Endonasal thermal imaging in the assessment of nasal obstruction and airflow

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Background: Objective tests that measure nasal resistance, peak flow, and cross-sectional area correlate poorly with the subjective perception of nasal breathing. Airflow perception is thought to be mediated by changes in mucosal temperature from radiant cooling from airflow rather than the direct sensation of the airflow. Changes in nasal mucosal temperature may better predict the subjective perception of nasal breathing. This study aims to develop the endonasal thermal image of the nasal passage and assess the intranasal mucosal temperature with the subjective perception of nasal breathing and objective measurement of nasal airflow.

Methods: A cross-sectional analysis of a single cohort of consecutively recruited and clinically evaluated patients with nasal obstruction at a tertiary rhinology center between August 2022 and February 2023 were recruited. Intranasal mucosal temperatures were extracted from the thermal endonasal image of the nasal passage generated from the infrared radiometric thermal camera (FILR VS290). The mid-expiration and mid-inspiration temperature data [internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway (mean value)] were compared to the patient-reported nasal breathing [visual analog scale (VAS), Nasal Obstruction Symptom Evaluation (NOSE) scale] and nasal airway resistance (NAR) pre-and post-decongestion.

Results: Thirty-three patients (age 33.94±11.65 years, 39.4.% female, 66 nasal cavities) were included. The NOSE scale (0–100), VAS (0–100), and NAR were 59.85±26.65, 57.03±28.35 mm, and 0.67±0.62 Pa/cm^3/s (normal <0.25 Pa/cm^3/s), respectively. VAS improved pre-post decongestion (57.03±28.35 *vs.* 33.30±24.16 mm,

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P<0.001). Mid-expiration temperature (ExT) of all areas were higher than mid-inspiration temperature (InT) at both pre- and post-decongestion states. ExT post-decongestion of three areas and overall airway were lower than ExT pre-decongestion. No statistically significant correlations were found between intranasal mucosal temperature, subjective perception of nasal breathing, and objective measurement of nasal airflow at pre-and post-decongestion states.

Conclusions: Endonasal thermal imaging can accurately measure intranasal mucosal temperature in patients with nasal obstruction. The lower intranasal mucosal temperature during inspiration pre- and post-decongestion and expiration post-decongestion are consistent with mucosal cooling and critical in the perception of nasal breathing. However, more precise imaging of the nasal passage and data acquisition is likely to be required before the clinical use of mucosal temperature as an objective measure of nasal obstruction.

Keywords: Nasal obstruction; thermal imaging; thermography; nasal mucosal temperature; nasal patency

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Introduction

Traditionally, the perception of nasal obstruction was assumed to be inadequate airflow or the sensation of increased airflow resistance through the nostrils (1). However, surgical experience dictates that simply providing increased nasal airflow does not always overcome "nasal obstruction" and no airflow receptors have been described (2). Direct airflow analysis from respiratory efforts or airflow resistance (rhinomanometry) has been the primary method for objectifying the perception of nasal breathing (3,4). Nonetheless, objective tests that evaluate resistance, peak inspiratory flow, and cross-sectional area correlate poorly with the subjective perception of nasal breathing (5-7). Current evidence suggests that nasal breathing is a result of mucosal cooling of the sensory receptors across the nasal cavity during inspiration (8-10). Pilot studies suggest the direct contact measures of nasal temperature might better predict the patient-reported perception of nasal breathing than nasal resistance and cross-sectional area (10). However, such direct contact techniques are unlikely to be tolerated by patients in the routine clinical setting.

Activation of cold thermoreceptors (TRPM8) through a temperature gradient on the sensory terminals of the trigeminal nerve in the nasal mucosa is thought to provide a sense of nasal breathing. A prime example of this process is the activation of the TRPM8 receptor by menthol, which induces a sense of clear nasal breathing without altering airflow (2). The impairment of the TRPM8 receptor or trigeminal nerve function contributes to the sensation of nasal obstruction (2,11,12).

Various objective tests for trigeminal nerve function have been proposed to measure trigeminal sensation for predicting the perception of nasal obstruction (10,13-17), including intranasal mucosal temperature measurement. Miniaturized and infrared thermocouples have been employed to assess intranasal mucosal temperature (16-18). Both methods demonstrated an association between a low mucosal temperature and a subjectively greater perception of nasal breathing (16-18). Nevertheless, the outcome is inconsistent, possibly due to mucosal irritation from the sensor after contact (10). Additionally, it is challenging to position the contact sensor on the inferior turbinates or nasal septum (10). Non-contact thermal sensing, such as an infrared (IR) camera, may be preferable.

The IR camera is a non-contact and non-invasive method for remote temperature monitoring. It is fast and can cover a large area simultaneously. The pseudo-color-coded thermograms are easy to interpret, and the technique has no radiation effects, making it suitable for repeated use. Moreover, the IR camera can monitor dynamic temperature changes in real time (19). Recent pilot studies seek to establish nasal vestibular temperature monitoring with the IR smartphone thermal camera as an objective measure of perception of nasal breathing (20,21). However, the temperature measurement result from the IR smartphone thermal camera was a number without the thermal image that can evaluate the area across nasal cavities, such as inferior turbinate or internal valve area (20,21).

Radiometric thermal imaging allows temperature data to be captured in each picture pixel. As a result, the camera can report the whole image with analyzed temperature data in a radiometric thermogram, producing quantitative results. The data was required to prove that intranasal mucosal temperature can be measured with the endonasal thermal image by the IR radiometric thermal camera. Consequently, this study was designed to develop the endonasal thermal image of the nasal passage to identify the association between intranasal mucosal temperature, subjective perception of nasal breathing, and objective measurement of nasal airflow in patients with nasal obstruction. We present this article in accordance with the STROBE reporting checklist (available at https://www.theajo.com/article/view/10.21037/ajo-23-20/rc).

Methods

Study design

A cross-sectional analysis of a single cohort of consecutively recruited and clinically evaluated patients with nasal obstruction at a tertiary rhinology center was performed between August 2022 and February 2023. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Macquarie University and St Vincent's Hospital Human Research Ethics Committee (2018/ETH00733), and informed consent was taken from all individual participants.

Study population

Adult patients (>18 years) with primary symptoms of nasal obstruction/blockage/congestion were included. Patients with prior septoplasty and/or turbinate reduction, recent physical exertion (<30 min prior to assessment), recent hot or cold food and beverage intake (<30 min prior to assessment), history of anxiety and hyper-ventilatory disorders, history of thermal dysregulation disorders that are likely to impair normal thermal control of the body (i.e., thyroid disorders) or recent use of decongestant within 24 hours were excluded from the study. Patients were in a controlled 22 ℃ environment for at least 15 minutes before assessment.

Method of assessment for subjective perception of nasal breathing

The Nasal Obstruction Symptom Evaluation (NOSE) scale and perception of nasal obstruction on a visual analog scale (VAS) were completed to assess the subjective perception of nasal breathing. The NOSE scale was composed of five questions concerning the severity of nasal obstruction. Each item is evaluated using a Likert scale from 0 = not a problem to 4 = severe problem, summarized, and then multiplied by 5, for a total final NOSE score range between 0 and 100. Higher NOSE scores reflect greater severity of self-reported nasal obstruction (22). Patients also rated their subjective perception of nasal obstruction on a VAS of 0 to 100 mm (0 mm representing no obstruction and 100 mm representing complete obstruction). Patients were asked to cover one nostril and evaluate their ability to breathe through the uncovered nostril. The VAS score was used primarily to assess instantaneous patency of the nasal airway at the time of measurement, as opposed to the NOSE score, which assessed nasal obstruction over the past month (10).

Method of assessment for objective measurement of nasal airflow

Four-phase active anterior rhinomanometry (AAR) was performed at the international standard of 150 Pa using an NR6 Rhinomanometer (GM Instruments, Bristol, UK) to assess the objective measurement of nasal airflow. Measurements were taken after resting for at least 15 min in a climate-controlled room (22 ℃) and with the patient seated. An anaesthetic mask was held airtight around the nose, with the nostril contralateral to the testing side sealed with a nasal foam plug. The patient was instructed to breathe normally through the nose with the mouth closed. The opposite side was then tested using the same method. At least two readings of nasal airway resistance (NAR) within 10% of each other were obtained on each side. NAR was calculated by representative reading for each side using NARIS software (GM Instruments) and reported in Pa/cm^3/s.

Intranasal mucosal temperature measurement

The VSC-IR21 probe with 19 mm round forward viewing tip connected to FILR VS290 infrared thermal videoscope kits (Teledyne FLIR, Wilsonville, Oregon) was placed approximately 1.5 cm from the subject's nostril, similar to a basal view rhinoplasty photograph. The probe cable was attached to the adjustable microphone stand for image stabilization. Two disposable tongue depressors with a 1.5-cm distance marker from one edge were tied to the tip of the probe with a rubber band on both sides to ensure constant distance among the patients. The tip of tongue depressor

Figure 1 Intranasal mucosal temperature measurement technique. (A) The probe cable was attached to the adjustable microphone stand for image stabilization. (B) Two disposable tongue depressors with a 1.5-cm distance marker from one edge were tied to the tip of the probe with a rubber band on both sides to ensure constant distance among the patients. (C) The patient was seated in a chair with an upright position. (D) The tip of tongue depressor that was near the midline was placed at the columella of the nose. These images are published with the patient's consent.

that was near the midline was placed at the columella of the nose (*Figure 1*). The intranasal mucosal temperature presented on the endonasal thermal image of the nasal passage during a normal respiratory cycle at mid-inspiration temperature (InT) and mid-expiration temperature (ExT) was recorded using the single shot recording mode (*Figure 2*). The patient was instructed to breathe normally through the nose with the mouth closed.

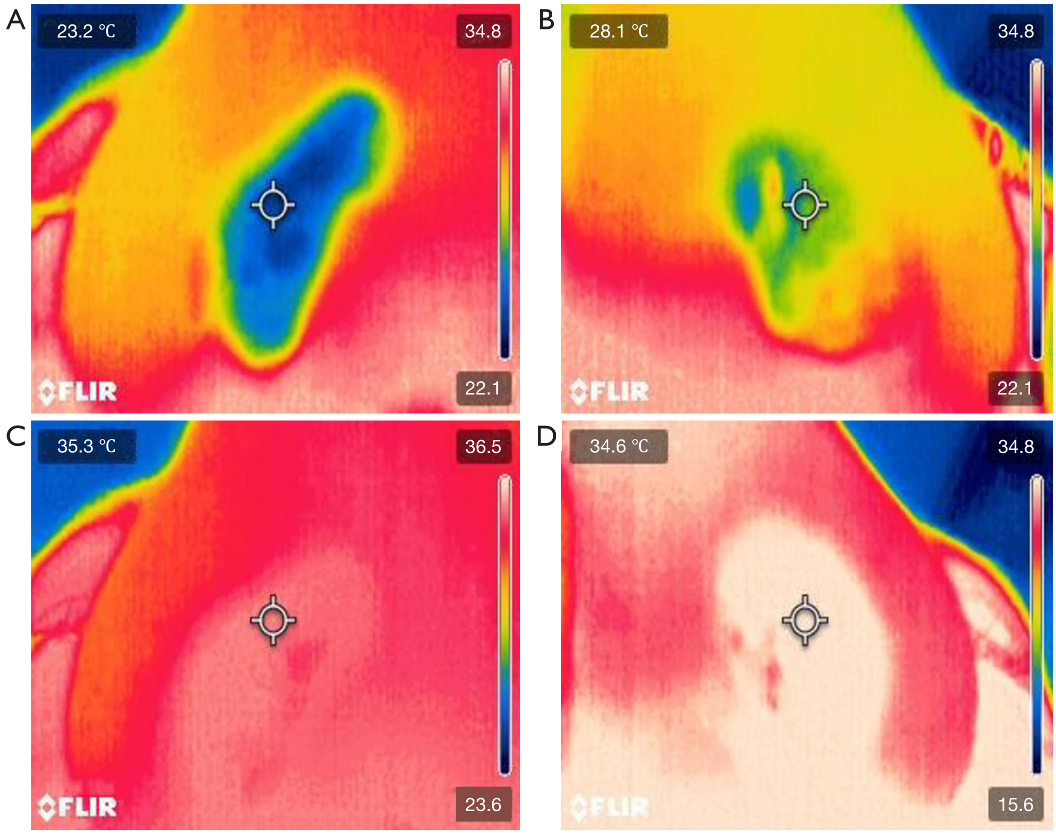

Figure 2 Endonasal thermal image of the nasal passage during a normal respiratory cycle at InT (A, B) and ExT (C,D). (A,C) Right nasal passage; (B,D) left nasal passage. InT, mid-inspiration temperature; ExT, mid-expiration temperature.

Measurement protocol

The intranasal mucosal temperature assessments were conducted by a single rhinologist utilizing a consistent protocol. All patients were measured with the following protocol. Patients spent at least 15 min acclimating in a climate-controlled room (22 ℃) before measurements. During this time, demographic data were obtained, including age and gender, and patients were administered the NOSE and pre-decongest VAS (VAS_{pre}) questionnaire. Next, the patient was seated in a chair for pre-decongest NAR (NAR_{pre}) measurement. Then, pre-decongest intranasal mucosal temperature measurement during a normal respiratory cycle at mid-inspiration (InT_{pre}) and mid-expiration (ExT_{pre}) was recorded using the single shot recording mode for three cycles per nostril. The measurement started with the left side first. Patients were sprayed with a topical decongestant, 0.05% oxymetazoline, 0.3 mL (3 sprays of 0.1 mL) per side. All patients waited 30 min before re-evaluating for post-decongestion measurements. The post-decongestion measurements comprised post-decongest VAS (VAS_{post}) questionnaire, post-decongest NAR (NAR_{post}), and post-decongest intranasal mucosal temperature measurement (InT_{post} and ExT_{post}).

Endonasal thermal image of the nasal passage

The FLIR thermal studio pro software (Teledyne FLIR, Wilsonville, Oregon) was used to edit thermal endonasal images of the nasal passage. The internal nasal valve area, nasal cavity area, and inferior turbinate area were defined in all thermal images. Two lines must be obtained to differentiate between nasal cavity and inferior turbinate area. The first line was the vertical-oblique line drawn from the highest to the lowest points of the thermal endonasal image. The second line, the horizontal-oblique line, was drawn from the lateral to medial borders of the thermal endonasal image perpendicularly through the midpoint of the first line. The area above the horizontal-oblique line was

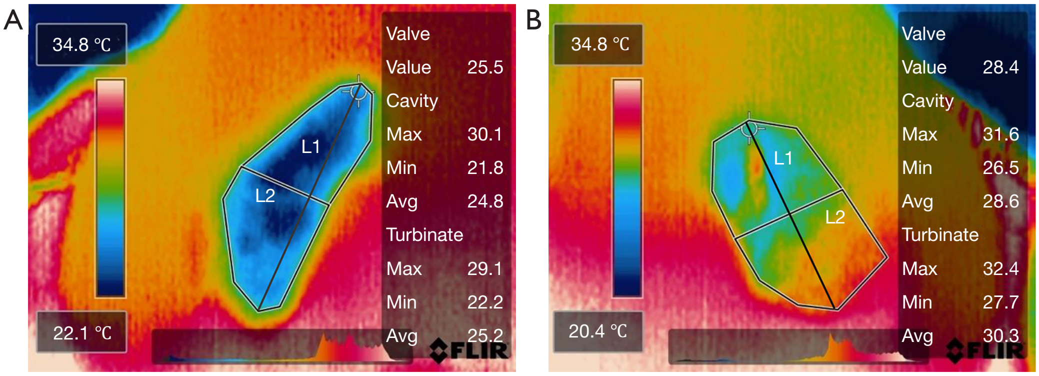

Figure 3 How to define the internal nasal valve area, nasal cavity area, and inferior turbinate endonasal thermal images. Two lines must be obtained to differentiate between nasal cavity and inferior turbinate area. The first line (L1) was the vertical-oblique line drawn from the highest to the lowest points of the thermal endonasal image. The second line (L2), the horizontal-oblique line, was drawn from the lateral to medial borders of the thermal endonasal image perpendicularly through the midpoint of the first line. The area above the horizontal-oblique line was defined as the nasal cavity area, whereas the area below the horizontal-oblique line was defined as the inferior turbinate area. Then, the highest point of the vertical-oblique line was defined as the internasal nasal valve area (target sign). (A) Right nasal passage, (B) left nasal passage.

defined as the nasal cavity area, whereas the area below the horizontal-oblique line was defined as the inferior turbinate area. Then, the highest point of the vertical-oblique line was defined as the internasal nasal valve area (*Figure 3*). The intranasal mucosal temperature of the three areas was calculated and reported in ℃. There were 24 thermal images per patient (3 mid-inspiration and 3 mid-expiration images for each nostril in pre- and post-decongestion states).

Statistical analysis

ExT and InT of internal nasal valve area, nasal cavity area, inferior turbinate area was calculated from the mean of three cycles measurement for each nostril. Comparisons between ExT and InT (ΔExT-InT) of internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway (mean of three areas) in pre- and post-decongestion states were performed. Statistical analysis was conducted using SPSS Statistics version 28 (IBMCorp., Armonk, NY, USA). Q-Q plots were used for the normality test. Parametric results were expressed as mean ± standard deviation. Non-parametric results were expressed as median (interquartile range). Paired *t*-test and Wilcoxon signed-rank test were used for parametric and non-parametric continuous variables, respectively. The correlation coefficients were computed between intranasal mucosal temperature, subjective perception of nasal breathing, and objective measurement of nasal airflow. Pearson and Spearman's rank correlation coefficients were used for parametric and non-parametric continuous variables, respectively. All P values were two-tailed, and a value of $P<0.05$ was considered statistically significant. The coefficient of variation was calculated to test the intraobserver variability.

Results

Of the 57 patients who were presented with primary symptoms of nasal obstruction, blockage, or congestion, 15 who had undergone prior septoplasty and/or turbinate reduction were excluded. Additionally, 9 patients with a history of anxiety were also excluded. Consequently, 33 patients (age 33.94±11.65 years, 39.4% female) were included in the study. Sixty-six nasal cavities were measured (left and right cavities for each participant). Fifteen patients were diagnosed with allergic rhinitis, and eighteen patients had non-allergic rhinitis. The data appeared to have a normal distribution when visually assessed using Q-Q plots. The NOSE scale was 59.85±26.65, VAS_{pre} was 57.03±28.35 mm, and NAR_{pre} was 0.67±0.62 $Pa/cm^3/s$ (normal <0.25 $Pa/cm^3/s$). The ExT_{pre} of the internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway were 31.32±2.19, 31.62±1.94, 32.18±1.81, and 31.71±1.95 ℃, respectively. The InT_{pre} of the internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway were 27.25±2.32,

Table 1 The ExT, InT, and ΔExT-InT of the internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway in pre- and post-decongestion states

Intranasal mucosal temperature (℃)	ExT (N=66)	InT (N=66)	ΔExT-InT (N=66)	P value
Pre-decongestion				
Internal nasal valve	31.32±2.19	27.25±2.32	4.08±2.24	<0.001
Nasal cavity	31.62±1.94	27.08±2.24	4.54±2.14	<0.001
Inferior turbinate	32.18±1.81	27.65±2.35	4.54±2.15	<0.001
Overall airway	31.71±1.95	27.32±2.23	4.39±2.08	<0.001
Post-decongestion				
Internal nasal valve	30.45±2.28	27.01±2.59	3.44±1.90	<0.001
Nasal cavity	30.82±1.88	26.73±2.29	4.09±1.76	<0.001
Inferior turbinate	31.36±1.71	27.16±2.32	4.20±1.76	<0.001
Overall airway	30.88±1.92	26.97±2.37	3.91±1.73	<0.001

Data are presented as mean ± standard deviation. ExT, mid-expiration temperature; InT, mid-inspiration temperature; pre, pre-decongestion; post, post-decongestion; SD, standard deviation.

Table 2 The VAS and NAR in pre- and post-decongestion states and ΔVASpre-post and ΔNARpre-post

Parameters	Pre (SD) (N=66)	Post (SD) (N=66)	ΔPre-Post (SD) (N=66)	P value
VAS (mm)	57.03±28.35	33.30±24.16	23.73±29.66	<0.001
NAR (Pa/cm^3/s)	0.67±0.62	0.38±0.23	0.29±0.48	<0.001

Data are presented as mean ± standard deviation. Pre, pre-decongestion; Post, post-decongestion; VAS, visual analog scale; SD, standard deviation; NAR, nasal airway resistant.

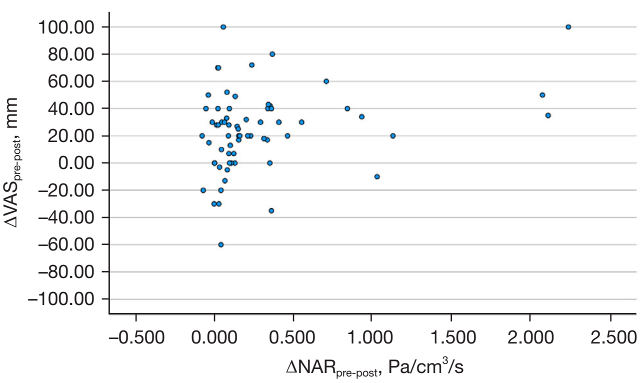

Figure 4 Correlation analysis comparing ΔVAS$_{pre-post}$ to ΔNAR$_{pre-post}$. VAS, visual analog scale; NAR, nasal airway resistant; pre, pre-decongestion; post, post-decongestion.

27.08±2.24, 27.65±2.35, and 27.32±2.23 ℃, respectively. ΔExT-InT of the internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway in pre- and post-decongestion states were presented in *Table 1*. ExT of all three areas and overall airway were higher than InT at both pre-decongestion and post-decongestion states. ΔExT-InT of the overall airway between left and right nasal cavities were not different in pre- (−0.23±0.51 ℃; P=0.66) and post-decongestion states (−0.51±0.42; P=0.23).

Influence of nasal decongestion

After decongestion, both VAS and NAR improved (57.03±28.35 *vs.* 33.30±24.16 mm, P<0.001; 0.67±0.62 *vs.* 0.38±0.23 Pa/cm^3/s, P<0.001; respectively) (*Table 2*). Correlation analysis comparing ΔVAS$_{pre-post}$ to ΔNAR$_{pre-post}$ was performed. ΔVAS$_{pre-post}$ had a statistically significant correlation with ΔNAR$_{pre-post}$ (Pearson r=0.3; 95% CI: 0.06–0.5; P=0.014) (*Figure 4*).

ΔExT$_{pre-post}$ and ΔInT$_{pre-post}$ of the internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway were presented in *Table 3*. ExT$_{post}$ of three areas and overall airway were lower than ExT$_{pre}$. However, ΔInT$_{pre-post}$ were not different. ΔExT-InT$_{pre-post}$ of the nasal cavity area,

Table 3 $\Delta ExT_{pre\text{-}post}$, $\Delta InT_{pre\text{-}post}$, and $\Delta ExT\text{-}InT_{pre\text{-}post}$ of the internal nasal valve area, nasal cavity area, inferior turbinate area, and overall airway

Parameters (℃)	Pre (SD) (N=66)	Post (SD) (N=66)	ΔPre-Post (SD) (N=66)	P value
Internal nasal valve				
ExT	31.32±2.19	30.45±2.28	0.87±2.04	<0.001
InT	27.25±2.32	27.01±2.59	0.24±2.17	0.374
ΔExT-InT	4.08±2.24	3.44±1.90	0.64±2.33	0.03
Nasal cavity				
ExT	31.62±1.94	30.82±1.88	0.81±1.82	<0.001
InT	27.08±2.24	26.73±2.29	0.35±2.10	0.183
ΔExT-InT	4.54±2.14	4.09±1.76	0.46±2.04	0.07
Inferior turbinate				
ExT	32.18±1.81	31.36±1.71	0.82±1.73	<0.001
InT	27.65±2.35	27.16±2.32	0.48±2.13	0.07
ΔExT-InT	4.54±2.15	4.20±1.76	0.34±1.99	0.173
Overall airway				
ExT	31.71±1.95	30.88±1.92	0.83±1.82	<0.001
InT	27.32±2.23	26.97±2.37	0.36±2.07	0.167
ΔExT-InT	4.39±2.08	3.91±1.73	0.48±2.01	0.059

Data are presented as mean ± standard deviation. ExT, mid-expiration temperature; InT, mid-inspiration temperature; Pre, pre-decongestion; Post, post-decongestion; SD, standard deviation.

inferior turbinate area, and overall airway were also not different, except $\Delta ExT\text{-}InT_{pre\text{-}post}$ of the internal nasal valve area, which was statistically different (0.64±2.33 ℃; P=0.03). The coefficient of variation of ΔExT-InT of overall airway in pre- and post-decongestion states were 47.4% and 44.3%, respectively. There are no undesired reactions of the intranasal mucosal temperature measurements due to the non-contact measurement technique by IR camera.

Association of intranasal mucosal temperature with symptoms and airway resistance

Correlation analysis comparing intranasal mucosal temperature (ΔExT-InT), subjective perception of nasal breathing (NOSE and VAS), and objective measurement of nasal airflow (NAR) of all areas at both pre- and post-decongestion states were performed. No correlations were found between intranasal mucosal temperature and subjective perception of nasal breathing (ΔExT-InT of overall airway and VAS pre-decongestion: Pearson r=−0.06; 95% CI: −0.31 to 0.19; P=0.612, ΔExT-InT of overall airway and NOSE pre-decongestion: Pearson r=−0.17; 95% CI: −0.42 to 0.07; P=0.165, ΔExT-InT of overall airway and VAS post-decongestion: Pearson r=−0.20; 95% CI: −0.44 to 0.05; P=0.109, ΔExT-InT of overall airway and NOSE post-decongestion: Pearson r=0.19; 95% CI: −0.06 to 0.43; P=0.138), and intranasal mucosal temperature and objective measurement of nasal airflow (ΔExT-InT of overall airway and NAR pre-decongestion: Pearson r=−0.02; 95% CI: −0.27 to 0.23; P=0.886, ΔExT-InT of overall airway and NAR post-decongestion: Pearson r=0.11; 95% CI: −0.14 to 0.36; P=0.385) at pre- and post-decongestion states. Additionally, correlation analysis was also performed between $\Delta ExT\text{-}InT_{pre\text{-}post}$, $\Delta VAS_{pre\text{-}post}$, and $\Delta NAR_{pre\text{-}post}$ at all areas. No correlations were found between $\Delta ExT\text{-}InT_{pre\text{-}post}$ and $\Delta VAS_{pre\text{-}post}$ (Pearson r=−0.12; 95% CI: −0.37 to 0.12; P=0.321), and between $\Delta ExT\text{-}InT_{pre\text{-}post}$ and $\Delta NAR_{pre\text{-}post}$ (Pearson r=0.03; 95% CI: −0.22 to 0.28; P=0.837) (*Figure 5*).

Discussion

Direct contact thermocouples have been used to measure the temperature of the intranasal mucosa (10,16,18). However, the development to use in clinical practice is

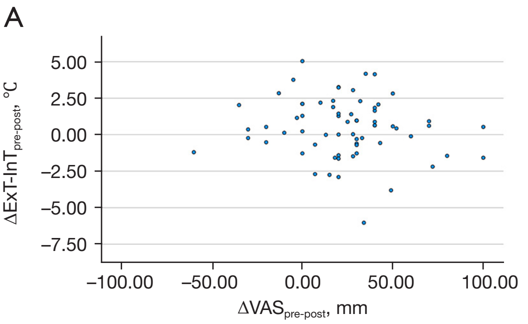

Figure 5 Correlations analysis comparing between (A) ΔExT-InT$_{pre\text{-}post}$ and ΔVAS$_{pre\text{-}post}$, and between (B) ΔExT-InT$_{pre\text{-}post}$ and ΔNAR$_{pre\text{-}post}$. ExT, mid-expiration temperature; InT, mid-inspiration temperature; VAS, visual analog scale; NAR, nasal airway resistant; pre, pre-decongestion; post, post-decongestion.

complex, potentially with patient discomfort and mucosal irritation from a contact sensor. The practical non-contact sensor with an IR smartphone camera was described to record the nasal vestibular temperature in healthy subjects from a remote distance (20,21). However, sensitivity is weak as only one sample area from the middle of the nasal cavity area is taken. Clinically, the ideal IR radiometric thermal camera could create an endonasal thermal image with the ability to produce quantitative results from visualized structures in the nose, such as turbinates and septal mucosa.

This study proves that the IR radiometric thermal camera can measure the intranasal mucosal temperature in patients with nasal obstruction and present the result with the endonasal thermal image of the nasal passage. There is clearly a heterogenous distribution of temperatures within the nasal airway from *Figure 3*. ExT of three areas and overall airway were statistically higher than InT at pre- and post-decongestion states. Data of ExT and InT at pre-decongestion and post-decongestion states was in line with the previous studies that used the miniaturized and IR smartphone camera in healthy subjects (10,16,20). Clearer breathing during inspiration is associated with lower mucosal temperatures (10,16). The inspiratory nasal airflow evaporates water from the epithelial lining and activates trigeminal TRPM8 receptors through a temperature gradient. This activation generates neuronal depolarization to the brainstem respiratory center and cerebral cortex. The detection of temperature gradients is subsequently regarded as clear nasal breathing (2). On the other hand, blocked sensation during expiration is associated with higher temperatures. Throughout the expiration, the rise in temperature led to heating of the nasal mucosa by the warm air emanating from the lungs (16). This finding supports the hypothesis that mucosal cooling of the nasal mucosa is a crucial factor in the perception of nasal breathing.

The decreased VAS$_{post}$ and NAR$_{post}$ from pre-decongestion with statistically significant results confirmed that topical oxymetazoline reduced NAR and made the patients have clear nasal breathing. Additionally, ΔVAS$_{pre\text{-}post}$ was significantly correlated with ΔNAR$_{pre\text{-}post}$. Although objective tests that evaluate resistance and cross-sectional area correlate poorly with the subjective perception of nasal breathing (5-7), some studies show more consistent correlation between rhinomanometry and subjective nasal obstruction (23,24). In the presence of a sensation of obstruction, the likelihood of correlation with objective tests is comparatively higher than in its absence. Furthermore, a stronger correlation has been observed between unilateral symptoms and objective measurements in contrast to bilateral symptoms and the cumulative mean cross-sectional areas or overall nasal resistance (25).

The present study shows that the ExT$_{post}$ of three areas and overall airway were statistically lower than ExT$_{pre}$ after topical oxymetazoline. Oxymetazoline is the mixed α1- and α2-adrenoreceptor agonist that acts on α1-adrenoreceptor on the arteriolar side and α2-adrenoreceptor on the venular side in nasal mucosal vasculature causing the vasoconstriction effect (26). The reduction of mucosal blood flow from topical decongestant decreases the intranasal mucosal temperature (27). Moreover, diminished intranasal mucosal temperature could be attributed to greater radiant cooling from airflow from increased nasal cavity volume (27). Either mechanism produces mucosal cooling.

This study cannot demonstrate the correlation between intranasal mucosal temperature (ΔExT-InT, ΔExT-InT$_{pre\text{-}post}$), subjective perception of nasal breathing

(NOSE, VAS, and $\Delta VAS_{pre\text{-}post}$), and objective measurement of nasal airflow (NAR and $\Delta NAR_{pre\text{-}post}$). The temperature measurement technique in this study differed from the previous studies that show the correlation between intranasal mucosal temperature and subjective perception of nasal breathing or objective measurement of nasal airflow (10,17,18). Miniaturized thermocouples used in the previous study were inserted in the nasal cavity and positioned on the nasal mucosa. The accuracy may be better than the IR radiometric thermal camera that measured from outside the nose. Nevertheless, the problem with the contact sensor pertained to mucosal irritation and its inability to consistently demonstrate a correlation between mucosal temperature and VAS across the nasal cavity (10).

Additionally, the participants in this study differed from the previous literature (16-18,20). The correlation between intranasal mucosal temperature and subjective perception of nasal breathing or objective measurement of nasal airflow was demonstrated in healthy subjects (10,17,18). However, there was no data on the patients with nasal obstruction. In the present study, some cases had structural abnormality problems, such as severe nasal septal deviation or nasal valve collapse, that hindered the view of the structure inside the nose. The endonasal thermal image from the IR radiometric thermal camera with the probe outside the nasal cavity may not represent the exact intranasal mucosa. The temperature data was extracted from each picture pixel of the thermal image. If the thermal image cannot depict the precise structure inside the nose, the accuracy of the intranasal temperature may be discrepant.

This study confirms that the endonasal thermal image of the nasal passage can measure the intranasal mucosal temperature in patients with nasal obstruction. The temperature measurement technique from the IR radiometric thermal camera is a potential novel objective test for evaluating the perception of nasal breathing. The benefit of this technique is a non-invasive, non-radiation, and non-contact with straightforward technical instruction and interpretation. Additionally, it can be used repetitively and is suitable for dynamic temperature changes in nasal breathing.

However, it is clear that much more anatomical definition of the IR image is required as substantial heterogeneity of temperatures exists within the nasal airway. Current IR cameras don't provide this and are too early for utilization in clinical practice. Moreover, the coefficient of variation of temperature measurement is high due to the limitation in thermal camera technology that cannot identify the precise structure inside the nose. Further studies require the IR radiometric thermal camera with a 3-4 mm diameter probe, short focal range, and the ability to give a true thermal endonasal image.

Conclusions

Endonasal thermal imaging demonstrates significant heterogeneity of readings within the nasal airway but is sensitive to changes in intra-nasal vascularity and airflow. The potential for IR radiometric thermal cameras as a reliable method for measuring intranasal mucosal temperature in patients with nasal obstruction warrants further investigation.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Macquarie University and St Vincent's Hospital Human Research Ethics Committee (2018/ETH00733) and informed consent was taken from all individual participants.

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