.06***	***−0.06***	***−0.09***	***0.03***	***0.03***	***−0.08***	***−0.06***	0.79*	1.00
	281	***281***	***281***	***281***	***155***	***155***	***154***	***154***	268	

Data presented in each cell as the Spearman correlation coefficient (top of cell) and sample size (bottom of cell) for each comparison.
**p < 0.001; all others p > 0.05.*
MCA = minimum cross-sectional area; Max = maximum; NOSE = nasal obstruction symptom evaluation scale; VAS = visual analog scale; Bold = acoustic rhinometry versus nasal flow correlations; bold italic = objective versus subjective correlations.

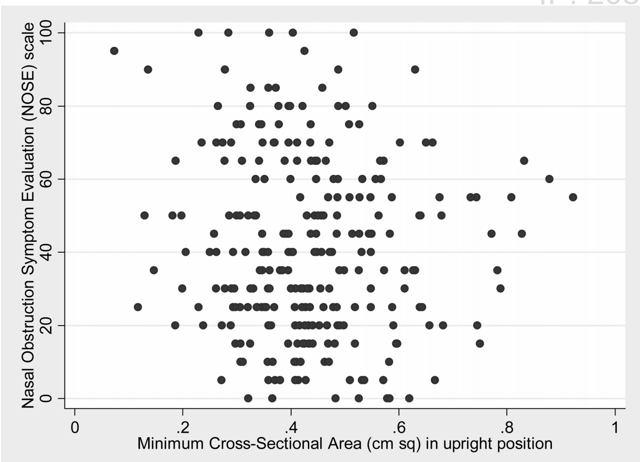

Figure 1. *Scatterplot of MCA in upright position and NOSE scale. Note the apparent lack of correlation.*

($r \geq 0.62$), with a mean correlation of 0.75 ± 0.07. Similarly, all six correlations between the nasal flow parameters were statistically significant and highly positive ($r \geq 0.86$), with a mean correlation of 0.90 ± 0.06. The two subjective instruments also showed a strong, significant correlation ($r = 0.79$; $p < 0.001$).

In multivariable linear regression analysis (Table 4), there were only two significant adjusted associations of 16 tested between subjective and objective measures. The association between nasal obstruction VAS and MCA in both the upright ($\beta = -30.4$; 95% CI,−57.8, −2.9) and the supine ($\beta = -29.7$, 95% CI, −58.0, −1.5) positions indicated that a decrease in MCA of 0.1 cm^2 corresponded to an ~3% increase in subjective nasal obstruction. The NOSE scale was not associated with any objective measure, and the VAS scale was not associated with volume or flow. Multiple logistic regression analyses confirmed no significant associations between subjective and objective measures (data not shown).

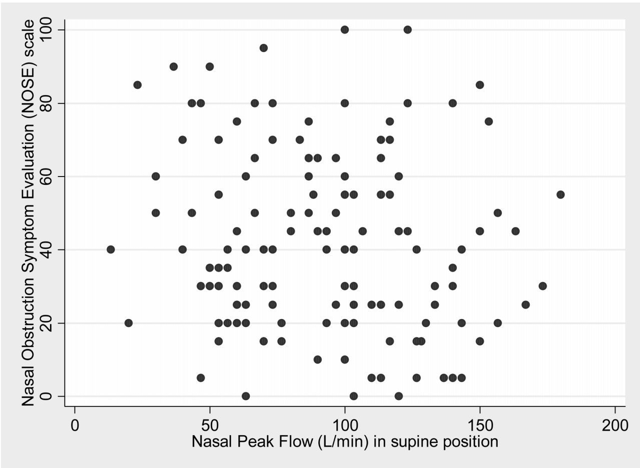

Figure 2. Scatterplot of mean nasal peak flow in supine position and NOSE scale. Note the apparent lack of correlation.

DISCUSSION

Our clinical experience suggests discordance between patient report of nasal obstruction and anatomic or physiological measures of the nasal airway. Previous studies have had mixed results with regard to the degree of correlation between subjective and objective nasal measures, depending on the study design, cohort, and measures compared.[22–25,37–43] Several studies found poor correlation between patient ratings of overall nasal obstruction and objective measures but found good correlation when the comparison was restricted to only one nostril or the other.[41–43] This study does not differentiate between the two sides of the nasal airway. The objective nasal flow measures, subjective NOSE scale, and subjective VAS all measure the nasal airway as a whole. Therefore, we compared these measures with combined bilateral acoustic rhinometry measures of the nasal airway. Because patients typically seek overall improvement of nasal breathing, we believe the overall nasal airway is most clinically relevant to patients.

The results of this study quantify the relative lack of correlation between anatomic, physiological, and subjective categories of nasal measures. One could argue that one reason for the poor correlation is a lack of validity or reliability for one or more of the measures being compared. However, each has been extensively and independently validated,[3–12] including the subjective NOSE scale, an important distinction from previous correlative studies. In addition, the correlations within each category of measure were consistently strong and highly significant, further suggesting good reliability and validity. Another argument for a lack of significant correlations is insufficient sample size. However, in this study the sample size was sufficient to provide >95% power to detect a clinically important correlation of 0.3.

The relative lack of correlation between the anatomic (rhinometry) and physiological (flow) categories of nasal measurement may seem particularly surprising. Although not significant, the correlations were consistently in the expected (positive) direction, as predicted by Poisseuille's law, where an increase in the size of the nasal airway should allow a higher rate of airflow through it. However, the results suggest that these two methods are measuring different aspects of the nasal airway, and the relationship between the anatomy of the nasal passage and the functional movement of air through it is more complicated than can be captured in a simple correlation analysis. For example, the nasal airway is not completely static, so the static rhinometry measures may not reflect dynamic changes in nasal resistance and flow related to turbulence.

Similarly, the poor correlation between the objective and subjective categories of nasal measurement may seem surprising initially. As expected, the correlations in this analysis were

Table 4 **Adjusted associations between objective (acoustic rhinometry and nasal flow) and subjective (NOSE and VAS) nasal measures***

	NOSE				Nasal Obstruction VAS			
	n	*β*	95% CI	*p* Value	*n*	*β*	95% CI	*p* Value
Acoustic Rhinometry								
Upright								
MCA	237	−18.5	−40.7,3.8	0.10	253	−30.4	−57.8,−2.9	**0.03**
Volume	237	−2.7	−7.8,2.4	0.29	253	−4.1	−10.0,1.9	0.18
Supine								
MCA	236	−19.3	−42.9,4.3	0.11	252	−29.7	−58.0,−1.5	**0.04**
Volume	236	−5.4	−11.0,0.3	0.06	252	−5.4	−12.1,1.3	0.11
Nasal flow								
Upright								
Mean	125	−0.07	−0.17,0.04	0.19	135	−0.03	−0.16,0.10	0.62
Maximum	125	−0.06	−0.16,0.04	0.25	135	−0.02	−0.14,0.10	0.70
Supine								
Mean	125	−0.09	−0.21,0.02	0.11	135	−0.07	−0.21,0.08	0.37
Maximum	125	−0.08	−0.19,0.02	0.13	135	−0.06	−0.19,0.08	0.41

**Linear regression model, adjusted for age, gender, race, BMI, and smoking history.*

predominantly in the negative direction. Although none of these negative correlations were statistically significant, this finding supports the validity of the methods used. However, the lack of significant association between the subjective and objective categories of nasal measures, which persisted even after adjusting for possible confounders, suggests that these different nasal measures may capture different aspects of the nasal airway.

One difference may be in the temporal aspects of the measurements. The subjective measures assess the perception of obstruction over a longer time period (the previous 4 weeks in the case of the NOSE scale) and the objective measurements are taken at a single point in time. The fact that only the VAS was associated with an objective measure (upright and supine MCA) on regression analysis supports this explanation. Because the VAS instructions do not specify a duration of time, subjects are more likely to rate their current nasal airway, which may correlate better with the simultaneous objective nasal measures.

Another explanation for the lack of association is that a patient's perception of nasal obstruction may depend on factors beyond the physical caliber of the nose. For example, patients with an objectively measured, fixed, longstanding nasal obstruction (*e.g.*, cartilaginous or bony obstruction) may become desensitized to the severity of obstruction over time and rate themselves as having no problem with nasal obstruction. This discrepancy suggests that the objective measures might be more useful clinically. However, the NOSE scale has been shown to be highly responsive to change in the nasal airway after septoplasty,[12] and the patient's perception of obstruction is clinically relevant insofar as it drives seeking medical attention and overall satisfaction with any intervention.

One important limitation to this study is the selected population of sleep apnea patients. Results from this cohort might not be generalizable to other patients, because sleep apnea patients might differ from the general population in nasal anatomy, physiology, or subjective report. However, as shown in Table 1, the mean rhinometry measurements were consistent with reported population norms,[34–36] which suggests generalizability. Furthermore, the wide range of all the nasal measures, including subjective instruments, indicates that this population is heterogeneous with respect to the nasal airway with both extremes represented. This heterogeneity increases the power to detect associations and improves generalizability.

It is plausible that chronic hypoxia or prior use of continuous positive airway pressure in sleep apnea patients might bias the results of the subjective nasal measures. The measurements used in this analysis were done at the time of diagnostic polysomnography and therefore prior to diagnosis or treatment for sleep apnea, so the subjective report should not be biased by prior knowledge of disease severity or use of continuous positive airway pressure. One might postulate that the chronic hypoxia caused by sleep apnea might affect perceptions of nasal airflow; however, subgroup analyses stratified on sleep apnea severity did not change the results. Stratification by apnea-hypopnea index (AHI), lowest oxygen saturation (LSAT), BMI, and Epworth sleepiness scale individually showed no patterns of improved correlation related to severity of the disorder. To further evaluate for a confounding effect of sleep apnea, we compared the subgroup extremes of normals (both, AHI <10 and LSAT >90) versus the most severe (both, AHI >50 and LSAT <80) and still found poor correlations between different categories of nasal measures (data not shown).

Another limitation is the possibility of other confounders that have not been accounted for in our analysis. For example, seasonal variation in the nasal airway and respiratory comorbidity were not included in the adjusted analysis, and either could potentially confound the association between the different measures compared. Seasonal variation is less likely to be a problem because the enrollment period was from July 2004 to March 2005, when allergies are less problematic in Washington State. Respiratory comorbidity could potentially affect the nasal peak inspiratory flow measurements by limiting inspiratory effort[44,45] and may be contributing to the poor correlation with acoustic rhinometry and the subjective measures. However, significant primary respiratory abnormalities were not common in our cohort and occur in the minority of the general population.

One may wonder which of the objective measures is most clinically relevant. The adjusted analyses showed that only upright and supine MCA are significantly associated with subjective measures of the nasal airway (VAS). In the correlation analyses between rhinometry and flow measures, MCA correlated more strongly than volume in each case, albeit none statistically significantly. These data together suggest that MCA may be the most relevant, although certainly not comprehensive, objective measure of the nasal airway.

Because none of the anatomic, physiological, or subjective measures appears to capture the full spectrum of clinically important aspects of the nasal airway when used individually, we hypothesize that a composite measure that includes components of all these assessment methods will provide a more sensitive and responsive measure of the nasal airway. This reasoning has been advocated in the measurement of sleep apnea severity[46] because sleep apnea is a disease process that has both physiological and subjective effects and has been studied with both objective and subjective health measures.[47,48] Nasal obstruction similarly has anatomic, physiological, and subjective aspects. Therefore, outcomes of nasal interventions may be assessed more accurately with a composite measure. Future studies should be aimed at developing and testing such a composite nasal measure.

CONCLUSION

This study establishes poor correlation between anatomic, physiological, and subjective categories of nasal measurement that have each been shown to be valid and reliable. This suggests that these different methods of assessment are capturing different aspects of the nasal airway and should be considered complementary rather than contradictory. Future studies should be directed toward developing a more comprehensive composite measure of the nasal airway that incorporates parameters from each of these categories of nasal measurement.

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