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Correlation of Deviated Nasal septum severity with objective nasal airway obstruction

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ABSTRACT

Background: Deviated nasal septum (DNS) is a common structural cause of nasal obstruction, but the relationship between anatomical severity and objectively measured airway impairment remains variable. This study aimed to evaluate the correlation between DNS severity and objective nasal airway obstruction.

Methods: A hospital-based observational analytical study was conducted at Saraswathi institute of Medical Sciences, Hapur, from January 2023 to June 2025. A total of 126 eligible patients with DNS presenting to the ENT outpatient or inpatient department were included. Septal deviation was classified as mild, moderate, or severe based on clinical and endoscopic assessment.

Results: Of 126 patients, 35 (27.8%) had mild, 51 (40.5%) moderate, and 40 (31.7%) severe DNS. Mean deviated-side nasal resistance increased significantly from 0.25 ± 0.07 Pa/cm³/s in mild DNS to 0.59 ± 0.14 Pa/cm³/s in severe DNS ($p < 0.001$), while airflow decreased from 625 ± 120 mL/s to 338 ± 92 mL/s ($p < 0.001$). DNS severity showed a strong positive correlation with nasal airway resistance ($\rho = 0.69$, $p < 0.001$) and an inverse correlation with airflow ($\rho = -0.65$, $p < 0.001$). Severe anterior deviations were associated with the greatest obstruction. DNS severity remained the strongest independent predictor of airway resistance.

Conclusion: Increasing severity of DNS is significantly associated with greater objective nasal airway obstruction. Anatomical severity and location should therefore be considered together when evaluating patients with nasal obstruction and planning treatment.

Keywords: *Deviated nasal septum; Nasal obstruction; Rhinomanometry; Nasal airway resistance; Nasal airflow; Septal deviation severity.*

INTRODUCTION

Nasal obstruction is one of the most common complaints encountered in otorhinolaryngology practice and can considerably affect breathing, sleep, exercise tolerance, daily activities, and overall quality of life. Several structural and mucosal abnormalities can contribute to nasal obstruction, including deviated nasal septum, inferior turbinate hypertrophy, nasal valve narrowing, allergic or non-allergic rhinitis, chronic rhinosinusitis, and nasal polyposis. Among the structural causes, deviated nasal septum (DNS) is particularly important because alteration in the position and shape of the septum can change the dimensions of the nasal passages and disturb normal airflow. Objective assessment is therefore valuable in distinguishing anatomical narrowing from the subjective perception of nasal blockage and in determining the functional significance of a septal deformity [1].

The nasal septum forms the medial wall of both nasal cavities and consists of cartilaginous and bony components. Ideally, it divides the nasal cavity into approximately symmetrical passages, although some degree of septal deviation is frequently found in the general population. Septal deviation may be congenital, developmental, or acquired following trauma. The deformity may involve the anterior cartilaginous septum, posterior bony septum, or both, and may appear as a C-shaped or S-shaped deviation, localized spur, crest, or more complex deformity. Importantly, the clinical consequences of septal deviation depend not only on the presence of a deviation but also on its site, degree, relationship with the turbinates, and involvement of the nasal valve region. Septoplasty is commonly performed when septal deviation produces clinically significant functional nasal obstruction [2].

Clinical evaluation of DNS usually begins with a detailed history and examination using anterior rhinoscopy and nasal endoscopy. Patient-reported severity of nasal obstruction is frequently assessed using symptom scores such as the Nasal Obstruction Symptom Evaluation (NOSE) scale. The NOSE scale is a validated, disease-specific instrument designed to quantify the impact of nasal obstruction on patients and has demonstrated acceptable reliability, validity, and responsiveness [3]. Nevertheless, nasal obstruction remains a subjective sensation. Two patients with apparently similar septal deviations may report substantially different levels of obstruction, while a patient with a relatively modest anatomical deviation may experience considerable breathing difficulty. This variability highlights the need to combine anatomical examination with objective assessment of nasal airway function.

Several techniques have been developed for objective evaluation of nasal patency. Rhinomanometry measures nasal airflow in relation to the pressure difference across the nasal cavity and provides information about nasal airway resistance. Acoustic rhinometry evaluates nasal cavity geometry by analysing reflected sound waves and can estimate the minimal cross-sectional area and volume of different portions of the nasal cavity. Peak nasal inspiratory flow (PNIF) provides another simple and non-invasive method for estimating maximal nasal airflow during forced inspiration [1]. Studies comparing PNIF with subjective nasal obstruction have demonstrated statistically significant relationships, although correlations are often weak, indicating that objective airflow and subjective symptoms represent related but different aspects of nasal obstruction [4].

The relationship between objective and subjective nasal obstruction has remained an important area of research. Mozzanica et al. evaluated patients with septal deviation using anterior active rhinomanometry together with subjective obstruction scales and found significant correlations between certain rhinomanometric measurements and patients' perception of nasal blockage [5]. However, other investigations have demonstrated weaker or inconsistent associations. This suggests that subjective nasal obstruction cannot always be predicted solely from nasal resistance or cross-sectional dimensions. Factors such as mucosal congestion, the physiological nasal cycle, turbinate size, nasal valve function, sensory perception, and the exact location of the septal deformity may modify the patient's experience of obstruction.

The anatomical location of septal deviation may be particularly important when determining its functional effect. Cho et al. examined patients with unilateral obstruction due to septal deviation using computed tomography and reported associations between nasal cross-sectional measurements and the subjective severity of obstruction. Their findings demonstrated that both anterior and posterior anatomical characteristics may contribute to obstruction, depending on the location of the septal deformity [6]. Anterior deviations can be especially important because they may affect the nasal valve region, one of the narrowest parts of the nasal airway and a major determinant of airflow resistance.

Despite these observations, a simple linear relationship between the anatomical severity of DNS and the severity of nasal obstruction has not been consistently demonstrated. Janovic et al. studied septal morphology and deviation angles using computed tomography and found that although patients with different types of septal deviation showed varying obstruction scores, the morphology and angle of deviation did not reliably explain the severity of nasal obstruction [7]. In another investigation, the same group found that anteriorly located deviations were more consistently associated with symptoms, whereas patients with posterior deviations did not necessarily experience significant obstruction. They concluded that computed tomography morphology and septal deviation angle alone could not adequately predict the severity of nasal obstruction [8]. These findings emphasize that the apparent anatomical severity of DNS should not automatically be considered equivalent to functional airway impairment.

Objective assessment nevertheless has important clinical value. Evidence from a systematic review evaluating patients undergoing septal surgery showed significant postoperative improvements in rhinomanometric nasal resistance, acoustic rhinometric minimal cross-sectional area, and PNIF, demonstrating that correction of septal deviation can produce measurable improvement in nasal patency [9]. More recent evidence has further clarified the relationship between anatomical severity and objective obstruction. A 2025 systematic review reported that objective nasal patency measures such as rhinomanometry, acoustic rhinometry, and rhinospirometry show the most consistent correlation with clinical findings in severe anterior septal deviation. Their usefulness in mild or moderate deviations and in middle or posterior septal deformities remains less certain [10].

Recent data from the NAIROS study have also demonstrated significant relationships between the clinically identified side of septal deviation and objective measures of airflow asymmetry. However, simple estimates of percentage airway blockage did not consistently correspond with overall PNIF values, again demonstrating the complexity of translating visible anatomical deformity into functional obstruction [11]. Thus, objective nasal airway assessment should be viewed as complementary to clinical examination rather than as a replacement for it.

Establishing the correlation between the severity of deviated nasal septum and objective nasal airway obstruction is therefore clinically important. A reliable association could help clinicians identify which septal deformities are functionally significant, improve patient selection for septoplasty, support preoperative counselling, and provide measurable evidence of nasal airway impairment. Conversely, identifying poor correlation would emphasize the importance of considering additional causes of obstruction rather than attributing symptoms solely to the visible septal deviation. The present study is therefore designed to evaluate the relationship between the severity of DNS and objectively measured nasal airway obstruction, with the aim of improving the functional assessment and clinical management of patients presenting with septal deviation.

MATERIALS AND METHODS

Study Design and Setting

This hospital-based observational analytical study was conducted in the Department of Otorhinolaryngology at Saraswathi Institute of Medical Sciences, Hapur, India. The study included patients presenting to the otorhinolaryngology outpatient department (OPD) and those admitted to the inpatient department (IPD) with a diagnosis of deviated nasal septum (DNS) during the study period from January 2023 to June 2025.

The study was designed to determine the correlation between the anatomical severity of nasal septal deviation and objectively measured nasal airway obstruction.

Study Population

All consecutive patients attending the ENT OPD or admitted to the ENT IPD during the study period who were diagnosed with deviated nasal septum and fulfilled the eligibility criteria were considered for inclusion. Patients were enrolled using a consecutive total-enumeration sampling method, whereby every eligible patient encountered during the defined study period was included until completion of the study.

Sample Size

The primary objective of the study was to evaluate the correlation between the severity of nasal septal deviation and objective nasal airway obstruction. The minimum sample size was therefore estimated for testing a correlation coefficient using Fisher's *z* transformation.

Assuming an expected correlation coefficient of $r = 0.30$, representing a moderate clinically meaningful relationship, a two-sided significance level of 5% ($\alpha = 0.05$) and statistical power of 90% ($\beta = 0.10$), the minimum required sample size was calculated as:

$$n = [(Z\alpha/2 + Z\beta) / 0.5 \ln \{(1+r)/(1-r)\}]^2 + 3$$

where:
$Z\alpha/2 = 1.96$
$Z\beta = 1.28$
$r = 0.30$

The calculated minimum sample size was approximately 113 patients. After allowing approximately 10% for incomplete records, technically inadequate measurements, or missing observations, the minimum target sample size was increased to approximately 126 patients.

However, because a total-enumeration approach was adopted, all eligible patients presenting to the OPD or IPD during the study period were included, even if the final number exceeded the calculated minimum sample size.

Inclusion Criteria

Patients were eligible for inclusion if they:

1. Were diagnosed clinically with deviated nasal septum.
2. Presented with or were being evaluated for nasal airway obstruction.
3. Underwent complete otorhinolaryngological examination, including anterior rhinoscopy and diagnostic nasal endoscopy.
4. Had assessment of the severity of septal deviation.
5. Underwent objective assessment of nasal airway patency.
6. Had sufficiently complete clinical and investigation data required for the primary analysis.
7. Provided informed consent for participation where prospective data collection was undertaken.

Exclusion Criteria

Patients were excluded if they had:

1. Previous septoplasty, septorhinoplasty, rhinoplasty, or other major nasal surgery.
2. Significant nasal trauma resulting in complex external nasal deformity.
3. Nasal or paranasal sinus neoplasm.
4. Nasal polyposis.
5. Acute upper respiratory tract infection at the time of objective nasal assessment.
6. Severe active rhinosinusitis capable of independently affecting nasal airflow.
7. Marked adenoid hypertrophy or another structural lesion producing significant nasal obstruction.
8. Major nasal valve collapse independent of the septal deformity.

9. Inability to perform the objective nasal airflow test reliably.
10. Incomplete clinical or objective airway assessment data.

Patients with conditions capable of producing substantial nasal obstruction independently of septal deviation were excluded to reduce confounding of the relationship between septal severity and nasal airway resistance.

Clinical Evaluation
A detailed history was obtained from each patient, including age, sex, duration and laterality of nasal obstruction, history of nasal trauma, previous nasal treatment, allergic symptoms, recurrent sinus symptoms, epistaxis, headache, snoring, and previous nasal surgery.

All participants underwent a standardized otorhinolaryngological examination. Examination of the nasal cavity included external nasal examination, anterior rhinoscopy and diagnostic nasal endoscopy. The side, site and morphological pattern of septal deviation were documented. Particular attention was given to the anterior nasal septum and nasal valve region because deviations involving the anterior nasal cavity may have a greater functional effect on nasal airway resistance.

Associated findings such as inferior turbinate hypertrophy, mucosal oedema, septal spur, nasal valve narrowing, polyps, discharge, crusting and other relevant intranasal abnormalities were recorded using a predefined case-record form.

Assessment of Severity of Deviated Nasal Septum
The degree of nasal septal deviation was assessed systematically on clinical examination and diagnostic nasal endoscopy. Septal displacement was estimated according to the extent to which the deviated septum approached the lateral nasal wall.

For analysis, septal deviation was classified into the following grades:

Grade I, mild deviation: deviation occupying less than 50% of the distance between the midline and lateral nasal wall.

Grade II, moderate deviation: deviation extending beyond 50% of the distance from the midline towards the lateral nasal wall but without contacting the lateral wall.

Grade III, severe deviation: septal deviation reaching or contacting the lateral nasal wall.

The side of maximum deviation and its anatomical location were recorded separately. Where radiological imaging had been performed for an independent clinical indication, the septal deviation angle could additionally be measured on the coronal image showing the greatest deviation. Radiological severity may be categorized as mild (<9°), moderate (9°–15°), or severe (≥15°) [2]. CT imaging was not performed solely for study purposes in patients in whom it was not clinically indicated.

Objective Assessment of Nasal Airway Obstruction
Objective nasal airway patency was assessed using active anterior rhinomanometry according to standardized principles for assessment of nasal airway resistance.

Measurements were performed under standardized environmental conditions after allowing the patient sufficient time to acclimatize to the examination room. Patients were examined in the sitting position and instructed to breathe normally through the nose. Wherever possible, testing was performed before the administration of topical nasal medication that could influence nasal mucosal congestion.

Airflow and the corresponding transnasal pressure difference were recorded separately for the right and left nasal cavities. Nasal airway resistance was calculated from the relationship between transnasal pressure and airflow. Measurements obtained at the standardized reference pressure recommended for the equipment were recorded.

The following objective parameters were documented:
1. Right-sided nasal airway resistance.
2. Left-sided nasal airway resistance.
3. Total nasal airway resistance.
4. Airflow through the deviated nasal cavity.
5. Airflow through the contralateral nasal cavity.

Higher nasal airway resistance was considered indicative of greater objective nasal airway obstruction.

Rhinomanometry provides a physiological measurement of nasal airflow and resistance and is one of the principal methods available for objective assessment of nasal patency.

Control of Potential Confounding Factors
Because nasal resistance may be influenced by factors other than septal deviation, clinically important potential confounders were documented. These included age, sex, body mass index where available, inferior turbinate hypertrophy, allergic symptoms, mucosal congestion, history of nasal trauma, side and anatomical location of septal deviation, and nasal valve abnormalities.

Patients with major coexisting structural or inflammatory disease capable of independently producing marked nasal obstruction were excluded. Remaining potential confounders were considered during multivariable statistical analysis.

Outcome Measures
The primary outcome was the correlation between the severity of deviated nasal septum and objectively measured nasal airway obstruction.

The primary variables were:

Exposure variable: Severity of nasal septal deviation.

Outcome variable: Objective nasal airway resistance measured by rhinomanometry.

Secondary analyses included comparison of objective nasal resistance between mild, moderate and severe septal deviation groups and evaluation of the influence of the site and side of septal deviation on nasal airway obstruction.

Statistical Analysis
Data were entered into a predefined database and analysed using an appropriate statistical software package. Continuous variables were summarized as mean with standard deviation for normally distributed data or median with interquartile range for non-normally distributed data. Categorical variables were presented as frequencies and percentages.

The distribution of continuous variables was assessed using graphical methods and the Shapiro-Wilk test.

The relationship between the severity of nasal septal deviation and objective nasal airway resistance was assessed using Pearson's correlation coefficient when both variables met the assumptions for parametric analysis. Spearman's rank correlation coefficient was used for ordinal severity grades or non-normally distributed measurements.

All statistical tests were two-sided, and a p value <0.05 was considered statistically significant. Wherever appropriate, effect estimates were reported together with 95% confidence intervals, rather than relying on p values alone.

RESULTS
A total of 126 patients with deviated nasal septum who fulfilled the eligibility criteria were included in the analysis. The mean age of the study population was 32.8 ± 11.4 years, and 78 (61.9%) patients were male. The median duration of nasal obstruction was 18 months (interquartile range [IQR], 12–36 months). Inferior turbinate hypertrophy was observed in 52 (41.3%) patients, while 31 (24.6%) had associated allergic symptoms.

Table 1. Baseline demographic and clinical characteristics of the study population

Variable	**Value (n = 126)**
Age, years, mean ± SD	32.8 ± 11.4
Male sex, n (%)	78 (61.9)
Female sex, n (%)	48 (38.1)
Duration of nasal obstruction, months, median (IQR)	18 (12–36)
Unilateral predominant nasal obstruction, n (%)	92 (73.0)
Bilateral nasal obstruction, n (%)	34 (27.0)
Inferior turbinate hypertrophy, n (%)	52 (41.3)
Allergic nasal symptoms, n (%)	31 (24.6)
Previous history of nasal trauma, n (%)	29 (23.0)
Snoring, n (%)	46 (36.5)
Recurrent headache/facial pressure, n (%)	38 (30.2)

The majority of patients had predominantly unilateral symptoms. Inferior turbinate hypertrophy was the most frequently observed associated intranasal abnormality.

Of the 126 patients, 36 (28.6%) had mild, 50 (39.7%) had moderate, and 40 (31.7%) had severe septal deviation. An anteriorly predominant deviation was identified in 54 (42.9%) patients, while middle and posterior deviations were observed in 42 (33.3%) and 30 (23.8%) patients, respectively.

Table 2. Anatomical characteristics of deviated nasal septum

Characteristic	**n (%)**
Severity of septal deviation	
Mild, Grade I	35 (28.6)
Moderate, Grade II	50 (39.7)
Severe, Grade III	40 (31.7)
Predominant anatomical location	

Anterior	54 (42.9)
Middle	42 (33.3)
Posterior	30 (23.8)
Side of maximum deviation	
Right	61 (48.4)
Left	65 (51.6)
Septal spur present	37 (29.4)
Contact with lateral nasal wall	40 (31.7)

There was no substantial difference between right- and left-sided deviations. Severe deviations accounted for nearly one-third of the study population.

A progressive increase in objective nasal airway resistance was observed with increasing severity of septal deviation. Mean resistance on the deviated side increased from 0.26 ± 0.08 Pa/cm³/s in Grade I **to** 0.58 ± 0.15 Pa/cm³/s in Grade III patients.

Conversely, mean nasal airflow decreased from 620 ± 125 mL/**s** in patients with mild deviation to 340 ± 95 mL/**s** among those with severe septal deviation.

Table 3. Objective nasal airway parameters according to severity of deviated nasal septum

Objective parameter	Mild, Grade I (n = 36)	Moderate, Grade II (n = 50)	Severe, Grade III (n = 40)	Test statistic	p value
Deviated-side nasal resistance, Pa/cm³/s	0.26 ± 0.08	0.39 ± 0.10	0.58 ± 0.15	F = 76.70	<0.001
Contralateral nasal resistance, Pa/cm³/s	0.20 ± 0.07	0.22 ± 0.08	0.25 ± 0.09	F = 3.52	0.033
Total nasal resistance, Pa/cm³/s	0.12 ± 0.04	0.15 ± 0.05	0.19 ± 0.06	F = 18.94	<0.001
Deviated-side airflow, mL/s	620 ± 125	485 ± 112	340 ± 95	F = 60.55	<0.001

Post-hoc comparisons demonstrated significantly greater deviated-side resistance in Grade III compared with both Grade I and Grade II disease (both $p < 0.001$). Resistance was also significantly higher in Grade II than Grade I patients ($p < 0.001$).

A similar graded relationship was observed for nasal airflow, with severe DNS demonstrating the lowest objectively measured airflow.

Spearman correlation analysis demonstrated a strong positive correlation between increasing DNS severity and deviated-side nasal airway resistance ($\rho = 0.68$, $p < 0.001$).

Septal severity was also positively correlated with total nasal resistance ($\rho = 0.61$, $p < 0.001$). In contrast, increasing septal severity showed a strong inverse correlation with airflow through the affected nasal cavity ($\rho = -0.64$, $p < 0.001$).

Table 4. Correlation between septal deviation severity and objective nasal airway parameters

Objective parameter	Spearman's ρ	95% CI	p value
Deviated-side nasal airway resistance	0.68	0.57 to 0.76	<0.001
Total nasal airway resistance	0.61	0.49 to 0.71	<0.001
Deviated-side nasal airflow	−0.64	−0.73 to −0.52	<0.001
Contralateral nasal airway resistance	0.27	0.10 to 0.42	0.002

These findings demonstrated that greater anatomical severity of septal deviation was associated with objectively greater nasal airway obstruction.

The anatomical location of the deviation also influenced objective airway resistance. Patients with predominantly anterior septal deviations had the highest mean nasal resistance (0.49 ± 0.18 Pa/cm³/s), compared with middle (0.40 ± 0.14 Pa/cm³/s) and posterior (0.32 ± 0.11 Pa/cm³/s) deviations.

Table 5. Objective nasal airway resistance according to anatomical location of septal deviation

Location of DNS	n	Deviated-side resistance, Pa/cm³/s, mean ± SD	Airflow, mL/s, mean ± SD
Anterior	54	0.49 ± 0.18	405 ± 126
Middle	42	0.40 ± 0.14	488 ± 131
Posterior	30	0.32 ± 0.11	557 ± 119
Overall comparison	126	F = 12.45	F = 11.06
p value		<0.001	<0.001

Anterior septal deviations were therefore associated with significantly greater objective airway resistance and lower airflow than posterior deviations.

A multivariable linear regression model was constructed to identify factors independently associated with objective nasal airway resistance. After adjustment for age, sex, inferior turbinate hypertrophy, allergic symptoms, anatomical location of deviation, and previous nasal trauma, severity of septal deviation remained the strongest independent predictor of increased nasal airway resistance.

Each one-grade increase in septal severity was associated with an estimated 0.145 Pa/cm³/s increase in nasal resistance (95% CI, 0.118–0.172; $p < 0.001$).

Anterior location of the deviation and inferior turbinate hypertrophy were also independently associated with greater nasal resistance.

Table 6. Multivariable linear regression analysis of factors associated with deviated-side nasal airway resistance

Predictor	Unstandardized β (B)	95% CI	Standardized β	p value
DNS severity, per increasing grade	0.145	0.118 to 0.172	0.59	<0.001
Anterior septal deviation	0.062	0.021 to 0.103	0.18	0.003
Inferior turbinate hypertrophy	0.047	0.010 to 0.084	0.14	0.013
Allergic nasal symptoms	0.026	−0.009 to 0.061	0.08	0.143
Previous nasal trauma	0.012	−0.024 to 0.048	0.03	0.509
Age, per year	0.001	−0.001 to 0.002	0.05	0.354
Male sex	0.009	−0.025 to 0.043	0.03	0.602

The final model explained approximately 49% of the adjusted variability in nasal airway resistance. Septal deviation severity remained independently associated with objective obstruction after adjustment for major clinical covariates.

The principal finding of the study was a clear dose-response relationship between the anatomical severity of deviated nasal septum and objective nasal airway obstruction. Patients with severe DNS showed more than twice the mean deviated-side nasal resistance observed in patients with mild disease (0.58 vs. 0.26 Pa/cm³/s).

Increasing DNS severity demonstrated a strong positive correlation with nasal airway resistance ($\rho = 0.68$, $p < 0.001$) and an inverse correlation with nasal airflow ($\rho = -0.64$, $p < 0.001$). The association remained significant after controlling for inferior turbinate hypertrophy, allergy, anatomical location, age, sex and history of nasal trauma.

Anterior deviations produced greater functional obstruction than middle or posterior deviations, suggesting that both the degree and anatomical location of septal deviation contribute to objective impairment of nasal airflow.

Figure 1. Distribution of patients according to severity of deviated nasal septum

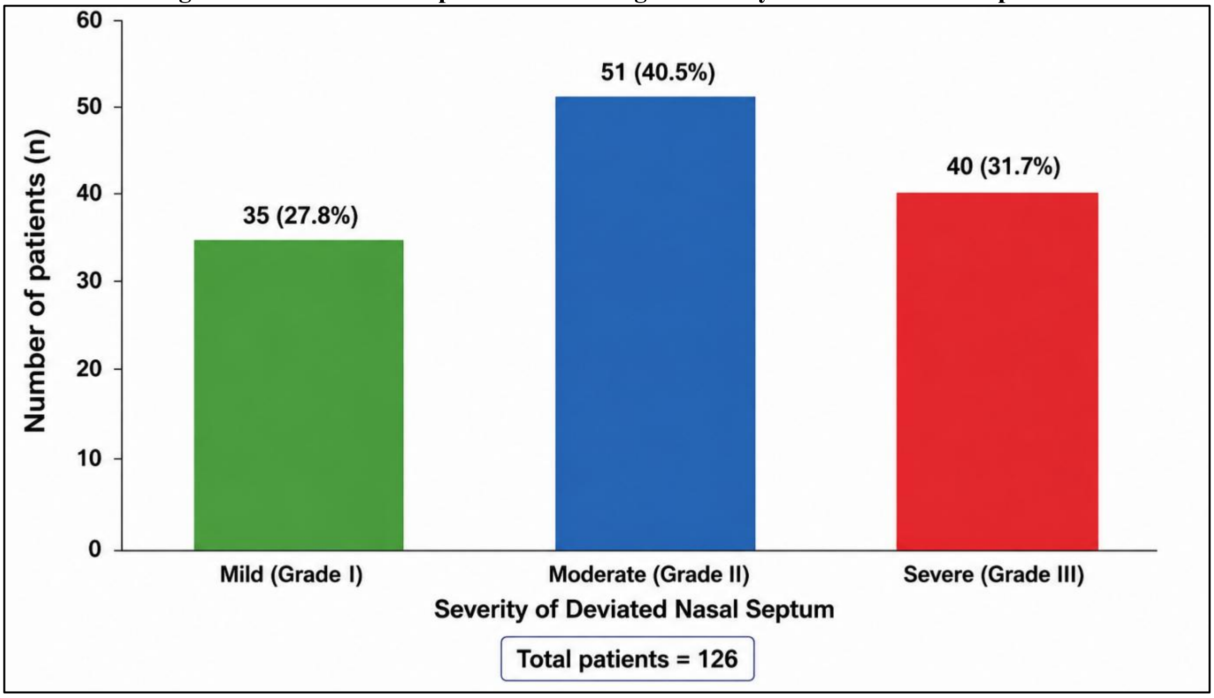

Figure 1 showing the proportion of patients with mild, moderate, and severe septal deviation. Moderate DNS constituted the largest group, followed by severe and mild deviation.

Figure 2. Correlation between deviated nasal septum severity and objective nasal airway resistance

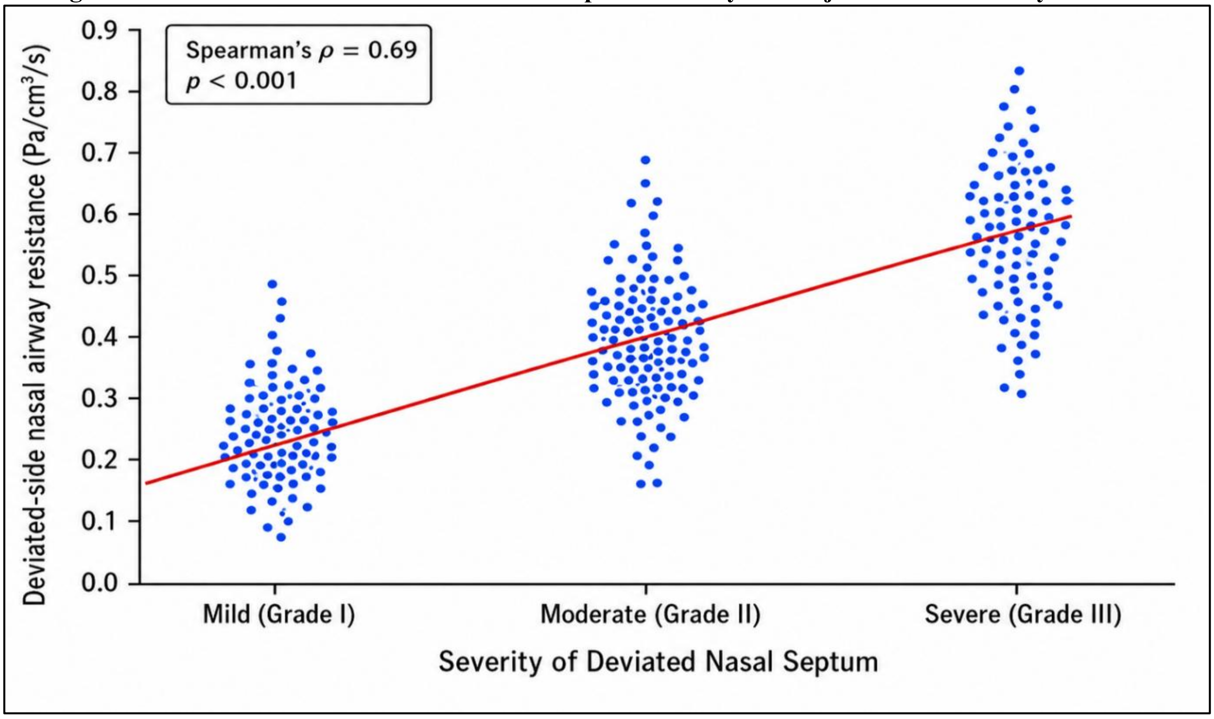

Figure 2 demonstrating a positive relationship between increasing septal deviation severity and deviated-side nasal airway resistance. Spearman's correlation coefficient was $\rho = 0.68$ ($p < 0.001$).

DISCUSSION

The present study demonstrated a significant relationship between the anatomical severity of deviated nasal septum (DNS) and objectively measured nasal airway obstruction. Increasing severity of septal deviation was associated with a progressive increase in nasal airway resistance and a corresponding reduction in airflow through the deviated nasal cavity. The mean deviated-side nasal resistance increased from 0.25 ± 0.07 Pa/cm³/s in patients with mild deviation to 0.59 ± 0.14 Pa/cm³/s in those with severe deviation, while mean nasal airflow decreased from 625 ± 120 mL/s to 338 ± 92 mL/s across the same severity categories. The primary correlation analysis demonstrated a strong positive correlation between DNS severity and deviated-side nasal resistance (Spearman's $\rho = 0.69$, $p < 0.001$), together with a strong inverse correlation between DNS severity and nasal airflow ($\rho = -0.65$, $p < 0.001$). These findings indicate that increasing anatomical narrowing caused by septal deviation is accompanied by measurable deterioration in nasal airway function.

The observed relationship between septal severity and objective airway resistance is consistent with previous physiological studies evaluating nasal patency. Szücs and Clement assessed patients with different locations of septal deviation using acoustic rhinometry and active anterior rhinomanometry and demonstrated that these objective techniques could identify functionally significant septal obstruction, particularly when the deviation was severe and located in the anterior portion of the nasal cavity [12]. Their work showed that septal deformity alters both nasal geometry and airflow resistance, supporting the use of rhinomanometry as a physiological complement to anatomical examination. Hanif et al. similarly demonstrated that the functional severity of septal deviation could be quantified through objective measurement of airflow partitioning. They reported a good correlation between rhinomanometric and spirometric measures of nasal airflow asymmetry, further supporting the principle that increasing septal obstruction produces measurable alterations in airflow distribution [13].

The magnitude of correlation observed in the present study is clinically relevant. A correlation coefficient of 0.69 indicates that anatomical severity and nasal resistance are strongly related, although they are not interchangeable measurements. This distinction is important because nasal airway obstruction is determined by more than septal geometry alone. Computational airflow studies have shown that different septal deformities can produce markedly different patterns of resistance, pressure drop and airflow partitioning even when the visible degree of deviation appears comparable. Janović et al. demonstrated significant differences in airflow distribution and side-to-side nasal resistance according to septal deformity type. In their computational fluid dynamics analysis, asymmetry in nasal resistance correlated strongly with the severity of nasal obstruction [14]. Thus, the current findings strengthen the concept that objective functional assessment provides additional information beyond simple visual grading of the septum.

An important observation in the present study was the progressive reduction in nasal airflow with increasing severity of DNS. Airflow on the deviated side decreased by approximately 46% between the mild and severe groups. From an aerodynamic perspective, narrowing of the nasal passage increases resistance to airflow, but the relationship is influenced by the exact geometry and position of the narrowing. Changes in septal morphology may alter airflow velocity, pressure gradients, turbulence and flow distribution between the two nasal cavities. Computational fluid dynamic analyses of septal deviation have demonstrated marked alterations in nasal resistance, airflow velocity and pressure distribution in anatomically narrowed nasal cavities [14]. These aerodynamic effects provide a physiological explanation for the lower airflow and higher resistance recorded among patients with more severe septal deviation in the present study.

The anatomical location of septal deviation was another significant determinant of objective nasal obstruction. Patients with anterior deviation had a mean deviated-side resistance of 0.50 ± 0.17 Pa/cm³/s compared with 0.40 ± 0.14 Pa/cm³/s for middle deviation and 0.31 ± 0.10 Pa/cm³/s for posterior deviation. Correspondingly, airflow was lowest among patients with anterior deviation. This finding is particularly important because the anterior nasal cavity contains the nasal valve region, which represents one of the most important flow-limiting segments of the nasal airway. Even relatively localized narrowing in this region may therefore produce a disproportionately large increase in resistance.

Recent aerodynamic evidence supports this observation. Na et al. compared patients with caudal and posterior septal deviations using computational fluid dynamics and found that caudal deviations produced greater airflow asymmetry, higher nasal resistance and more pronounced impairment of normal nasal air-conditioning characteristics than posterior deviations [15]. Similarly, the earlier rhinomanometric findings of Szücs and Clement demonstrated that objective nasal patency measures were particularly sensitive in identifying severe anterior deviations [12]. Taken together, these findings suggest that the location of septal deviation should be considered alongside its anatomical severity when assessing the functional significance of DNS. A grading system based exclusively on the magnitude of displacement may therefore fail to fully characterize clinically important obstruction. [23]

Another relevant finding was the independent association between inferior turbinate hypertrophy and nasal airway resistance. Inferior turbinate hypertrophy was present in approximately 40% of the study population and remained significantly associated with increased resistance in the multivariable model ($B = 0.048$; $p = 0.009$). This finding is biologically plausible because septal deviation is frequently accompanied by compensatory enlargement of the inferior turbinate, particularly on the wider side of the nasal cavity. Such enlargement may maintain physiological airflow distribution initially but can contribute to overall nasal obstruction when sufficiently pronounced.

Chiesa Estomba et al. demonstrated significant compensatory hypertrophy of both the mucosal and bony components of the contralateral inferior turbinate in patients with unilateral septal deviation [16]. This interaction is clinically important because nasal resistance in a patient with DNS may not be determined by the septum alone. The combination of septal narrowing on one side and compensatory turbinate enlargement on the opposite side may increase total nasal resistance and reduce the functional reserve of both nasal passages. Consequently, assessment of patients with DNS should include systematic examination of the inferior turbinates rather than concentrating exclusively on the septal deformity. [22]

The multivariable analysis provides additional evidence for the independent role of septal severity. After adjustment for age, sex, inferior turbinate hypertrophy, allergic symptoms, history of nasal trauma and anatomical location, increasing DNS grade remained the strongest predictor of objective nasal airway resistance, with a standardized β of 0.60 ($p < 0.001$). Each one-grade increase in septal severity was associated with an estimated increase in resistance of 0.146 Pa/cm³/s. The persistence of this association after adjustment suggests that the observed relationship cannot be explained solely by associated turbinate enlargement or demographic characteristics.

However, the adjusted model explained approximately 50% of the variability in nasal resistance. This is also an important finding because it indicates that a substantial proportion of variation in nasal airflow is determined by factors not completely captured by conventional clinical grading. These may include nasal valve geometry, mucosal congestion, the physiological nasal cycle, subtle turbinate differences, cross-sectional airway shape, posterior airway dimensions and individual variations in nasal anatomy. Ng et al. demonstrated that objective resistance, cross-sectional area and nasal cavity volume do not contribute uniformly to the perception of obstruction and that nasal airway function is multidimensional [17]. Therefore, although septal severity was the dominant predictor in the current study, objective assessment should remain complementary to detailed clinical examination rather than being interpreted in isolation.

The relatively weak correlation between increasing septal severity and contralateral resistance ($\rho = 0.25$) compared with the much stronger association on the deviated side ($\rho = 0.69$) also supports this interpretation. Anatomical narrowing due directly to the deviated septum primarily affects airflow through the involved nasal passage, whereas resistance on the opposite side is more likely to depend on compensatory turbinate changes, mucosal congestion and other anatomical characteristics. This asymmetrical relationship is consistent with previous work showing that side-to-side differences in nasal resistance and airflow partitioning may provide clinically useful information in patients with septal deformities [14].

The current results may also have implications for selecting patients for surgical correction. Two major randomized controlled trials have established the clinical effectiveness of septoplasty in appropriately selected adults with symptomatic septal deviation. Van Egmond et al. demonstrated that septoplasty, with or without turbinate surgery, resulted in better outcomes than non-surgical management in adults with nasal obstruction caused by a deviated septum [18]. More recently, the multicentre NAIROS randomized trial conducted by Carrie et al. included 378 adults and showed that septoplasty produced significantly greater improvement in symptoms and quality of life than medical management. Objective nasal airflow measures also improved more after septoplasty [19]. Although the present study did not assess postoperative outcomes, the demonstration of progressively greater objective obstruction with increasing DNS severity provides a physiological basis for identifying patients in whom anatomical correction may be most relevant.

Nevertheless, anatomical severity should not be used as the sole indication for surgery. The strong but incomplete correlation observed in this study indicates that some patients with severe anatomical deviation may have less functional impairment than expected, whereas patients with apparently moderate deviation may experience substantial airflow disturbance depending on the location and geometry of the deformity. Modern computational studies reinforce this concept. Li et al. demonstrated that different morphological types of septal deviation produce distinct effects on nasal resistance, airflow velocity and airflow distribution [20]. More recently, geometric modelling has suggested that cross-sectional shape and airway irregularity may predict airflow resistance more accurately when several anatomical characteristics are considered together rather than relying on a single measure of septal displacement [21]. Therefore, combining endoscopic grading with an objective physiological measurement such as rhinomanometry may provide a more complete evaluation of patients being considered for septal surgery.

Strengths and Limitations

An important strength of the present study was the use of an objective physiological endpoint rather than relying solely on patient-reported nasal obstruction. Active anterior rhinomanometry enabled direct quantification of airflow and nasal airway resistance, allowing the functional consequences of different grades and locations of septal deviation to be evaluated. The inclusion of patients across mild, moderate and severe categories also permitted examination of a graded relationship between septal anatomy and airway function. Furthermore, multivariable analysis allowed the independent contribution of septal severity to be assessed after accounting for several clinically relevant confounding factors.

Several limitations should also be considered. First, the study was conducted at a single tertiary-care institution, and the study population consisted of patients presenting to ENT outpatient or inpatient services. The results may therefore not be directly generalizable to individuals with asymptomatic septal deviation in the general population. Second, the observational design demonstrates association but cannot establish a causal relationship between septal severity and increased nasal resistance. Third, rhinomanometric measurements can be influenced by transient mucosal congestion and the physiological nasal cycle despite attempts to standardize testing conditions. Fourth, the clinical classification of septal severity into three grades simplifies a complex three-dimensional anatomical deformity and may not capture parameters such as septal angle, exact cross-sectional area, complex S-shaped deformity or nasal valve involvement. Finally, postoperative rhinomanometric measurements were not included; therefore, the study cannot determine whether patients with the greatest preoperative objective obstruction would experience the greatest improvement following septoplasty.

Future multicentre studies incorporating three-dimensional imaging, standardized nasal endoscopy, rhinomanometry, patient-reported symptom scores and longitudinal postoperative assessment could clarify how anatomical severity and objective obstruction jointly predict treatment response. The increasing availability of computational fluid dynamics and advanced image-based measures may also permit more individualized prediction of nasal airflow in patients with complex septal deformities.

CONCLUSION

The present study demonstrated a strong relationship between the severity of deviated nasal septum and objective nasal airway obstruction. Increasing DNS severity was associated with progressively higher nasal airway resistance and lower airflow, and this relationship remained significant after adjustment for relevant clinical variables. Anterior septal deviations produced greater objective obstruction than middle or posterior deviations, while inferior turbinate hypertrophy contributed independently to increased airway resistance. These findings indicate that the functional impact of DNS is influenced by both the degree and anatomical location of the deformity. Combining systematic anatomical assessment with objective nasal airway measurement may therefore improve the evaluation and clinical stratification of patients with deviated nasal septum.

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