Check for updates

The Laryngoscope

The Nasal Obstruction Balance Index: A Novel Approach to Improving Correlation Between Unilateral Nasal Airway Measurements and Evaluating Nasal Airway Asymmetry

Anika Kaura, MA(Hons) MBBS MRCS DOHNS; Alfonso Luca Pendolino, MD; Annakan Navaratnam, FRCS; Peter J. Andrews, FRCS MD(res); Terence S. Leung, PhD

Objectives/Hypothesis: Demonstrate that the Nasal Obstruction Balance Index (NOBI) model fulfils the unmet need of improving unilateral correlation between subjective and objective nasal obstruction outcome measures and identifying the more obstructed side.

1. Improve correlation between unilateral objective nasal airway measurements (nasal inspiratory peak flow [NIPF] and acoustic rhinometry [AR]) and subjective Visual Analogue Scale for nasal obstruction (VAS-NO) scores.
2. Improve assessment of nasal airway asymmetry by evaluating unilateral measurements both before and after the application of nasal decongestant; which the patient could better understand.

NOBI represents a ratio calculated by taking the difference between left and right nasal airway measurements and divided by the maximum unilateral measurement. It is based on Poiseuille's law and aims to reduce the confounding variables which challenge nasal airway measurement.

Study Design: Prospective cohort study.

Methods: Forty-three controls and 34 patients with nasal obstruction underwent both unilateral and bilateral NIPF, AR and VAS-NO measurements; these were repeated after the application of nasal decongestant. The NOBI values for unilateral NIPF, AR, and VAS-NO were calculated both before and after decongestant.

Results: The correlation between unilateral NIPF and AR measurements was enhanced considerably ($r = 0.57$, $P < .01$) when NOBI was applied. The NOBI metric significantly increased the correlation between unilateral NIPF, AR, and VAS-NO scores. Postdecongestant NOBI for NIPF and AR measurements correctly identified the more obstructed side in 82.4% and 94.1% of the deviated nasal septum (DNS) cases, respectively.

Conclusion: The NOBI model provides a better correlation between unilateral subjective and objective measurements and identifies the more obstructed side.

Key Words: Nasal obstruction, nasal cycle, nasal inspiratory peak flow, deviated nasal septum.

Level of Evidence: Prospective cohort study (level III)

***Laryngoscope*, 00:1–8, 2021**

INTRODUCTION

Nasal obstruction (NO) is a common complaint; accurate assessment of the nasal airway is crucial for its diagnosis and management. The assessment of NO as well as nasal airway asymmetry can be undertaken by using objective or subjective tools. In clinical practice, objective assessments include nasal inspiratory peak flow (NIPF), acoustic rhinometry (AR), or rhinomanometry (RMM). The subjective measurement of NO is performed using patient reported outcomes measures (PROMs) such as the SNOT-22 and NOSE questionnaires, or the Visual Analogue Scale for nasal obstruction (VAS-NO). However, a significant correlation between these subjective and objective measurements has not been demonstrated.[1–7]

The presence of the nasal cycle, the spontaneous, reciprocal congestion, and decongestion of the nasal mucosa, has been considered a contributing factor to this lack of correlation between objective and subjective measures.[8] Local application of nasal decongestant spray is often used to eliminate this confounding effect. In this way, Kjaergaard et al[9] demonstrated significant correlation between changes in bilateral AR, NIPF, and VAS-NO scores following nasal decongestant application. These results along with other studies[10–13] have established the value of taking postdecongestant measurement.

When assessing nasal airway asymmetry, the measurement of unilateral nasal patency is essential. However,

From the Department of Rhinology and Facial Plastic Surgery (A.K., A.L.P., A.N., P.J.A.), Royal National Throat Nose and Ear Hospital, London, United Kingdom; Ear Institute (A.K., A.L.P., P.J.A.), University College London, Grays Inn Road, London, United Kingdom, United Kingdom; and the Department of Medical Physics and Biomedical Engineering (T.S.L.), University College London, London, United Kingdom.

Editor's Note: This Manuscript was accepted for publication on April 16, 2021.

The authors have no funding, financial relationships, or conflicts of interest to disclose.

Send correspondence to Anika Kaura, UCL Ear Institute, 332 Grays Inn Road, London WC1X 8EE, UK. E-mail: anika.kaura.19@ucl.ac.uk

DOI: 10.1002/lary.29597

the correlation between unilateral AR (minimal cross-sectional area), unilateral NIPF, unilateral VAS-NO, and unilateral nasal airway resistance (from RMM), is poor.[1–6]

By using ratios of left and right measurements, several studies have reported improved correlation with PROMs. In the context of nasal spirometry, the nasal partitioning of airflow ratio (NPR), which is the subtraction between the two ratios of unilateral total expired nasal volumes, has been shown to correlate well with visual analogue scores ($r = 0.94$, $P < .01$).[14] Using ratios also improves the correlation between different objective tools; Hanif et al found a strong correlation ($r = 0.83$, $P < .01$) between nasal spirometry and posterior RMM when ratios were used.[15]

The Nasal Obstruction Balance Index (NOBI) model is based on Poiseuille's law (relationship between airflow and resistance), and considers left and right sides of the nose concurrently, by using unilateral nasal measurements (such as NIPF and AR) both before and after applying nasal decongestant. The model proposes to minimize the effect of differing breathing efforts in different subjects. To better understand the relationship between airflow, cross-sectional area, and subjective outcomes, we aim to determine whether the novel NOBI metric improves correlation between unilateral NIPF, AR, and VAS-NO scores.

MATERIAL AND METHODS

Study Design and Protocol

Seventy-seven participants were recruited at the Royal National Throat Nose and Ear Hospital, including 43 controls and 34 patients, as part of this prospective controlled study. Controls were 18 years or above and free from rhinological conditions or symptoms. Patients complaining of NO included subjects with one or more of the following diagnoses: septal deviation, nasal valve collapse, allergic rhinitis, chronic rhinosinusitis, or a combination. Patients with allergies were not excluded.

The following tools were used to make the clinical diagnosis: 1) clinical history, 2) nasendoscopic evaluation, 3) computerized tomography findings, 4) skin prick tests, and 5) sinonasal outcome test (SNOT-22) quality of life scores (a score of more than 10).[16,17]

Fisher's Z-transformation was used to determine the minimal sample size required to observe a correlation between two measures of $r = 0.6$, which would be considered a strong correlation. At the 0.05 significance level (two-sided test) and 80% power level, at least 19 subjects/observations would be needed for a correlation of $r = 0.6$. For both the pre and post decongestant parts of the study we ensured that more than 19 subjects were included in each group.

Demographics, including gender, age, ethnicity, weight and height were recorded. To investigate the effect of applying nasal decongestant, 20 controls and 22 patients had postdecongestant recordings.

NIPF was measured using a modified Youlten flow meter (Clement Clark International, UK). Bilateral, right and left measurements were performed (highest value from 3 attempts was recorded in each case). Unliteral measurements were recorded by placing tape over one nostril.[6]

The A1 Acoustic Rhinometer (GM Instruments, Kilwinning, UK) was used to measure the Mean Cross-sectional Area (MCA). To simplify analysis, we considered only the MCA1 value which is the narrowest point in the nasal cavity and contributes significantly to nasal airway resistance.[18] We have used $MCA1^2$, as according to Poiseuille's law it is the radius to the power of 4 that is proportional to flow. In the second part of the study, both NIPF and AR were repeated 10 minutes after applying nasal decongestant spray (xylometazoline hydrochloride 0.1% w/v).

Statistical analysis was carried out using IBM SPSS Statistics software version 26; Spearman correlation was used.

Ethical Considerations

Full ethical approval was granted (London – City & East Research Ethics Committee. Reference: 15/LO/0187). Written consent was obtained from all participants.

The NOBI model

To evaluate nasal airway asymmetry using unilateral measurements like airflow or MCA, we define the NOBI as:

$$\mathrm{NOBI}(X) = \frac{X_L - X_R}{\max(X_L, X_R)} \times 100\%$$

where X refers to either nasal airflow, MCA measurements, or VAS-NO. Subscripts L and R signify the left and right side of the nose, and max() is an operator selecting the larger value between X_L and X_R. Positive values of NOBI correspond to a more obstructed right side, while negative values a more obstructed left side. A zero NOBI value would mean both sides have the same degree of or no obstruction (balanced). NOBI can vary between -100% (left side completely obstructed) and $+100\%$ (right side completely obstructed). If the measurements of both sides have a numerical value of 0 then the NOBI will be assigned a value of 0.

Intuitively, nasal airflow should increase with the MCA of the nasal cavity. A more theoretical model can be established by considering Poiseuille's law which describes airflow in a tube: $\Delta P = 8\mu LQ/(\pi r^4)$, where ΔP, μ, Q, r, and L correspond to the pressure difference, air viscosity, airflow, radius, and length of the tube, respectively.[19] With some algebra manipulation, it can be shown that $A^2 = kQ/\Delta P$, where A is the cross-sectional area of the tube and $k = 8\pi\mu L$ is a constant. Although Q and A^2 are directly proportional to each other, they are also influenced by the pressure difference (ΔP), which is associated with breathing effort and is a major confounding factor in using NIPF.

The NOBI is essentially a ratio of the left to right-side measurements, which tends to cancel out factors common to both sides of the nose, including ΔP, μ, Q, and L. As such, the NOBI of A^2 is theoretically the same as that of airflow, that is, $\mathrm{NOBI}(A^2) = (A_L^2 - A_R^2)/\max(A_L^2, A_R^2) = (kQ_L/\Delta P - kQ_R/\Delta P)/\max(kQ_L/\Delta P, kQ_R/\Delta P) = (Q_L - Q_R)/\max(Q_L, Q_R) = \mathrm{NOBI}(Q)$.

In this work, the unilateral NIPF (UNIPF) and MCA1 are considered as the airflow (Q) and cross-sectional area (A) in the formulation. Strictly speaking, Poiseuille's law is only applicable in an idealized long tube. Therefore, applying it to the nasal cavity, one should expect certain discrepancy between NOBI(MCA^2) and NOBI(UNIPF), which is further increased by measurement errors in both UNIPF and MCA.

Investigating Nasal Cycle with NOBI

The NOBI can be applied to single snapshot measurements to investigate the reciprocal and periodic nature of the nasal cycle, where one side becomes more blocked and the other clearer, and after a period it switches. Figure 1 depicts a nasal cycle over 4 hours whereby congestion and decongestion of the left and right sides of the nose are reflected by variation of MCA^2 in Figure 1a and airflow in Figure 1b. In this idealized model, both NOBI(Q) and NOBI(MCA^2) have the same amount of variation over a nasal cycle in full agreement of Poiseuille's law (Fig. 1c). The NOBI model is depicted in Figure 1d as a diagonal straight line. When the right (or left) side is more obstructed in the nasal cycle, the corresponding data point would occupy quadrant I (or III).

RESULTS

A statistically significant difference between the demographics of patient and controls groups was not found.

In both the patient and control groups, the correlations between unilateral NIPF and unilateral MCA^2 measurements were not significant (Table I). However, when applying the NOBI formula to the unilateral

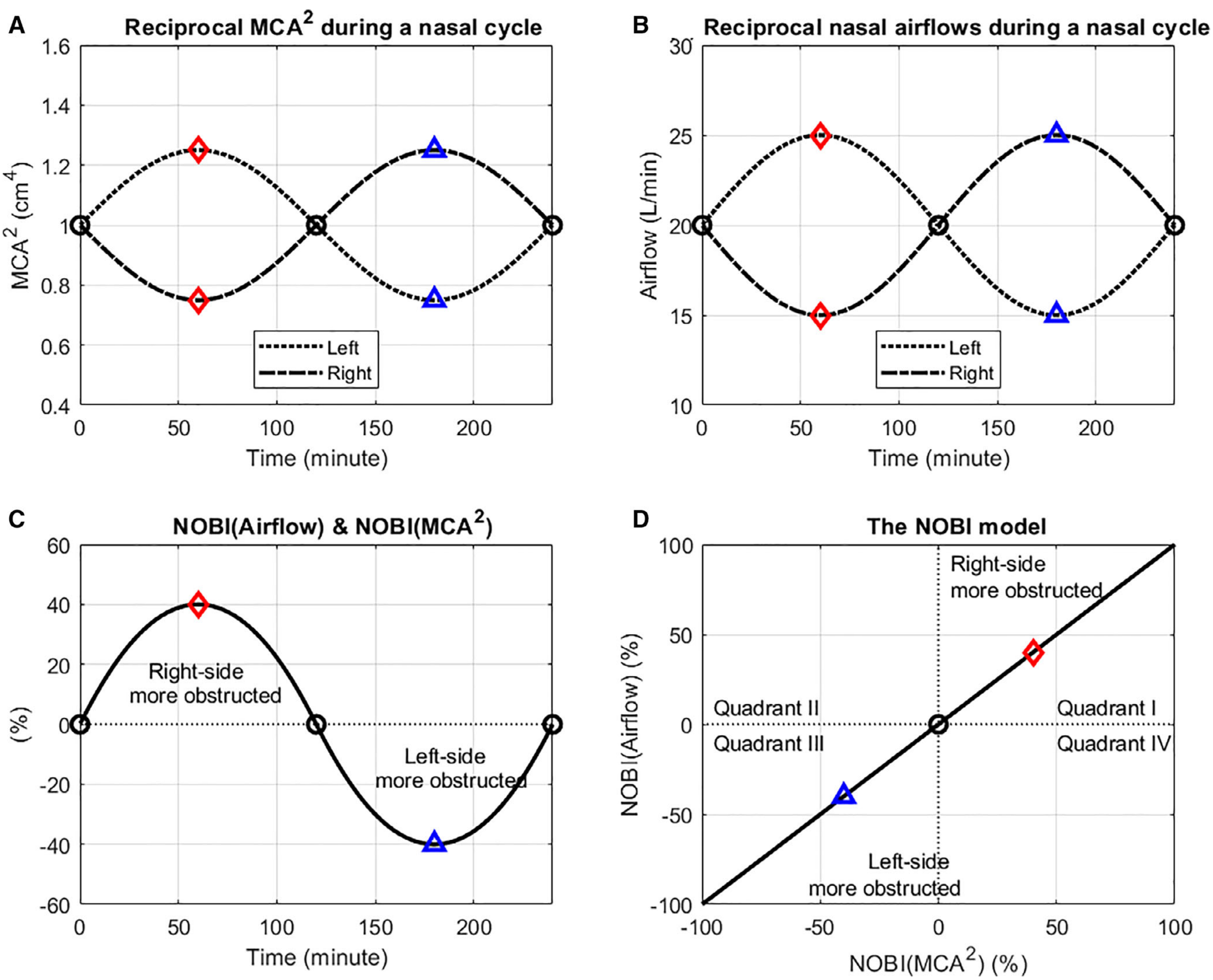

Fig. 1. The Nasal Obstruction Balance Index (NOBI) model: variation of (a) minimal cross-sectional area squared (MCA^2), (b) airflow and (c) the NOBI of MCA^2 and airflow over an idealized nasal cycle; (d) the NOBI model manifested as a diagonal line (the diamond and triangle symbols correspond to the points where NOBI = +40% and −40%, respectively). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

TABLE I.
Correlation of Unilateral Nasal Inspiratory Peak Flow and Acoustic Rhinometry Measurements in Patients and Controls Before the Application of Decongestant (Full Dataset n = 77, see Fig. 2).

Correlation			Correlation Coefficient (r)	*P*-value
Patients	NOBI(NIPF)	NOBI(MCA^2)	0.65*	.000
	L NIPF	L MCA^2	0.34	.050
	R NIPF	R MCA^2	0.18	.305
Controls	NOBI(NIPF)	NOBI(MCA^2)	0.46*	.002
	L NIPF	L MCA^2	0.14	.379
	R NIPF	R MCA^2	0.06	.706

L, left; NIPF, nasal inspiratory peak flow; NOBI, nasal obstruction balance index; MCA, minimal cross-sectional area; R, right.

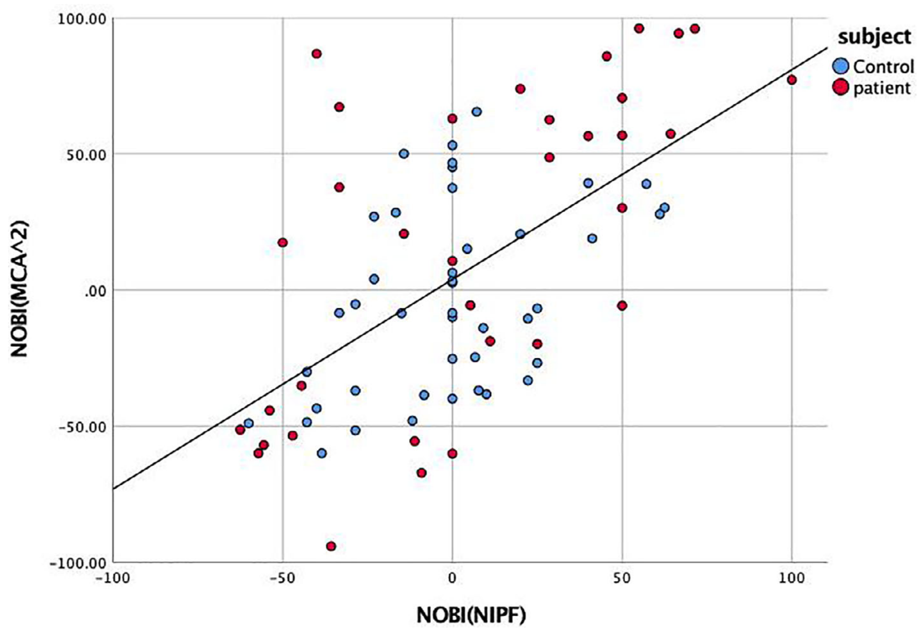

Fig. 2. Correlation between NOBI(MCA^2) and NOBI(NIPF) – pre-decongestant results for the control and patient groups (r = 0.57, $P < .01$, n = 77) (Table I). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

TABLE II.
Pre- and Postdecongestant Correlations for Unilateral NIPF and AR Measurements in Subset of Controls (n = 20) and Patients (n = 22).

Correlation		Controls		Patients	
		Correlation Coefficient (r)	*P*-Value	Correlation Coefficient (r)	*P*-Value
NOBI(NIPF)pre	NOBI(MCA^2)pre	0.65*	.002	0.49*	.021
NOBI(NIPF)post	NOBI(MCA^2)post	−0.27	.267	0.66*	.001
L NIPF pre	L MCA^{2}pre	0.32	.173	0.24	.291
L NIPF post	L MCA^{2}post	0.27	.250	0.46*	.037
R NIPF pre	R MCA^2 pre	0.13	.578	0.19	.405
R NIPF post	R MCA^2 post	0.40	.091	0.43	.052

L, left; MCA, minimal cross-sectional area; NIPF, nasal inspiratory peak flow; NOBI, nasal obstruction balance index; post, after decongestant; pre, before decongestant; R, right.

measurements, we observed statistically significant correlations for patients (r = 0.65, $P < .01$) and controls (r = 0.46, $P < .01$).

Figure 2 shows the scatter plot for NOBI(UNIPF) and NOBI(MCA^2). The correlation coefficient for the controls and patients combined is r = 0.57 ($P < .01$), n = 77, indicating a statistically significant linear relationship between NOBI(UNIPF) and NOBI($MCA1^2$). The data points in Figure 2 are distributed along the NOBI model, that is, the diagonal line.

Decongestant Study

Of the 77 subjects, 22 patients and 20 controls also underwent NIPF and AR 10 minutes after receiving nasal decongestant. The postdecongestant results were analyzed against the pre-decongestant results for this group (Table II). In the control group, we observed little correlation between unilateral NIPF and MCA^2 measurements.

When analyzing the correlation between NOBI(UNIPF) and NOBI(MCA^2) before decongestant in these controls, the correlation was $r = 0.65$ ($P = .002$). However, the post-decongestant NOBI results did not show significant correlation, $r = -0.27$ ($P = .267$).

For the patient group, the correlation coefficients for left- and right-sided NIPF and MCA^2 measurements before decongestant were $r = 0.24$ ($P = .291$) and $r = 0.19$ ($P = .405$), respectively; and postdecongestant were $r = 0.46$ ($P = .037$) and $r = 0.43$ ($P = .052$), respectively.

TABLE III.
Patient Group Pre- and Postdecongestant Results – Correlation Between NIPF and VAS-NO, MCA^2 and VAS-NO, and the Derived NOBI Values (Fig. 3).

Correlation		Decongestant	Correlation Coefficient (r)	*P* Value
B/L NIPF	B/L VAS-NO	Pre	−0.51*	.004
		Post	−0.16	.405
L NIPF	L VAS-NO	Pre	−0.21	.274
		Post	−0.04	.849
R NIPF	R VAS-NO	Pre	−0.28	.141
		Post	−0.37	.055
L $MCA1^2$	L VAS-NO	Pre	0.21	.338
		Post	0.02	.934
R $MCA1^2$	R VAS-NO	Pre	0.11	.614
		Post	−0.33	.139
NOBI(VAS-NO)	NOBI(NIPF)	Pre	−0.10	.603
		Post	−0.38*	.045
NOBI(VAS-NO)	NOBI(MCA^2)	Pre	−0.45*	.035
		Post	−0.45*	.042

B/L, bilateral; L, left; MCA, minimal cross-sectional area; NIPF, nasal inspiratory peak flow, R, right, NOBI, nasal obstruction balance index, VAS-NO, visual analogue scale for nasal obstruction.

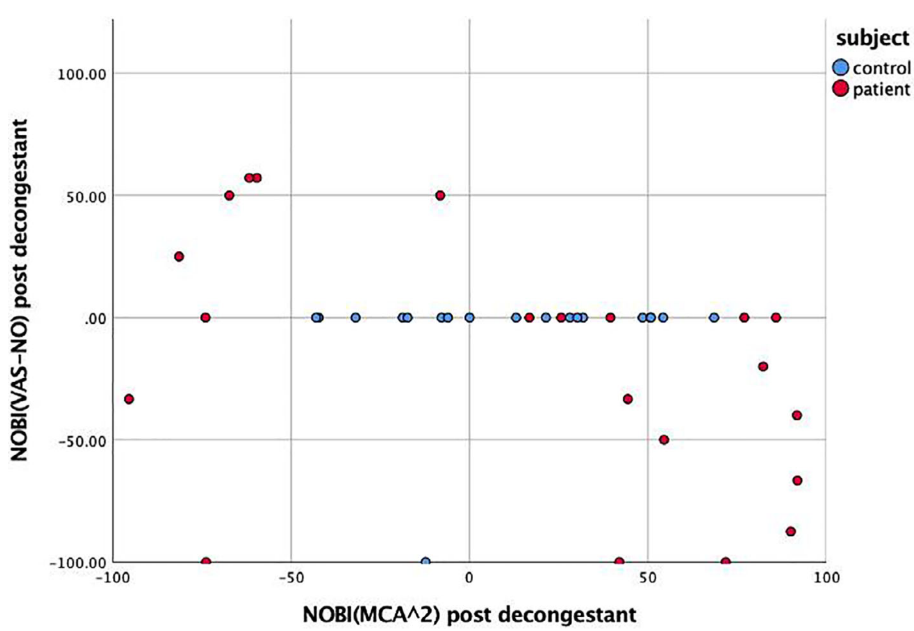

Fig. 3. Correlation between NOBI(MCA^2) and NOBI(VAS-NO) postdecongestant in the control ($r = 0.17$, $P = .48$) and patient ($P = -.45$, $P < .05$) groups (Table III). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

The correlation between NOBI(UNIPF) and NOBI(MCA^2) both pre-decongestant ($r = 0.49$ [$P = .021$]) and post-decongestant ($r = 0.66$ [$P < .01$]) were statistically significant.

NOBI as a Predictor of deviated nasal septum

Of the 22 patients, 17 had a deviation where one side was significantly more obstructed than the other. Using the NOBI(NIPF) and NOBI(MCA^2) metric pre- and post-decongestant, we analyzed whether the NOBI value correctly identified the side that was more obstructed. NOBI(NIPF) correctly identified the more obstructed side in 88.2% of cases pre-decongestant, and 92.4% post-decongestant. For NOBI(MCA^2), the more obstructed side was correctly identified in 76.5% of patients pre-decongestant and 94.1% postdecongestant.

Visual Analogue Scale for Nasal Obstruction

In the cohort of 22 patients and 20 controls that underwent nasal decongestion, we asked them to score their nasal blockage (bilateral, left and right) out of 10 using the Visual Analogue Scale both pre- and post-decongestant. The results of the correlation between VAS-NO scores and both the NIPF and MCA^2 measurements for the patient group are demonstrated in Table III. Bilateral NIPF measurements correlated with bilateral VAS-NO scores pre-decongestant ($r = -0.513$, $P = .004$), indicating that as VAS-NO scores are lower (less blocked), flow increases as measured by NIPF.

There was no significant correlation between unilateral VAS-NO and unilateral NIPF before or after decongestant. The same was true for unilateral VAS-NO and unilateral MCA^2 measurement. There was a degree of correlation between NOBI(VAS-NO) and NOBI(NIPF) postdecongestant ($r = -0.382$, $P = .045$). There was moderate correlation between NOBI(VAS-NO) and NOBI(MCA^2) both before and after decongestant ($r = -0.451$, $P = .035$ and $r = -0.447$, $P = .042$, respectively). Figure 3 demonstrates the negative correlation between NOBI(VAS-NO) and NOBI(MCA^2) post-decongestant in patients.

The majority of control subjects scored 0 out of 10 for VAS-NO. When we performed the same correlation analyses for the control group, the only pairing that had a statistically significant correlation was pre-decongestant left NIPF compared with left VAS-NO ($r = -0.45$ $P = .04$).

DISCUSSION

Key Findings

We have introduced a new methodology to analyze unilateral NIPF and AR measurements. In general, the unilateral measurements in this study do not correlate, which in part we attribute to different individuals' peak inspiratory efforts and repeatability of measurements. However, after converting unilateral NIPF and MCA measurements into NOBI(NIPF) and NOBI(MCA^2), a statistically significant correlation emerges for both patients and controls. The advantage of NOBI is that the effect of transnasal pressure ΔP has been minimized, assuming the breathing effort (ΔP) is the same for right and left NIPF measurements. When analyzing the NOBI measurement before and after decongestant for patients and controls, we observed significant correlations pre-decongestant for controls ($r = 0.65$, $P < .01$) and post-decongestant for patients ($r = 0.66$, $P < .01$).

While subjects with no nasal cycle (or at the balanced point) have their data points located close to zero in the NOBI model, the data points of controls with a "classic" nasal cycle[8] occupy the central area along the NOBI model. The data points for patients, on the other hand, tend to occupy the far ends of the NOBI model, that is, those with NOBI(MCA^2) $< -40\%$ or $> +40\%$ (Fig. 2). The majority of patients had septal deviation, and this could be why the NOBI(MCA^2) is distributed more at the extremes.

We first introduced the NOBI concept in a pilot study using the nasal acoustic device to diagnose nasal obstruction (NO).[20] Here we demonstrated that the NOBI model could be applied to NIPF measurements and nasal acoustic scores. The NOBI values were used to identify the presence of a deviated nasal septum (DNS) with a sensitivity of 68% using NIPF and 77% using NAD acoustic scores. In this way, the NOBI can be used to more accurately assess nasal airway asymmetry.

Importance of Using Nasal Decongestant

Interestingly, we observed greater correlation in NOBI measurements pre-decongestant for controls and postdecongestant for patients. This could be attributed to the fact that the application of decongestant eliminates mucosal engorgement and the nasal cycle effect, enabling more accurate evaluation of physical obstruction. This is evident in the results where NOBI(NIPF) and NOBI(MCA^2) are used to predict the more obstructed side of the nose. The accuracy increases postdecongestant, again supporting the idea that decongestant enables better identification of structural asymmetry. In this way, the NOBI could be used to identify patients with significant nasal asymmetry.

When analyzing the relationship between NOBI(NIPF) and NOBI(MCA^2) before decongestant in controls, there is significant correlation ($r = 0.65$, $P = .002$). Interestingly, the postdecongestant NOBI results do not show significant correlation, $r = -0.27$ ($P = .267$). Considering that 70%–80% of people are reported to experience the nasal cycle,[8] we would expect the majority of controls in this study to experience a pattern of alternating congestion/decongestion. Therefore, when we carry out pre-decongestant recordings one side of the nose will be more blocked with respect to the other resulting in a higher NOBI value whether that be more positive or negative depending on whether the right or left side is more blocked. This asymmetry from the nasal cycle could result in higher correlation between measures of airflow (NIPF) and cross-sectional area (MCA^2). After decongestant is applied, we expect the two sides to be very similar in a control and therefore the NOBI values for NIPF and MCA^2 would tend toward 0, resulting in reduced correlation.

Visual Analogue Scale Scores for Nasal Obstruction

In the patient group, a moderate statistically significant correlation is observed between bilateral NIPF and bilateral VAS-NO pre-decongestant ($r = -0.51$, $P < .01$). In contrast, we see no significant correlation between unilateral VAS-NO score and unilateral NIPF, or unilateral VAS-NO score and unilateral MCA^2.

When we apply the NOBI principle to the unilateral measurements, we see increased correlation as it is a better indicator of asymmetry which factors in the left and right sides of the nose concurrently. This is particularly true for NOBI(VAS-NO) scores compared with NOBI(MCA^2) measurements before and after decongestant, over and above NIPF. This could be because AR measurement is more easily repeated postdecongestant and therefore more reliable. Whereas NIPF is both effort and technique dependent, and measurement can vary significantly because of these human factors.

In the case of NOBI(NIPF) compared with NOBI(VAS-NO), the results are less convincing, with no significant correlation pre-decongestant, and low but significant correlation postdecongestant. This could be related to 1) the reliability of NIPF as a measuring tool, 2) pre-decongestant measurements are complicated by the nasal cycle, and 3) the study is underpowered for this part of the correlation analysis. Indeed, a larger study, particularly with regard to the VAS-NO results is required to determine the reliability of the observations detailed in our study.

While the NOBI model increases the correlation between unilateral subjective and objective measures such that they are statistically significant; the r-value is moderate (−0.38 and −0.45 for NOBI(NIPF) and NOBI(VAS), respectively, when correlated with NOBI(VAS-NO) post decongestant). This is in keeping with the literature, where strong correlations between subjective and objective measures have not been observed in small studies.[21–24]

Comparisons with Other Studies

Similar to our findings in unilateral NIPF and MCA1 measurements, a study based on bilateral NIPF and MCA1 concluded that these two measurements did not have significant correlation ($n = 290$), which the authors found "particularly surprising".[25] A much larger scale study ($n = 2,523$), however, indicated statistically significant association between NIPF and MCA1.[26] They attributed their success to their sample composition and size.

Our explanation for the lack of correlation is based on Poiseuille's law that highlights pressure difference (transnasal pressure or breathing effort) as a major confounding factor for the relationship between MCA and airflow. The use of NOBI in these two measurements can minimize the effect of breathing effort and results in a strong correlation ($r = 0.57$, $P < .01$), even for a small sample size ($n = 77$).

Several papers have concluded that UNIPF could be useful in assessing unilateral nasal patency. Ottaviano et al demonstrated that UNIPF was as accurate as anterior active RMM in identifying NO.[27] In our study, we demonstrated that by combing UNIPF and MCA1 measurements and applying the NOBI model, one could obtain diagnostic information about pathologies like DNS.

The NOBI is closely related to the NPR which describes a ratio derived from unilateral measurements of nasal airflow using nasal spirometry.[15,28] A more recent study used a nasal airflow logger to measure the ratio of airflows on both sides of the nose, called respiration laterality index (LI)[29] (Note: LI = −NPR). The NOBI is defined in a more general term and can be applied to any unilateral measurements.

The NOBI, NPR, and LI are not meant to measure absolute obstruction level. Whether the patient has no NO at all or severe but equal level of obstruction on both sides; the numerical value of these metrics would still be 0% or 0%.

Practical Application of the NOBI Model

The NOBI model can be used as a way to explain nasal asymmetry to patients, for example, those with a septal deformity or those with nasal valve dysfunction. The NOBI gives a numeric value to how much one side of the nose is blocked with respect to the other. For example, a NOBI value of 70 from AR readings, would indicate that the right side is 70% more blocked compared with the left. This can serve as a way for patients to better understand their nasal airway obstruction and asymmetry, on a scale of −100% to +100%; and how much this changes once any mucosal element is eliminated with the application of decongestant.

Limitations of the Study

The NOBI model is based on Poiseuille's law and the assumption that the nose behaves the same way as a longitudinal tube. From computational flow dynamics[30] we know that this is not the case, while we acknowledge the NOBI model is simplistic, it is a practical approach to the interpretation of unilateral NIPF and AR values.

Four patterns of nasal cycle have been described in the literature.[31] Our NOBI model and the diagonal line described in Figure 1d comply with the classic type of nasal cycle. We have not considered the "parallel" and "irregular" types. Another limitation is that the observations were carried out at one time point giving us a single snapshot in the nasal cycle.

The number of patients studied here is large enough to support the study conclusions regarding NOBI(NIPF) compared with NOBI(MCA^2) in both the pre- and post-decongestant parts of the study. A larger sample size is required to improve power with regard to the VAS-NO results and other unilateral correlations, and to determine whether similar results are observed in a larger dataset.

CONCLUSION

Despite the high burden of NO, its diagnosis and management remain challenging.[32] There is an increasing need for an objective tool in Rhinology that can both aid diagnosis and which better correlates with the patient's symptoms.[33–36]

We demonstrated that the application of the NOBI model significantly improved correlation between unilateral NIPF and AR measurements because the model helped to eliminate confounding variables such as the difference in breathing effort between individual subjects and different sides of the nose. Moreover, it improved the correlation between unilateral objective (NIPF and AR) and subjective (VAS-NO) measurements of NO.

Taken together, our results show the NOBI as a valuable model in more accurately interpreting the unilateral measurements of NIPF and AR, particularly in identifying cases of DNS. NOBI outcomes are easy to apply and understand, and can serve as a useful way to explain obstruction or asymmetry to patients.

Acknowledgments

The authors would like to thank the patients and volunteers for their participation in the study.

BIBLIOGRAPHY

1. Tomkinson A, Eccles R. Comparison of the relative abilities of acoustic rhinometry, rhinomanometry, and the visual analogue scale in detecting change in the nasal cavity in a healthy adult population. *Am J Rhinol* 1996;10:161–166.
2. Døsen LK, Kvinnesland K, TarAngen M, Shiryaeva O, Gay C, Haye R. Unilateral and bilateral PNIF in quality control of nasal septal surgery. *Int J Otolaryngol* 2018;2018:1–7.
3. Isaac A, Major M, Witmans M, et al. Correlations between acoustic rhinometry, subjective symptoms, and endoscopic findings in symptomatic children with nasal obstruction. *JAMA Otolaryngol Head Neck Surg* 2015; 141:550–555.
4. Edizer DT, Erisir F, Alimoglu Y, Gokce S. Nasal obstruction following septorhinoplasty: how well does acoustic rhinometry work? *Eur Arch Otorhinolaryngol* 2013;270:609–613.
5. Chan K-O, Huang Z-L, Wang D-Y. Acoustic rhinometric assessment of nasal obstruction after treatment with fluticasone propionate in patients with perennial rhinitis. *Auris Nasus Larynx* 2003;30:379–383.
6. Kaura A, Virk JS, Joseph J, Rennie C, Singh Randhawa P, Andrews PJ. The role of unilateral nasal inspiratory peak flow in nasal obstruction-a study of 70 patients undergoing septorhinoplasty surgery. *Clin Otolaryngol* 2019;44:427–430.
7. Ottaviano G, Pendolino AL, Nardello E, et al. Peak nasal inspiratory flow measurement and visual analogue scale in a large adult population. *Clin Otolaryngol* 2019;44:541–548.
8. Pendolino AL, Lund VJ, Nardello E, Ottaviano G. The nasal cycle: a comprehensive review. *Rhinology Online* 2018;1:67–76.
9. Kjaergaard T, Cvancarova M, Steinsvag SK. Nasal congestion index: a measure for nasal obstruction. *Laryngoscope* 2009;119:1628–1632.
10. Chin D. Nasal peak inspiratory flow (NPIF) as a diagnostic tool for differentiating decongestable from structural nasal obstruction. *Rhinol J* 2014;52: 116–121.
11. Widiarni D, Paramyta W, Wardani R, Bachtiar A. Comparison of nasal obstruction symptom evaluation, peak nasal inspiratory flowmeter, and rhinomanometry in patients with nasal deformities. *J Phys Conf Ser* 2018; 1073:022024.
12. Teixeira RUF, Zappelini CEM, Oliveira LG, Basile LCG, da Costa EA. Correlation between the peak nasal inspiratory flow and the visual analogue scale before and after using a nasal decongestant. *Int Arch Otorhinolaryngol* 2011;15:156–162.
13. Farmer S, Eccles R. Chronic inferior turbinate enlargement and the implications for surgical intervention. *Rhinology* 2006;44:234.
14. Cuddihy PJ, Eccles R. The use of nasal spirometry as an objective measure of nasal septal deviation and the effectiveness of septal surgery. *Clin Otolaryngol Allied Sci* 2003;28:325–330.
15. Hanif J, Eccles R, Jawad SS. Use of a portable spirometer for studies on the nasal cycle. *Am J Rhinol* 2001;15:303–306.
16. Erskine SE, Hopkins C, Clark A, et al. SNOT-22 in a control population. *Clin Otolaryngol* 2016;42:81–85.
17. Scadding GK, Kariyawasam HH, Scadding G, et al. BSACI guideline for the diagnosis and management of allergic and non-allergic rhinitis (revised edition 2017; first edition 2007). *Clin Exp Allergy* 2017;47:856–889.
18. Roithmann R, Cole P, Chapnik J, Shpirer I, Hoffstein V, Zamel N. Acoustic rhinometry in the evaluation of nasal obstruction. *Laryngoscope* 1995;105: 275–281.
19. Courtiss EH, Goldwyn RM. The effects of nasal surgery on airflow. *Plast Reconstr Surg* 1983;72:9–21.
20. Li CH, Kaura A, Tan C, Whitcroft KL, Leung TS, Andrews P. Diagnosing nasal obstruction and its common causes using the nasal acoustic device: a pilot study. *Laryngoscope Investig Otolaryngol* 2020;5:796–806.
21. Stewart MG, Smith TL. Objective versus subjective outcomes assessment in rhinology. *Am J Rhinol* 2005;19:529–535.
22. Murrell GL. Correlation between subjective and objective results in nasal surgery. *Aesthet Surg J* 2014;34:249–257.
23. Hirschberg A, Rezek Ö. Correlation between objective and subjective assessments of nasal patency. *ORL* 1998;60:206–211.
24. Yepes-Nuñez J, Bartra J, Muñoz-Cano R, et al. Assessment of nasal obstruction: correlation between subjective and objective techniques. *Allergol Immunopathol* 2013;41:397–401.
25. Lam DJ, James KT, Weaver EM. Comparison of anatomic, physiological, and subjective measures of the nasal airway. *Am J Rhinol* 2006;20: 463–470.
26. Kjaergaard T, Cvancarova M, Steinsvåg SK. Relation of nasal air flow to nasal cavity dimensions. *Arch Otolaryngol Head Neck Surg* 2009;135: 565–570.
27. Ottaviano G, Lund VJ, Nardello E, et al. Comparison between unilateral PNIF and rhinomanometry in healthy and obstructed noses. *Rhinology* 2014;52:25–30.
28. Roblin DG, Eccles R. Normal range for nasal partitioning of airflow determined by nasal spirometry in 100 healthy subjects. *Am J Rhinol* 2003;17: 179–183.
29. Kahana-Zweig R, Geva-Sagiv M, Weissbrod A, Secundo L, Soroker N, Sobel N. Measuring and characterizing the human nasal cycle. *PLoS One* 2016;11:e0162918.
30. Lintermann A. Application of computational fluid dynamics methods to understand nasal cavity flows. *All Around the Nose*. Europe: Springer; 2020:75–84.
31. Anselmo-Lima WT, Lund VJ. The effects of endoscopic sinus surgery on the nasal cycle as assessed by acoustic rhinometry. *Am J Rhinol* 2001;15: 165–168.
32. Andrews P, Joseph J, Li CH, Nip L, Jacques T, Leung T. A UKsurvey of current ENT practice in the assessment of nasal patency. *J Laryngol Otol* 2017;131:702–706.
33. Andrews PJ, Choudhury N, Takhar A, Poirrier AL, Jacques T, Randhawa PS. The need for an objective measure in septorhinoplasty surgery: are we any closer to finding an answer? *Clin Otolaryngol* 2015;40: 698–703.
34. Poirrier AL, Ahluwalia S, Goodson A, Ellis M, Bentley M, Andrews P. Is the Sino-nasal outcome test-22 a suitable evaluation for septorhinoplasty? *Laryngoscope* 2013;123:76–81.
35. Whitcroft KL, Andrews PJ, Randhawa PS. Peak nasal inspiratory flow correlates with quality of life in functional endoscopic sinus surgery. *Clin Otolaryngol* 2017;42:1187–1192.
36. Kaura A, Tan M, Whitcroft K, et al. A North London pilot survey to assess the need for a medical device in diagnosing chronic rhinosinusitis in primary care. *Open J Otolaryngol* 2019;2:24–29.