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The Use of Infrared Thermal Imaging to Determine Functional Nasal Adequacy: A Pilot Study

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Abstract

Objective. The goal of this study was to establish a numeric threshold to separate functional from substantially obstructed noses using comparisons of thermal imaging and subjective scores.

Study Design. An inexpensive smartphone application and hardware attachment that uses infrared thermal imaging was tested to differentiate between substantial nasal blockage from an adequately functioning nose.

Setting. Sequential adult participants who presented to a public hospital otolaryngology clinic between June and August 2018 were asked to complete the Nasal Obstruction Symptom Evaluation (NOSE) tool.

Methods. A thermal video imaging device was used to record the difference in temperature (ΔT) between inspired (I) and expired (E) air at each nostril. The nostril ΔT between I and E air of patients with severe obstruction by the subjective measure (NOSE score) was compared with that of patients with minimal symptoms.

Results. A total of 26 participants were enrolled in the study. During normal respiration, Total ΔT for the nonobstructed group had a mean of 9.0, whereas the Total ΔT for the obstructed group had a mean of 7.69, a 17% difference that was statistically significant at P = .045. For the worst-performing nostril tested, ΔT for the nonobstructed group had a mean/median of 4°C, while the obstructed group had a mean of 3.23°C (median 3; 23.8% difference, P = .023).

Conclusion. Measures of thermal imaging, particularly at the threshold between the median scores of the worst-performing nostril, may be a useful clinical test to differentiate between a substantially obstructed nose from an adequately functioning nose, although more data are required.

Keywords

nasal obstruction, nasal disuse, thermal imaging, nasal airway, septal deviation, nasal valve, NOSE scores, nasal vestibule, nasal airflow, obstructive sleep apnea, infrared airflow measurement

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A reliable, cost-effective, and noninvasive objective measure of nasal airflow remains undiscovered. The lack of a simple objective measurement to complement validated subjective measures may be why measuring outcomes in functional nasal surgery remains challenging and controversial. The currently acknowledged gold standard in the measurement of nasal obstruction is a widely used survey known as the Nasal Obstruction and Septoplasty Effective (NOSE) scale instrument.[1,2]

While well accepted as the best current measure of obstruction, the NOSE survey is subjective and unable to measure actual flow for obvious reasons. Since the survey consists of only patients' reported symptoms, it is useful in comparing data in the same patient, such as before and after surgical treatment. However, comparing scores between patients, populations, or interventions can be challenging because of the variability of very different obstructive experiences between patients. In addition, the survey scale cannot discriminate between actual anatomic obstruction requiring repair and other conditions that mimic anatomic obstruction from allergy to chronic habitual mouth breathing. For this reason, a reliable, objective measure of airflow may permit physicians to better select patients for surgery, combining subjective symptoms, physical examination, and photographs with measurement of objective flow data. Acoustic rhinometry and rhinomanometry have been explored and largely been dismissed by most clinicians and even many researchers in the United

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States for being too cumbersome and in many cases unreliable because of distortion of the nostril.[3-5] Because of the inconsistency of the existing objective measures, and the inherent limitations of the subjective measures, we decided for this study to attempt to correlate the novel device solely with grossly high and low NOSE scores as a broad measure of adequacy or inadequacy. Attempting to correlate the device with existing but inconsistent or inaccurate objective measures risked classifying the device as useless not on its own sake but to the failure of its predecessors.

Recent research has shown it is not nasal airflow resistance but rather mucosal cooling by inspired air that predicts the sensation of nasal airflow.[6,7] More importantly, a recent study showed that change in mucosal temperature (ΔT), when measured with an intranasal probe within the nostril, from inspiration to expiration can serve as a surrogate for nasal airflow.[8] The nostril is the location of the transition point between room inspired temperature air, generally approaching 27°C in an indoor environment, and lung-warmed air, which approaches human body temperature of 37°C in the healthy individual, but of course there is some heat loss during expiration in the respiratory tract, making this figure a theoretic approximation.[9,10] Thus, a fully functioning and adequate nostril would theoretically have a change in temperature ΔT of 10°C between the environmental air just before the moment of inspiration (27°C) and the moment of peak expiration (37°C). While this 10°C change is based on theory, one could reasonably assume that a generally functional nasal airway would have a similar profile and approximate ΔT of 10. In contrast, a closed or poorly functioning nostril would have a smaller ΔT, with less efficient temperature change. In extreme, a completely closed nostril would be expected to not communicate with the lungs and would have a ΔT approaching zero. Thus, one might expect an individual's ΔT to generally fall within these 2 extremes of 0 to 10°C, roughly tracking the function of the nose. The data from the nasal temperature probe study correlated ΔT with respiratory effort and seemed to precisely track inspiration and expiration in healthy individuals. From a nasal functional perspective, however, ΔT correlated statistically only with NOSE scores in the right vestibule. The authors of the nasal probe study attributed this lack of correlation to probe interference or ''noise'' in the NOSE scale data to track actual airflow.[8]

Heeding the limitations that a mucosal temperature probe might interfere with nasal airflow and confound ΔT, we aimed to employ an inexpensive phone-connected thermal imaging device and associated digital application to record ΔT as a nostril base-view video and photograph. Thermal imaging has been used in the past to monitor respiration at the nose.[11,12] We hypothesized that this noninvasive thermal imaging modality would similarly record inspiratory to expiratory temperature changes at the nostril and could serve as a surrogate for distinguishing between very low NOSE scores (little anatomic pathology) and very high NOSE scores (severe anatomic obstruction).

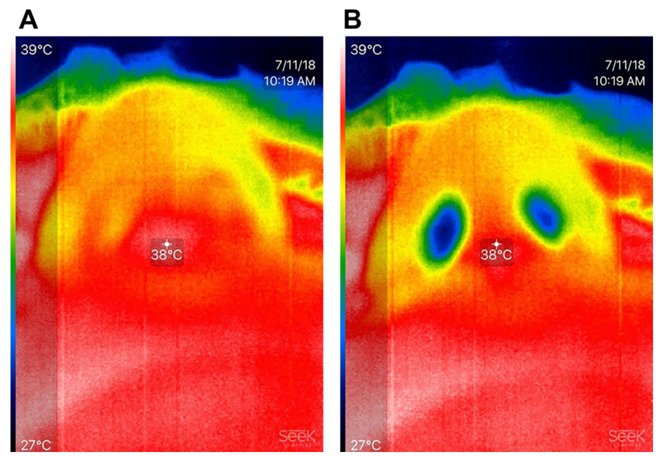

Figure 1. Thermal images nasal base view. (A) At the end of expiration, the temperature at the nostril approaches body temperature. (B) Seconds later, upon inspiration, the air filling the nostril approaches room temperature.

Methods

Institutional review board (IRB) approval for this study was obtained from the Albert Einstein College of Medicine, Bronx, New York, including the off-label use of a thermal imaging device. The study is registered at clinicaltrials.gov (NCT03233373). The study was conducted in a public hospital otolaryngology clinic at Jacobi Medical Center of the Albert Einstein College of Medicine in Bronx County, New York City. Patient volunteers who presented to clinic between June 2018 and August 2018 were included in this study. Patients with active acute sinus infection were excluded, although the number and characteristics of these excluded patients were not recorded. All patients in outpatient clinic days where testing was done without severe airway issues (including laryngectomy tracheotomy or other severe airway abnormalities such as tracheal stenosis, severe obstructive laryngeal diseases) or severe mental disturbance were eligible for inclusion in the study and were approached for consent to be tested. All patients with any otolaryngologic complaint including nasal issues or lack thereof were eligible to participate, although data from patients who did not participate in the study were not recorded and thus are not available. Neither nasal endoscopy nor pulmonary function tests were performed nor recorded as part of this study. After written consent, the Seek thermalPRO (Santa Barbara, California) imaging device, in pinpoint-temperature reading video mode, was placed approximately 5 to 20 cm from the subject's nostril, similar to a basal view rhinoplasty photograph. This device was previously tested in another biomedical application.[13] Maximal inspiratory (I) and expiratory (E) temperatures were recorded for each nostril, and the difference between the 2 extremes was recorded as ΔT in several conditions (**Figure 1**; Supplemental Video 1) The conditions were (1) normal comfortable respiration, with the subject at rest in

Table 1. Mean Total ΔT as Correlated With Nasal Obstruction Symptom Evaluation (NOSE) Score During Normal Respiration, Maximal Respiration, Cottle Maneuver With Normal Respiration, and Cottle Maneuver With Maximal Respiration.[a]

	Normal	Normal max	Cottle	Cottle max
NOSE 0-25 (normal)	9 (IQR 2)	10.474 (IQR 3)	7.88 (IQR 3)	9.47 (IQR 2)
NOSE 30-100 (obstructed)	7.69 (IQR 3)	9.31 (IQR 5)	7.92 (IQR 3)	8.84 (IQR 4)
Student *t* test *P*	**.045**	.13	.48	.27

[a]Bold value indicates statistical significance.

Table 2. Mean ΔT of the Best- and Worst-Performing Nostril as Correlated With Nasal Obstruction Symptom Evaluation (NOSE) Score During Normal Respiration, Maximal Respiration, Cottle Maneuver With Normal Respiration, and Cottle Maneuver With Maximal Respiration.[a]

	Better normal	Worst normal	Better max	Worst max	Better cottle	Worst cottle	Better cottle max	Worst cottle max
NOSE 0-25 (normal)	5 (IQR 2)	4 (IQR 0)	5.65 (IQR 1)	4.82 (IQR 2)	4.17 (IQR 2)	3.70 (IQR 1)	5.35 (IQR 1)	4.12 (IQR 1)
NOSE 30-100 (obstructed)	4.46 (IQR 1)	3.23 (IQR 1)	5.31 (IQR 3)	4 (IQR 3)	4.46 (IQR 1)	3.46 (IQR 1)	5 (IQR 3)	3.85 (IQR 2)
Student *t* test *P*	.11	**.023**	.27	**.075**	.26	.29	.24	.32

[a]Bold values indicate statistical significance and near statistical significance.

an exam chair; (2) maximal deep respiration; (3) with nostrils dilated using a modified Q-Tip Cottle maneuver by the research assistant; and (4) with nostrils dilated using the Cottle maneuver by the research assistant during maximal respiration. The Cottle maneuver was performed with a disposable Q-Tip with an attempt to stretch the nostril laterally. All patients completed a written NOSE instrument survey at the time they completed their written consent. Patients were then stratified into 2 groups based on a NOSE score of greater than or less than 30, based on research that showed this to be the important threshold between pathologic anatomic obstruction (score greater than 30) and nasal complaints not associated with anatomic obstruction (score less than 30), as opposed to the arbitrary cutoff of 50 in this scale of 5 (no complaints) to 100 (maximal complaints). In the study by Lipan and Most,[14] the authors noted 30 to be the statistical threshold for differentiating between groups with and without true nasal obstruction. Thus, in our study, patients with a NOSE score of 0 to 25 were considered to be without nasal obstruction, and patients with a NOSE score of 30 to 100 were categorized as having nasal obstruction. To account for the nasal cycle, which causes physiologic switching between functional and obstructive sides of the nose in healthy individuals, we added the ΔT between the 2 nostrils for each individual for all measured states as a sum we noted as Total ΔT. A NOSE score less than 30 and NOSE score greater than or equal to 30 groups were recorded for all states (normal respiration, obstructed, Cottle, and maximal respiratory effort) as the median, mean, and interquartile range (IQR) and compared using Student single-tailed *t* test. In addition to Total ΔT (sum of the 2 nostrils), we compared the best and worst breathing of the 2 nostrils, also dividing the patients into greater than or equal to 30 and less than 30 NOSE score groups using the same statistical test to determine if perhaps instead of the sum of the nostrils, the best- or worst-performing nostril better predicted symptomatology. The temperature of the examination was not recorded during each subject in the study but is generally maintained between 20 and 22°C in our clinic.

Results

Twenty-six healthy patients were enrolled in the study. Fifteen patients were in the nonobstructed group (NOSE score 0-25), whereas 11 patients were in the obstructed group (NOSE score 30-100). Because the NOSE scale is a 20-point possible score multiplied by a factor 5, scores of 26 to 29 are not possible, as these are not factors of 5, and fractions are not possible. Scores of 25 are included in the 0 to 25 category, and 30 is included in the 30 to 100 category. The median Total ΔT of the 2 groups are listed in **Table 1**. During normal respiration, the Total ΔT for the nonobstructed group had a median 9°C (IQR 2), while the Total ΔT for the obstructed group had a median of 8°C, (IQR 3), a 17% difference that was statistically significant at $P = .045$.

The median ΔT of the best- and worst-performing nostrils in the 2 groups was also compared with NOSE data using a single-tailed Student *t* test for all 4 states of respiration (**Table 2**). For the worst-performing nostril in each patient during normal respiration, the median ΔT was compared between the 2 groups and was found to have a median ΔT of 4°C (IQR 0) in the nonobstructed group and a median ΔT of 3°C (IQR 1)in the obstructed group, a 23.8% difference ($P = .023$). For the worst-performing nostril in each patient during maximal respiratory effort, the median ΔT was compared between the 2 groups and was found to be 4 (IQR 3) in the nonobstructed group and a 4 (IQR 3) in the obstructed group, a 20.5% difference that approached significance ($P = .075$). No other comparison showed statistical significance.

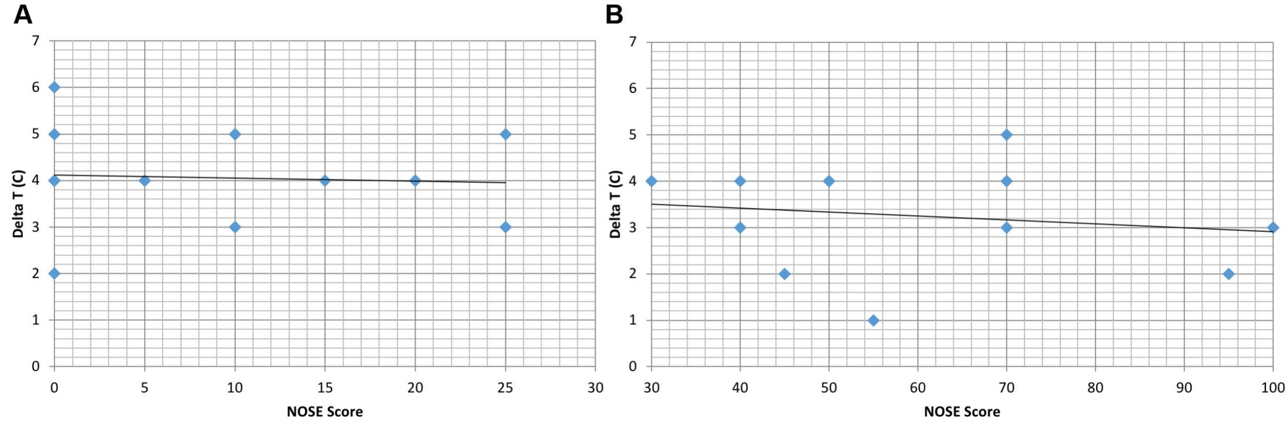

Figure 2. Scatterplot of worst-performing nostril ΔT plotted against Nasal Obstruction Symptom Evaluation (NOSE) scores (0-100). (A) NOSE score 0 to 25, indicating no substantial obstruction, median ΔT of 4. (B) NOSE score 30 to 100, indicating substantial obstruction, median ΔT of 3.

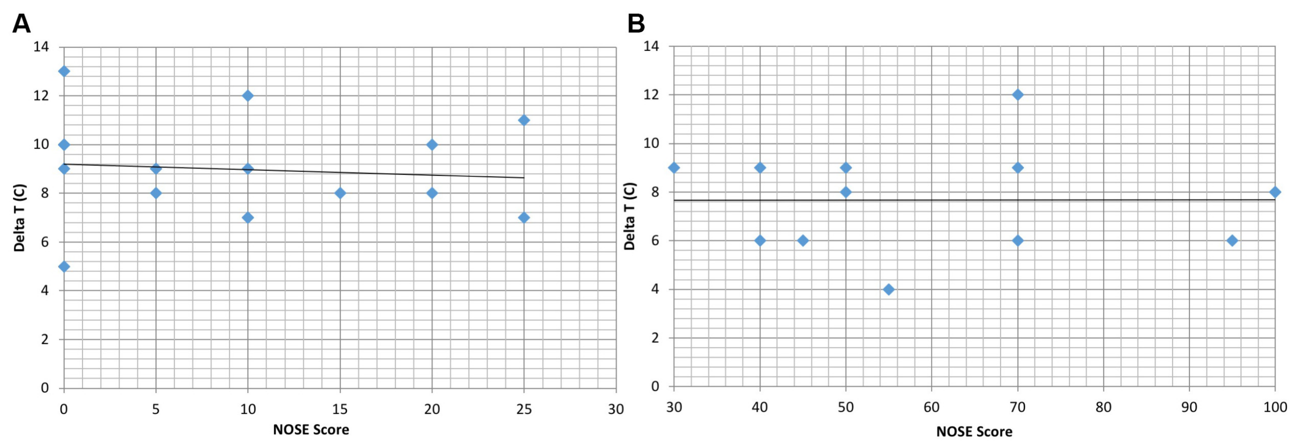

Figure 3. Scatterplot of Total ΔT plotted against Nasal Obstruction Symptom Evaluation (NOSE) scores (0-100). (A) NOSE score 0-25, indicating no substantial obstruction, median ΔT of 9. (B) NOSE score 30 to 100, indicating substantial obstruction, median ΔT of 8.

Based on the above data, to find a clinically useful threshold to differentiate obstructed from nonobstructed noses, we then compared groups sorted by the median ΔTs for Total ΔT ($\leq$8°C and versus $\geq$9°C) and worst-performing nostril ΔT ($\leq$3°C versus $\geq$4°C), which had the most significant difference between the groups. Finding a threshold between symptomatic and asymptomatic patients is not to encourage immediate clinical use but to use for feasibility for future studies. To approximate a potential clinically relevant threshold, we used the median and IQR values seen in **Tables 1** and **2** that had the most significant difference in the type of measurement when separated by gross symptom score (NOSE scale). This is represented in in a scatterplot in **Figures 2** and **3**. The clinically relevant threshold simply lies between the trendlines or median scores between the groups. For worst-performing nostril ΔT, the median NOSE score for the $\leq$3°C group was 45, and for the $\geq$4°C group, the score was only 15 ($P < .04$). For Total ΔT, the median NOSE score for the $\leq$8°C group was 40, and for the $\geq$3°C group, the score was only 10 ($P < .01$; **Figures 2** and **3**).

The Cottle maneuver, however, failed to significantly improve ΔT in either nostril and in some cases diminished the ΔT, counter to expectations of the research team. Although the Cottle maneuver failed to result in dynamic change to ΔT, all patients briefly occluded each nostril during the measuring process and, in all cases, the ΔT dropped to less than 1°C, demonstrating a measured dynamic changed to airflow.

Discussion

This pilot study shows that a smartphone thermal imaging device may be useful in differentiating adequate nasal airways from inadequate ones. Previous studies have shown the utility of using thermal imaging to measure nasal function, but previously, these devices were large, expensive, and cumbersome, and they preceded the smartphone.[15] The device used in this study is inexpensive and portable and able to attach to any smartphone for immediate use. The device was easy to use. The "selfie" mode posed a difficulty because the camera moves opposite to the direction of motion, and right and left were switched on the application. In "pinpoint-read" mode with the point in the center of the nostril, the device worked reliably and was capable of taking a moving image. The device requires precise aiming at each nostril, which can be awkward and time-consuming. However, compared with any other objective device, all of which require patient contact, the device is noninvasive, very comparable to recording close-up videos or photographs. Resting measures can be recorded in pinpoint mode in a matter of seconds (Supplemental Video 1). Furthermore, ambient air and skin temperature may be confounders for the device but were not recorded specifically, although they did not seem to create a problem reading airflow for the research team. In general, the mobile thermal imaging device in its current form provides a promising measure of nasal airflow, not necessarily as a linear measure of function, but it seems to be at least capable of discriminating between substantial obstruction and a generally adequate nasal airway, as our data show. Because of the variability and subjectivity of the NOSE survey scores, we did not expect to track these data in a linear fashion with airflow, as patients could not be expected to compare their experience closely with other patients of similar function. Instead, we expect NOSE scores to at best serve as a gross measure of symptomatology and also at best able to discriminate between severe obstruction (score of 30-100) and minimal symptoms (score of 5-30).

In previous studies, the difference in temperature between inspiratory and expiratory peaks appears to correlate with nasal airflow.[8] The results of our study support these results as well. We found that both the sum of the nostrils (Total ΔT) and the worst-performing nostril (at normal comfortable respiration) showed a significant difference in ΔT between nonobstructed and obstructed nasal airway groups. This may give some insight into how the experience of nasal airflow may manifest. This makes some sense, as many patients have physical obstruction of at least 1 nostril causing symptoms, whereas patients with the most severe deformities have bilateral obstruction. A very recent 15-patient study showed similar results to the present study, also using a handheld thermal imaging device, with a mean ΔT of 6.9°C, increasing to 7.9°C with medical decongestion, further supporting the present concept.[16]

The Cottle maneuver failed to improve ΔT in any measure and in many cases worsened the ΔT.

There are several possibilities for the cause of this. (1) The maneuver was not performed correctly by the research team. (2) The Q-Tip used to perform the maneuver, while opening the nostril more, may have obstructed the sensor device view of the temperature increase. (3) The Cottle maneuver, despite the widely accepted sensation of increased airflow, may not actually improve airflow, particularly in an already functional nostril. The utility of even a well-executed Cottle in predicting nasal airflow and symptomatology has been clearly called into question in a recent study.[17] In any case, the Cottle maneuver data from our study seems only to confuse the outcomes further, and for analysis we have tried to limit considering this confounding factor. In contrast, finger closure of the nostril did severely reduce airflow as measured by ΔT to zero. Another weakness of the study is that we compared only the results of the thermal imaging tests with subjective NOSE scores and not that of an objective measure such as rhinomanometry or acoustic rhinometry. Because these 2 diagnostic maneuvers are considered unreliable by most sources, we preferred to correlate the imaging results with the validated survey data instead of risking comparison of thermal imaging with unreliable although objective outcomes. Further, tests using maximum effort airflow failed to achieve statistical significance when comparing ΔT in all categories. This could reflect testing procedural error and varied maximal effort by subjects but more likely reflects that a maximal effort diffuses the importance of the resistance of the nose and thus reduces the value of comparing inadequate versus adequate noses. Maximal effort may be a better indicator of lung function than nasal function, but more data are required to confirm this.[18]

Finally, what is the relevance of this study? Why is a device that can predict nasal adequacy from inadequacy relevant? First, the device may be useful in a patient with symptoms that match anatomic nasal obstruction but actually has a diagnosis of allergy or even ‘‘nasal disuse,’’ a term coined by Guilleminault.[19] Nasal disuse, a common problem, occurs when the mouth is the primary route of respiration, despite an adequate nasal airway. Despite a lack of obstruction or septal deformity in the nose, the patient subjectively feels that the nose is obstructed or underused but is simply ‘‘congested’’ with some widespread mucosal edema. These patients, despite symptomatic complaints, make poor functional surgical candidates as their symptoms tend to persist after surgery. Thermal imaging may help confirm or reject this adequacy, using numeric thresholds of adequate versus inadequate ΔT of total ΔT or worst-performing nostrils when taken with other data points. Similarly, in patients who have had successful nasoseptal reconstruction with obvious improvement in airflow and anatomy, habitual nasal disuse can create persistent sensation of congestion. Thermal imaging can demonstrate an adequate nasal airway in these cases as well as reassure the patient and surgeon. Finally, in patients without severe symptoms but with an anatomically inadequate airway (eg, stoic individuals who have severe septal deviation), thermal imaging can be useful in demonstrating a substantially inadequate airway to help inform decision making. For most patients with nasal obstruction, thermal imaging can be useful in making surgical or postsurgical decisions only as part of a greater clinical picture that includes NOSE scores, multiview photographs, a physical examination, and possibly other diagnostic procedures.

Conclusion

This pilot study shows that thermographic imaging holds promise as an objective measure of nasal airflow. A statistically significant correlation was observed between subjective nasal airflow obstruction (high NOSE scores) and decreased change in temperature between inspiration and expiration in both nostrils (Total ΔT) and the worst-performing nostril on thermal imaging analysis. The correlation was further enhanced when comparing the ΔT of the worst-performing nostril of each patient in each group with the NOSE score, which suggests that the patient's experience of nasal obstruction may be correlated with the worst-performing nostril. More extensive data points are needed, and future work will consist of the correlation of thermographic imaging with NOSE scores in patients with nasal pathologies before and after operations for nasal obstruction. Further evaluation of the measurement using the Cottle maneuver is required as well.

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Author Contributions

Sydney Jiang, data collection, manuscript preparation, analysis; **Jason Chan**, data collection, manuscript preparation, analysis; **Howard D. Stupak**, manuscript preparation, analysis

Disclosures

Competing interests: Dr Stupak owns intellectual property related to a nasal valve surgical device (Alar, Medtronic ENT) unrelated to this study and has no relationship nor commercial interest in the device or any related devices present in this study.

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Supplemental Material

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References

1. Stewart MG, Witsell DL, Smith TL, Weaver EM, Yueh B, Hannley MT. Development and validation of the Nasal Obstruction Symptom Evaluation (NOSE) scale. *Otolaryngol Head Neck Surg*. 2004;130(2):157-163.
2. Braun T, Rich M, Kramer MF. Correlation of three variables describing nasal patency (HD, MCA, NOSE score) in healthy subjects. *Braz J Otorhinolaryngol*. 2013;79(3):354-358.
3. Ta NH, Gao J, Philpott C. A systematic review to examine the relationship between objective and patient-reported outcome measures in sinonasal disorders: recommendations for use in research and clinical practice. *Int Forum Allergy Rhinol*. 2021; 11(5):910-923.
4. Lam DJ, James KT, Weaver EM. Comparison of anatomic, physiological, and subjective measures of the nasal airway. *Am J Rhinol*. 2006;20(5):463-470.
5. Mendes AI, Wandalsen GF, Solé D. Objective and subjective assessments of nasal obstruction in children and adolescents with allergic rhinitis. *J Pediatr*. 2012;88(5):389-395.
6. Sozansky J, Houser SM. The physiological mechanism for sensing nasal airflow: a literature review. *Int Forum Allergy Rhinol*. 2014;4(10):834-838.
7. Willatt DJ, Jones AS. The role of the temperature of the nasal lining in the sensation of nasal patency. *Clin Otolaryngol Allied Sci*. 1996;21(6):519-523.
8. Bailey R, Casey KP, Pawar SS, Garcia GJM. Correlation of nasal mucosal temperature with subjective nasal patency in healthy individuals. *JAMA Facial Plast Surg*. 2017;19(1):46-52.
9. Johnson KG, Callahan SM, Strack R. Temperature and humidity of expired air of sheep. *Aust J Biol Sci*. 1988;41(3):309-313.
10. Kolkhorst FW, Toepfer TD, Dolgener FA. Expired air temperature during steady-state running. *Med Sci Sports Exerc*. 1995; 27(12):1621-1625.
11. Lahiri BB, Bagavathiappan S, Jayakumar T, Philip J. Medical applications of infrared thermography: a review. *Infrared Physics Technol*. 2012;55(4):221-235.
12. Shakhi MF, Wahab AA, Maheza IMS. Assessment of inspiration and expiration time using infrared thermal imaging modality. *Infrared Physics Technol*. 2019;99:129-139.
13. Kirimtat A, Krejcar O, Selamat A, et al. FLIR vs SEEK thermal cameras in biomedicine: comparative diagnosis through infrared thermography. *BMC Bioinformatics*. 2020;21:88.
14. Lipan MJ, Most SP. Development of a severity classification system for subjective nasal obstruction. *JAMA Facial Plast Surg*. 2013;15(5):358-361.
15. Willatt DJ, Jones AS. Continuous infrared thermometry of the nasal mucosa. *Rhinology*. 1993;31(2):63-67.
16. Davila RO, Flynn J, Sykes KJ, Villwock J, Kriet JD, Humphrey CD. Nasal vestibular temperature as an objective measurement of the nasal airway utilizing a smartphone thermal imager: proof of concept. *Facial Plast Surg Aesthet Med*. 2020;23(5):395-396.
17. Bonaparte JP, Campbell R. A prospective cohort study assessing the clinical utility of the Cottle maneuver in nasal septal surgery. *J Otolaryngol Head Neck Surg*. 2018;47:45.
18. Okazawa M, Imaizumi K, Mieno Y, Takahashi H, Paré PD. Ratio of maximal inspiratory to expiratory flow aids in the separation of COPD from asthma. *COPD*. 2020;17(3):230-239.
19. Lee SY, Guilleminault C, Chiu HY, Sullivan SS. Mouth breathing, ''nasal disuse,'' and pediatric sleep-disordered breathing. *Sleep Breath*. 2015;19(4):1257-1264.