Comparison of nasal obstruction symptom evaluation, peak nasal inspiratory flowmeter, and rhinomanometry in patients with nasal deformities

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Abstract. Nasal obstruction is the most common symptom in daily otolaryngology practice that correlates with quality of life. Nasal obstruction etiology is multifactorial and can result from mucosal or structural factors. Subjective and objective evaluation approaches are a significant challenge in its diagnosis. This study aimed to evaluate correlations among the nasal obstruction and symptom evaluation (NOSE) and peak nasal inspiratory flowmeter (PNIF) scores and active anterior rhinomanometry values for nasal obstruction diagnosis in subjects with nasal deformities including crooked nose, saddle nose, nasal valve incompetence, and deviated septum. Furthermore, the correlation of nasal obstruction with sleep-disordered breathing was evaluated. Data in this cross-sectional analytical study in 52 consecutive subjects with nasal deformities and 10 consecutive normal subjects were analyzed with the bootstrapping method. Mean nasal resistance in normal subjects and those with nasal deformities were 0.172 and 0.173 Pa/cm$^3$/s, respectively, on 75 Pa. The NOSE score was not significantly correlated with the PNIF score or the nasal airflow resistance determined by rhinomanometry. However, there was a significant correlation between PNIF and nasal airflow resistance.

1. Introduction
Nasal obstruction is a subjective sensation that can stem from physiological and pathological changes and results in low patency of the nose. Causes of nasal obstruction can be categorized into fixed components that require repair by surgery and dynamic components that can be controlled with medical therapy. Differential diagnosis of nasal obstruction is broad, and its etiology may be multifactorial. Therefore, it is critical for the ear/nose/throat (ENT) specialist to determine the exact cause of nasal obstruction to provide appropriate therapy [1-5].

Nasal obstruction can be subjectively measured using a questionnaire to assess the degree of blockage from the patient’s point of view. Objective assessment of nasal congestion is necessary to facilitate quantitative evaluation without the emotional contribution of the patient. Robust objective measurements provide optimal results that can be replicated and are easy, noninvasive, and low cost;
the results can be utilized to evaluate therapeutic response. Such assessments can assist in diagnosis, treatment, research, and medicolegal documentation [2,3,4].

Type of nasal obstruction can be determined by assessment of nasal resistance before and after topical decongestant administration. Nasal obstruction caused by mucosal abnormalities will decrease nasal resistance more than 35% after topical decongestant administration. Conversely, if there is only a slight decrease in nasal resistance after the application of topical decongestants, especially in the case of asymmetric obstruction, nasal congestion is more likely due to structural abnormalities. Mucosal disorders can be treated by medical therapy; however, nasal obstruction due to structural abnormalities often requires surgical intervention to alleviate the patient’s complaints [6].

Presently, there are several validated qualitative questionnaires and standardized symptom assessment systems. Assessment of patients with the nasal obstruction symptoms evaluation (NOSE) questionnaire, a standardized tool to assess nasal congestion symptoms developed by Stewart et al. [7], revealed that the symptoms experienced by the patient were not always in agreement with the signs found by physical examination. The NOSE questionnaire consists of five questions on nasal congestion and impaired quality of life. Each question has a score from 0 to 4, and total score is multiplied by 5 to get a score between 0 and 100, with 0 indicating no nasal blockage and 100 representing very heavy nasal congestion [7].

Other tools for objective assessment include nasoendoscopy to determine blockage location, peak nasal inspiratory flowmeter (PNIF) to assess airflow, and rhinomanometry to measure transnasal pressure and nasal airflow. PNIF measures maximum forced airflow in the nose by rapid inhalation of air at maximum strength from both nostrils. PNIF is a cheap and easy-to-use tool in daily practice. Rhinomanometry is a gold standard tool to assess nasal resistance that can be utilized to evaluate nasal obstruction before and after surgery as well as the degree of postoperative repair. Rhinomanometry can be either active or passive rhinomanometry, and can also be classified into anterior, posterior, and postnasal rhinomanometry depending on the location of the pressure gauge [3,4,8].

Nasal obstruction can affect the quality of life of patients in several ways including sleep disorders such as sleep-disordered breathing (SDB), which is characterized by partial or total upper respiratory tract obstruction that results in termination of breath in the form of apnea (total) or hypopnea (partial), known as obstructive sleep apnea (OSA)-hypopnea syndrome (OSAHS), or in the form of upper airway resistance syndrome (UARS) [9].

In Indonesia, there are no data on internal or external nasal deformities and their relationship with nasal obstruction assessed by NOSE, PNIF, or active anterior rhinomanometry questionnaires, or on their association with sleep disorders including SDB, assessed by the Epworth Sleepiness Scale (ESS). Therefore, in this study conducted in Indonesia, we assessed nasal deformities including septum deviation, nasal valve disorder, crooked nose, and saddle nose and compared PNIF with active anterior rhinomanometry, with the aim to determine if one method could be used as an alternative if both tools were not available at the same health facility.

Complains of nasal congestion may differ according to the type and degree of the nasal deformity. Operative measures such as septorhinoplasty are not only useful for correcting aesthetic nasal deformities but also functional issues. The study aimed to establish subjective and objective assessment tools for nose blockage in patients with nasal deformities to ensure that surgery for nasal deformities is for cosmetic reasons as well as for restoration of nasal function.

2. Methods
This cross-sectional analytical study was designed to assess the utility of the NOSE questionnaire and PNIF questionnaire and active anterior rhinomanometry as well as their association with quality of life and included 52 consecutive patients with nasal deformities and 10 consecutive individuals with no nasal deformities who were evaluated at a single center in Indonesia between March and June 2017 and fulfilled the inclusion criteria.

The study protocol was approved by the Health Research Ethics Committee, Faculty of Medicine, Universitas Indonesia-Cipto Mangunkusumo Hospital. The subjects were provided a detailed
explanation of the study aims, evaluation procedure, and techniques used. All subjects or their parent/guardian provided signed informed consent. All subjects participating in the study were recorded in the research form and fill out the status of the study. All patients underwent the following procedures. First, a complete history of nasal obstruction was recorded using the NOSE questionnaire. Next, a pilot documentation of six directions (i.e., frontal, right and left oblique, lateral, left lateral and basal) was conducted. Then, the subjects underwent ENT examination followed by nasal endoscopy using 4% xylolcaine. Then, the subjects were evaluated by PNIF by instructing the subjects to inspire for a maximum of three times; the best value was then recorded. This was followed by an anterior rhinomanometry by closing one nostril to measure posterior nares pressure while airflow velocity was measured through contralateral nostril with the pneumococcus located at the end of the lid. Before inspection, the rhinomanometry was calibrated according to the manufacturer’s manual. Mathematical calculations and analysis were performed using a special computer software. Anterior rhinomanometric examination was performed twice, before and after administration of topical decongestants, and readings over an average of four respiratory cycles were recorded. Airflow (cm$^3$/s), transnasal pressure (Pa), and resistance (Pa/cm$^3$/s) were displayed on the monitor. Finally, PNIF after topical decongestant application was reassessed.

3. Results

Data were analyzed using the bootstrapping method to utilize a small sample size as a representative of actual population data and included repeated resampling until new data were obtained.

### Table 1. Nasal resistance of the study population with 75 Pa deep nasal deformity.

|                  | R right I$^a$ | R right II$^b$ | R left I$^c$ | R left II$^d$ | R total I$^e$ | R total II$^f$ | ΔR total$^g$ (%) |
|------------------|---------------|----------------|--------------|---------------|---------------|-----------------|------------------|
| Mean             | 0.329         | 0.352          | 0.457        | 0.502         | 0.173         | 0.164           | 6.4%             |
| SD               | 0.108         | 0.316          | 0.37         | 1.01          | 0.15          | 0.99            | 24               |

$^a$ R right I, right nasal resistance pre-decongestant  
$^b$ R right II, right nasal resistance post-decongestant  
$^c$ R left I, left nasal resistance pre-decongestant  
$^d$ R left II, left nasal resistance post-decongestant  
$^e$ R total I, total nasal resistance pre-decongestant  
$^f$ R total II, total nasal resistance post-decongestant  
$^g$ ΔR total, percent difference in mean nasal resistance between pre- and post-decongestants

As presented in Table 1, mean total nasal resistance at 75 Pa before decongestant administration was 0.173 (standard deviation [SD], 0.15) Pa/cm$^3$/s in subjects with nasal deformities. Mean right and left nasal resistance values before decongestant administration were 0.329 (SD, 0.108) and 0.457 (SD, 0.37) Pa/cm$^3$/s, respectively. Percent difference in mean nasal resistance between pre- and post-decongestants was 6.4%.

### Table 2. Airflow values determined by PNIF in subjects with nasal deformity.

|                  | PNIF pre-decongestant | PNIF post-decongestant | ΔPNIF (%) |
|------------------|-----------------------|------------------------|-----------|
| Mean             | 86.54                 | 95.96                  | 13.67%    |
| SD               | 27.19                 | 27.15                  | 20.69     |
| SE               | 3.772                 | 3.265                  | 2.869     |

PNIF, peak nasal inspiratory flowmeter; SD, standard deviation; SE, standard error

As summarized in Table 2, mean airflow rates before and after decongestant administration in subjects with nasal deformities were 86.54 (SD, 27.19) and 95.95 (SD, 27.15) l/min, respectively. Percent difference in mean airflow rates between pre- and post-decongestants was 13.67%.
As illustrated in Figure 1, assessment of the relationship between the NOSE and PNIF scores using nonlinear quadratic regression test with the bootstrapping method revealed an $R^2$ of 0.102 ($p > 0.05$), with the following equation: PNIF score $= 75.031 + 1.015$ (NOSE score) $- 0.013$ (NOSE score)$^2$

Figure 1. Correlation between NOSE and PNIF scores.

Figure 2. Correlation between NOSE and active anterior rhinomanometry scores.
As presented in Figure 2, assessment of the relationship between the NOSE and active anterior rhinomanometry scores using nonlinear quadratic regression test with the bootstrapping method revealed an $R^2$ of 0.040 ($p > 0.05$) with the following equation: \[ RM_{\text{tot}} = 0.166 + 0.0001 \times \text{NOSE} + 6.490E-006 \times (\text{NOSE})^2 \]

Figure 3. Correlation between PNIF and active anterior rhinomanometry scores.

Examination of the relationship between PNIF score and active anterior rhinomanometry (Figure 3) using nonlinear quadratic regression test with the bootstrapping method revealed an $R^2$ of 0.177 ($p < 0.05$) with the following equation: \[ RM_{\text{tot}} = 0.321 - 0.003 \times \text{PNIF} + 9.877E-006 \times (\text{PNIF})^2 \]

Table 3. Relationships among NOSE, PNIF, and active anterior rhinomanometry scores according to the type of nose deformity.

| Type of deformity       | NOSE |                |                | PNIF |                |                | Active anterior rhinomanometry |
|-------------------------|------|----------------|----------------|------|----------------|----------------|-------------------|
|                         | Mean | SD             | 95% CI (bootstrap) | Mean | SD             | 95% CI (bootstrap) | Mean | SD              | 95% CI (bootstrap) |
| Septum deviation        | 34.22 | 24.3           | 5.45–42.99       | 90   | 27.8           | 79.9–100         | 0.168 | 0.04           | 0.154–0.183        |
| Crooked nose            | 33.75 | 33.7           | 17.21–50.29      | 88.75| 24.4           | 71.2–106.2       | 0.161 | 0.03           | 0.141–0.180        |
| Valve disturbance       | 45   | 35.3           | –272.6–362.6     | 55   | 21.2           | –135.6–245.6     | 0.293 | 0.20           | –1.588–2.173       |
| Saddle nose             | 32.5 | 37.2           | 6.59–71.59       | 74.17| 18             | 55.27–93.06      | 0.183 | 0.05           | 0.127–0.239        |
As summarized in Table 3, mean NOSE and PNIF scores and nasal airway resistance for those with valve disturbance were 45 (95% confidence interval [CI] −272.6–362.6), 55 (95% CI −135.6–245.6) l/min, and 0.293 (95% CI −1.588–2.173) Pa/cm³/s, respectively. One-way analysis of variance (ANOVA) with the bootstrapping method revealed p values of 0.370, 0.004, and 0.015 for PNIF and NOSE scores and nasal airway resistance, respectively.

Table 4. Relationships among NOSE, PNIF, and active anterior rhinomanometry scores based on ESS scores.

| ESS value | N    | NOSE Mean | SD | 95% CI (bootstrap) | PNIF Mean | SD | 95% CI (bootstrap) | Active anterior rhinomanometry Mean | SD | 95% CI (bootstrap) |
|-----------|------|-----------|----|---------------------|------------|----|---------------------|-------------------------------------|----|---------------------|
| 0–4       | 4    | 21.25     | 19.31 | 9.48–51.98          | 100        | 24.43 | 53.16–146.84       | 0.132                               | 0.01 | 0.114–0.149         |
| 5–9       | 13   | 27.31     | 20.47 | 14.93–39.68         | 90         | 27.08 | 73.64–106.36       | 0.160                               | 0.02 | 0.143–0.177         |
| ≥10       | 11   | 61.36     | 20.98 | 47.26–75.46         | 84.55      | 28.41 | 65.46–103.63       | 0.197                               | 0.09 | 0.135–0.260         |

As presented in Table 4, we also assessed the relationships among NOSE and PNIF scores and anterior rhinomanometry values in patients with sleep disorders according to the ESS scores. We found that mean NOSE score of 21.25 in patients with an ESS score between 0 and 4 was increased in patients with higher ESS scores. Additionally, one-way ANOVA using the bootstrapping method revealed a significant relationship between the ESS and NOSE scores (p = 0.001). Additionally, mean PNIF score in patients with an ESS score of 0 to 4 was 100, which was lower in patients with higher ESS scores (p < 0.638, one-way ANOVA with the bootstrapping method). Finally, mean nasal airflow resistance in patients with ESS scores ranging from 0 to 4 was 0.132, which was higher in patients with higher ESS scores, albeit without statistical significance (p = 0.154, one-way ANOVA with the bootstrapping method).

4. Discussion
The relatively small number of normal subjects is partially due to the difficulty in locating individuals with completely straight nasal septa and no nasal deformities. Statistical analysis was performed utilizing the bootstrapping method to sample 1000 times, which was predicted to represent nasal resistance in the normal population. Naito compared two rhinomanometers for nasal resistance measurements and found a difference of 1.6 between the rhinomanometers, which can also be due to differences in conditions at the time of the study [10]. Kobayashi et al. reported that nasal patency varied according to several parameters such as posture of the patient and ambient temperature as well as physiological variations such as nasal cycles [11].

In the current study, a decrease in symmetrical nasal resistance in both the cavum nasi and a decrease in total nasal resistance to below 15% indicates a structural factor that plays a role in patients with nasal deformities, who have a low therapeutic response to the provision of medication. Silkoff, as quoted by Chin et al. [12] reported that a 15% decrease in unilateral nasal air resistance after decongestants was reflective of minimal mucosal changes. Eccles et al. as quoted by Chin et al. [12] stated that significant asymmetric values in patients with unilateral nasal congestion could indicate disturbances in the nasal cycle rather than pathological abnormalities. A bilateral increase or decrease in nasal resistance by less than 15% suggests a symmetrical structural nose blockage, whereas presents a change of more than 15% on one side and less than 15% on the other side following decongestant administration suggests asymmetrical blockage [12].

Table 2 shows the mean value of PNIF in the nose deformity population of 86.54 l/min pre-decongestant and 95.96 l/min after post-decongestant with 13.67% difference, whereas the normal
population in this study amounted to an average of 87.5 l/min pre-decongestant and 100.5 l/min post-decongestant with difference 16.62%. Samsudin quoted by Tamus et al. found that the PNIF scores in normal males and females of the Deutero-Malay ethnic background were 80–200 (mean, 123) and 80–140 (mean, 96) l/min, respectively [13].

In this study, nasal airflow was evaluated based on the mean values reported by Samsudin cited as Tamus et al. [13] because the subjects in the present study were similar to individuals with the Deutero-Malay ethnic background, with similar nasal morphology including a low and wide dorsum of the nose and a wide and less prominent tip. Teixeira [14] reported that PNIF values in normal individuals and those with inferior grade I, II, and II hypertrophy were 151.4, 141.2, 138.2, and 116.4 l/min, respectively. The nasal airflow in subjects with nasal deformities due to airflow obstruction was lower in the present study [13,14].

This study also found no significant relationship between the NOSE and PNIF scores (Figure 1). Tsounis [15] found that PNIF and NOSE scores were strongly correlated, whereas Bayram et al. [2] found that patients with concomitant hypertrophy who received medicinal therapy had reduced NOSE scores compared with those prior to therapy, which was followed by an increase in the PNIF score as the treatment progressed. Whitcroft, as quoted Bayram et al. [16] found that NOSE score was significantly related to nasal airflow in patients with chronic rhinosinusitis without a polyp [15,16].

Our analysis also found that there was no significant association between NOSE score and active anterior rhinomanometry (Figure 2). The relationship of the NOSE score with the rhinomanometry and PNIF was not meaningful because they measure subjective and objective parameters. The patient’s subjectivity can be influenced by emotions and personality. Aesthetic disorders of the nasal deformity can also impact a person’s subjectivity. The absence of a meaningful association can also be caused by overly heterogeneous research subjects, i.e., patients with nasal deformities including saddle nose, crooked nose, septum deviation, and valvular interference. Such a heterogeneous study population is one of the confounding factors that could potentially interfere with the results of the study. Subjects in this study were patients with a variety of nasal deformities both with and without nasal obstruction, and this study did not focus on patients with one type of nasal deformity or those with nasal deformity and nasal congestion because these patient might have adapted to nasal airflow conditions independent of the nasal congestion. The current study included only four patients with nasal deformities and no nasal obstruction, and two of these patients had a PNIF score <80 l/min.

Stewart stated that the NOSE questionnaire was better suited to compare groups of subjects or conditions such as changes in complaints after therapy or effect of different therapies but was not as appropriate for individual data points or comparison of treatment outcomes in individuals [7]. No meaningful relationships may also be caused by possible differences in the meaning of the NOSE questionnaires following the translation of the first and second questions regarding nasal congestion and obstruction. In that case, the question is replaced to describe the condition of mucosal and structural nasal congestion, which may be translatable describes the degree of nasal blockage. This difference in meaning might underlie the absence of a significant relationship between the NOSE score and the current objective examination as the questionnaire might not be describing the true state of nasal congestion.

As shown in Figure 3, although an inverse correlation between the PNIF score and the rhinomanometric value was noted, the latter value tended to increase beyond a certain point. Estimation of the active anterior rhinomanometric value based on the PNIF score was obtained by the following equation: RM tot = 0.321 − 0.003 (PNIF) + 9.877E-006 (PNIF). [2] Importantly, there was a significant relationship between nasal airflow assessed by PNIF and nasal resistance assessed using active anterior rhinomanometry.

Our finding is in accordance with previous studies that demonstrated the inverse correlation between PNIF score and nasal airflow resistance. Clarke and Jones, as quoted Ottaviano [17] and Bermuller [6], found no correlation between PNIF and active anterior rhinomanometry. In the study by Bermuller, one possibility is that two different aspects of the nose were measured. In contrast, Clarke et al. as quoted by Teixeira [14] found a positive relationship between PNIF and rhinomanometry.
before and after the use of topical decongestants, with rhinomanometry giving slightly better results
while examining differences in nasal patency. Analysis of the accuracy of PNIF diagnosis and active
anterior rhinomanometry in both normal and pathologic groups indicates that both examinations are
accurate in determining pathology [6,14,17,18].

The NOSE scores and the nasal airflow resistance of subjects with sleep disorders increased with
increasing ESS scores, whereas the PNIF scores decreased with decreasing ESS scores. Michael’s [19]
study showed an average ESS score of 9.29 ± 2.81 in patients with nasal obstruction, which was found
to decrease to a median of 4.00 after operative action on the nose. In the current study, normal ESS
range was 0–4, and scores >4, 5–9, and ≥10 were considered to indicate tendency for SDB, tendency
for UARS/OSHS, likelihood for OSA, respectively [19,20].

This study found a significant relationship between the NOSE and ESS scores. The NOSE score
reflects nasal blockage, with a range from 0 to 100, and higher NOSE score implies worse nasal
blockage. Our analysis determined that the NOSE scores increased with increasing ESS scores,
suggesting that as nasal blockage gets worse, the more likely it will be for the individual to experience
sleep disturbance. Ishii found that NOSE and ESS scores were correlated, it is reported that snoring,
increased NOSE score, and septum deviation led to an 88% increase in the ESS score and that an
increase in the NOSE score in addition to either snoring or septum deviation led up to 70% increase in
the ESS score and certain patients with nasal obstruction might suffer from undetectable OSA [21].
The current study findings also suggest that higher ESS scores were correlated with worse sleep
disturbance-related complaints.

The current study also revealed that the nasal resistance increased in parallel with increasing ESS
scores, suggesting that increased nasal resistance might occur in patients with sleep disorders, with a
direct correlation between nasal resistance and the severity of the sleep disorder. As nasal resistance is
inversely proportional to nasal airflow, such an increase in resistance leads to a decrease in nasal
airflow. Additionally, the current study revealed that nasal airflow decreased with increasing ESS
scores, indicating that decreased nasal airflow might lead to more severe sleep disorders.

5. Conclusion
The current study determined that there was a significant and inverse correlation between the PNIF
score and nasal airflow resistance, although nasal airflow resistance tended to increase beyond a
certain point. The NOSE score did not show significant associations with the PNIF score or nasal
airflow resistance. There were also significant differences in the NOSE scores and nasal airflow
resistance among different types of nasal defects. Specifically, there were significant differences in the
PNIF scores between subjects with valve disorders and septum deviation and those with a crooked
nose. There was a significant difference in the NOSE score of the subjects with a saddle nose. Nasal
airflow resistance values and PNIF scores of subjects with a saddle nose type were different than those
without this nose type, albeit without statistical significance.

The mean NOSE score, as well as the nasal airflow resistance, were correlated with the ESS score,
whereas the PNIF score was inversely correlated with the ESS score. Finally, the relationship between
NOSE and ESS scores was statistically significant.

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