The Impact of Nasal Anatomical Abnormalities on Respiratory Conditions: A Focused Literature Review

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Introduction: The anatomic abnormalities of the nose impacts the pathophysiology of distal cardiopulmonary conditions. **Method:** In this study, we reviewed the current literature on the trends in how nasal anatomic abnormalities affect obstructive sleep apnea, asthma, and cardiopulmonary function. Independent searches of the PubMed databases were used to collect all studies which described nasal anatomic abnormalities and respiratory conditions using relevant term combinations such as "deviated nasal septum", "respiratory", "cardiopulmonary", "pulmonary", "asthma", "cough", "obstructive sleep apnea". **Results:** A total of 40 relevant unique articles that met the inclusion criteria were analyzed and reviewed. Due to the variability in study methods and outcome measures, meta-analysis was unattainable. **Conclusions:** This comprehensive review aims to highlight the impact of nasal obstruction on respiratory disorders such as sleep apnea and cardiopulmonary function. Though there remains no consenus on management of these nasal anatomic abnormalities, surgical management to correct septal the management of these nasal anatomic abnormalities, surgical management to correct septal deviation can reduce the apnea–hypopnea index, pulmonary artery pressure, and increase forced expiratory volumes, forced vital capacities, and peak expiratory flow rate.

Keywords

Asthma, cardiopulmonary, deviated nasal septum, nasal anatomy, nasal septal deviation, obstructive sleep apnoea, pulmonary artery pressure, pulmonary function test, respiratory, rhinitis

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The nasal airway serves as the primary entry point of air and oxygen into the body. It serves critical functions, such as providing a physical barrier against external irritants and pathogens and warming and humidifying incoming air.[1] Consequently, disorders of the nose and nasal cavity may lead to pathological downstream effects by impacting the normal physiological functions of the nose. In fact, the unified airway theory posits that inflammatory conditions that affect the nasal cavity or paranasal sinuses, such as chronic rhinosinusitis, allergic rhinitis and aspirin-exacerbated respiratory disease, are closely linked to increased prevalence of respiratory disorders, such as asthma and bronchiectasis.[2–5]

The impact of purely anatomical abnormalities of the nose on the respiratory system as a whole is understudied. The most common anatomical abnormalities of the nasal cavity are deviated nasal septum (DNS), turbinate hypertrophy, internal and external nasal valve collapse and concha bullosa, all of which may lead to chronic and fixed nasal obstruction. Surgical correction of nasal airway obstruction is a frequently performed and effective method to improve the subjective nasal breathing symptoms and the quality of life of patients.[6] However, data on how conditions, such as obstructive sleep apnoea (OSA) and asthma may be impacted, are more limited.

The objective of this review is to perform a focused literature search to identify the existing data on how nasal anatomical abnormalities impact respiratory conditions, such as OSA and underlying cardiopulmonary functions. In addition, we will briefly review the available data on the association between nasal anatomical abnormalities and asthma. We hope that this knowledge could serve as a valuable resource for clinicians in making informed decisions regarding patient management. It may also facilitate discussions with patients and their families, offering insights into expected clinical outcomes. Lastly, this review will help to determine the areas in need of further research.

Methods

Search strategy

A scoping review was performed via a literature search using the PubMed electronic database and limited to the English literature from inception to December 2023. Search terms and keywords related to nasal anatomical abnormalities and respiratory conditions, such as nasal obstruction, deviated nasal septum, turbinate hypertrophy, asthma, cough, obstructive sleep apnea, respiratory and pulmonary, were included in multiple combinations, for example (sinus[MeSH Major Topic]) OR (nasal[MeSH Major Topic])) AND (deviated nasal septum OR DNS) AND (respiratory OR cardiopulmonary OR pulmonary OR asthma OR cough OR OSA OR obstructive sleep apnea); (Deviated nasal septum[MeSH Major Topic] OR DNS[MeSH Major Topic]) OR turbinate[MeSH Major Topic]) AND (cough OR obstructive sleep apnea OR OSA OR asthma OR respiratory OR cough OR CPAP).

Articles deemed to meet the inclusion criteria were included in the full-text review. Reference lists for reviewed articles were also reviewed for additional articles for inclusion.

Study evaluation

Screening of full-text articles was performed by the authors. Exclusion criteria include (1) case reports, (2) lack of relevant outcomes or unclear outcomes, (3) outcomes related to patients with inflammatory disease (chronic rhinosinusitis, rhinitis, aspirin-exacerbated respiratory disease, etc.), (4) not written in English and (5) participants <18 years old.

Narrative synthesis

Postoperative outcomes in males and females were reviewed and categorized by two independent reviewers, with the senior author weighing in for the final approval. The reported interventions and their results are summarized in the Results section.

Results

Nasal anatomy and obstructive sleep apnoea

The role of nasal anatomical variations in OSA is unclear, with mixed results published in the literature (*Table 1*).[7–29] Numerous epidemiological studies indicate that there is a higher percentage of OSA among patients with nasal obstruction compared with those without. Among 60 patients, Michalska et al. found that 52.5% of patients with OSA had nasal obstruction compared with none of those without and that DNS was the most common cause of nasal obstruction.[21] A study by Magliulo et al. identified a group of 50 patients with OSA and evaluated them for nasal obstruction via clinical evaluation or rhinomanometry. Seventy per cent of these patients demonstrated some form of nasal obstruction.[20] Most convincingly, Yeom et al. conducted a retrospective cohort study of 11,238 patients diagnosed with a DNS and 22,476 control patients.[28] This study found that the overall hazard ratio for OSA in the DNS group was 4.39 (95% confidence interval [CI]: 3.56–5.42) compared with controls, and the hazard ratio for OSA after septoplasty was 0.71 (95% CI: 0.54–0.94). Conversely, a cross-sectional study of 100 patients by Leitzen et al. did not find a correlation between nasal anatomical abnormalities and the presence or severity of OSA among the included patients.[17] A study by Miljeteig et al. found no difference in OSA severity between 683 patients divided into three groups based on the severity of nasal resistance.[22]

Numerous studies looked at the impact of topical medical interventions designed to alleviate nasal obstruction on OSA. A study by Clarenbach et al. designed a randomized controlled trial of 12 patients with OSA with nasal obstruction who were given either oxymetazoline or a placebo for 1 week. Following treatment, there was no significant difference in the apnoea–hypopnoea index (AHI) between the experimental and placebo groups (29.3 ± 32.5 versus 33.2 ± 32.8).[8,22] Kerr et al. similarly looked at 10 patients with OSA and found no change in AHI with the application of oxymetazoline and nasal dilators compared with placebo.[13] A systematic review and meta-analysis of five studies by Nguyen et al. did not find a significant decrease in AHI among patients using topically applied nasal decongestants.[25]

Prospective trials have been performed to further elucidate the role of nasal surgery alone in OSA. Koutsourelakis et al. randomly assigned 49 patients with OSA with symptomatic DNS to either septoplasty or sham surgery and then repeated polysomnography (PSG). Of the 27 patients who underwent septoplasty, only 4 patients showed a statistically significant improvement in AHI with one patient demonstrating complete response (AHI <5). No patients from the sham group had improvement.[16] Kim et al. conducted a study of 21 patients with nasal obstruction with pre- and postoperative PSG. They found a statistically significant reduction in respiratory disturbance index (RDI) (39 to 29, p<0.01), AHI (19 to 16, p<0.02) and oxygen saturation index (OSI) (48 to 32, p<0.01) following septoplasty with or without inferior turbinectomy.[14] Similarly, Park et al. found a statistically significant reduction in AHI (23.96 ± 14.9 to 12.2 ± 6.4, p<0.05) and RDI (28.8 ± 14.4 to 17.1 ± 7.5, p<0.05) in 25 patients with OSA with DNS treated with septoplasty and/or turbinoplasty.[26] Studies by Moxness et al., Kim et al. and Hisamatsu et al. also found a statistically significant reduction in AHI among other PSG parameters in patients who underwent surgery to correct nasal obstruction, as summarized in *Table 1*.[10,15,23]

In contrast, four meta-analyses have been conducted, which look at the role of nasal surgery in OSA, published in 2011 (Li et al.), 2015 (Ishii et al.), 2017 (Wu et al.) and 2022 (Schoustra et al.).[12,18,27,29] Li et al. included 11 prospective trials and found no statistically significant decrease in mean AHI (35.2 ± 22.6 to 33.5 ± 23.8, p=0.69) after nasal surgery.[18] However, patient-reported outcomes measured via the Epworth Sleepiness Scale (ESS) significantly decreased from 10.6 ± 3.9 to 7.1 ± 3.7 (p<0.001) following isolated nasal surgery. Ishii et al. included 10 studies and similarly found no significant decrease in AHI. They did report a significant decrease in ESS by 3.53 points (95% CI: 0.64–6.23) and RDI by 11.06 points (95% CI: 5.92–16.19).[12] Wu et al. included 18 trials and noted a statistically significant improvement in AHI with a weighted mean difference (WMD) of 4.15 fewer events per hour following nasal surgery. As with the other studies, they also noted a significant reduction in ESS with a WMD of -4.08.[29] Schoustra et al. included 21 studies and found a statistically significant improvement in AHI with a WMD of 4.08 and a significant improvement in ESS with a WMD of 4.01 following nasal surgery alone.[27]

Lastly, the impact of nasal surgery on continuous positive airway pressure (CPAP) tolerance and effectiveness has been studied. A 2015 meta-analysis by Camacho et al. included 11 studies and found that isolated nasal surgery converted 89% (57 of 64 patients) of non-CPAP users to CPAP-tolerant users and improved objective CPAP use hours from 3.0 ± 3.1 h per night to 5.5 ± 2.0 h per night.[7]

Nasal anatomy and cardiopulmonary function

Adenotonsillar hypertrophy as a source of chronic upper airway obstruction in children has been known to impact cardiopulmonary function.[30] Nasal resistance comprises approximately one-half of the total airway resistance during nasal breathing.[31] Nasal anatomical factors, such as DNS, turbinate hypertrophy and internal/external nasal valve collapse, can limit nasal airflow and increase nasal resistance. Through our literature search, we identified 16 articles that discussed how this nasal obstruction may contribute to abnormalities of the cardiopulmonary system.[32–39] Eight studies examining DNS and pulmonary arterial pressure (PAP) found that patients with DNS have increased PAP over control populations, including when controlled for OSA.[32–37,40] Nine studies tested pre- and post-septoplasty PAP values, and all nine found a statistically significant postoperative decrease in PAP (*Table 2*).[30,32–45] Six studies also reported an improvement in

Table 1: Studies investigated the relationship between nasal anatomical abnormalities and obstructive sleep apnoea[7–29]

Author (year)	Study participants	Objective	Study design	Primary outcomes
OSA				
Camacho et al. (2015)[7]	11 studies included 279 pooled patients with OSA	To evaluate the effect of nasal surgery alone in improving CPAP tolerance among patients with OSA	Retrospective chart review	Nasal surgery converted 89% of non-PAP users into PAP-tolerant users and improved objective CPAP use hours from 3.0 ± 3.1 h per night to 5.5 ± 2.0 h per night
Clarenbach et al. (2008)[8]	12 patients with OSA	To determine whether medical management of nasal obstruction would improve OSA	Randomized controlled trial	No significant difference in AHI between the experimental and placebo groups (29.3 ± 32.5 versus 33.2 ± 32.8, p=non-significant)
Genta et al. (2017)[9]	31 patients with OSA	To determine whether collapse driven by the tongue would exhibit minimal negative effort dependence, whereas collapse at the epiglottis or palate would exhibit substantial negative effort dependence	Prospective cohort study	Negative effort dependence was associated with the structure causing collapse (p<0.001). Tongue-related obstruction was associated with a small amount of negative effort dependence. Moderate negative effort dependence was found among patients with isolated palatal collapse. The epiglottis was associated with severe negative effort dependence and abrupt discontinuities in inspiratory flow
Hisamatsu et al. (2015)[10]	45 patients with OSA	To study the effect of the compound nasal surgery method, which consists of septoplasty combined with submucosal inferior turbinectomy and posterior nasal neurectomy, on patients with OSA	Prospective cohort study	Compound nasal surgery (septoplasty, inferior turbinoplasty and posterior nasal neurectomy) showed improvements in one or more PSG findings in 24 of 32 (75%) patients with severe OSA and 4 of 7 (57.1%) patients with moderate OSA. Significance was not reported
Hoel et al. (2023)[11]	139 patients with OSA (all male)	To determine whether patients with OSA with an elevated hypopnoea–apnoea ratio are associated with differences in acoustic rhinometry measurements	Prospective case–control study	Patients with OSA with an elevated hypopnoea–apnoea ratio are four times more likely to present with increased nasal resistance measured by four-phase rhinomanometry (p<0.01)
Ishii et al. (2015)[12]	10 studies included 320 pooled patients with OSA	To determine the role of nasal surgery alone in treating OSA	Systematic review and meta-analysis	No significant decrease in AHI. Significant decrease in ESS by 3.53 points (95% CI: 0.64–6.23) and RDI by 11.06 points (95% CI: 5.92–16.19)
Kerr et al. (1992)[13]	10 patients with OSA	To determine whether medical management of nasal obstruction would improve OSA	Randomized controlled trial	No change in AHI with the application of oxymetazoline and nasal dilators compared with placebo
Kim et al. (2004)[14]	21 patients with nasal obstruction and snoring	To study the polysomnographic effects of nasal surgery for snoring and OSA	Retrospective chart review	Nasal surgery had the following effects: RDI decreased from 39 to 29 (p=0.0001), AHI decreased from 19 to 16 (p=0.0209), OSI decreased from 48 to 32 (p=0.0001) and the duration of snoring decreased from 44 to 39% (p=0.1595). Snoring and OSA were completely relieved in 4 patients (19%) who did not require any additional surgical therapy
Kim et al. (2021)[15]	35 patients with nasal obstruction and OSA	To evaluate the outcomes after isolated nasal surgery in patients with OSA	Prospective cohort study	Statistically significant reduction in mean AHI, from 28.5 ± 22.3 to 18.5 ± 19.8 (p<0.001), and in mean RDI, from 32.3 ± 20.1 to 21.1 ± 17.7 (p<0.001). Patients with AR had a significantly better success rate compared with patients without AR (50.0 versus 3.8%, p=0.026); patients with moderate-to-severe nasal obstruction had a significantly better success rate compared with patients with mild obstruction (p=0.033)

Continued

Table 1: Continued

Author (year)	Study participants	Objective	Study design	Primary outcomes
Koutsourelakis et al. (2008)[16]	49 patients with OSA with DNS	To evaluate whether post-septoplasty improvement is associated with increased nasal breathing	Randomized controlled trial	4 of 27 patients who underwent septoplasty showed significant clinical improvement in AHI, with one patient demonstrating complete response (AHI <5). No statistically significant difference in AHI between surgery and sham groups. No significant difference in ESS between groups
Leitzen et al. (2014)[17]	59 patients with OSA	To determine whether a correlation exists between nasal anatomical obstruction and OSA	Prospective cohort study	Objectively assessed whether abnormal nasal anatomy was not found to be significantly correlated with PSG-measured OSA severity
Li et al. (2011)[18]	13 studies totalled 474 patients with OSA for nasal surgery	To evaluate the effect of nasal surgery alone in improving CPAP tolerance among patients with OSA	Systematic review and meta-analysis	The weighted mean AHI in nine studies did not significantly decrease; 35.2 ± 22.6 to 33.5 ± 23.8, p=0.69). The pooled success rate of nasal surgery in treating OSA was 16.7%. ESS scores in eight studies decreased from 10.6 ± 3.9 to 7.1 ± 3.7 (p<0.001)
Li et al. (2022)[19]	30 patients with OSA	To assess pre- and postoperative alterations of airflow characteristics using computational fluid dynamics	Retrospective chart review	The airflow velocity and pressure in both nasal and palatopharyngeal cavities, nasal and palatopharyngeal pressure differences and total upper airway resistance statistically decreased after nasal surgery
Magliulo et al. (2019)[20]	50 patients with OSA	To determine the nasal pathologies that are common among patients with OSA	Prospective observational study	70% of these patients demonstrating nasal obstruction were confirmed by clinical evaluation and rhinomanometry testing. The incidence of OSA in patients with a diagnosis of allergic rhinitis and non-allergic cellular rhinitis was 18 and 26%. A diagnosis of allergic rhinitis or non-allergic cellular rhinitis does not seem to correlate with OSA severity
Michalska et al. (2016)[21]	60 patients with nasal obstruction	To determine the impact of DNS on OSA	Prospective cohort study	OSA is present in 52.5% of cases. The most frequent cause of impaired nasal patency was nasal septum deviation, which was found in 82.5% of the patients
Miljeteig et al. (1992)[22]	683 patients with OSA	To determine whether nasal obstruction was correlated with OSA severity	Prospective observational study	No difference in OSA severity between patients with and without DNS
Moxness et al. (2014)[23]	59 patients with OSA	To evaluate the outcomes of nasal surgery alone in patients with OSA	Prospective observational study	There was a significant reduction in the AHI only in the group that had septoplasty with turbinate reduction, 17.4 ± 14.4 compared to 11.7 ± 8.2, p<0.01. This effect was significantly better than in the group treated with septoplasty alone
Moxness et al. (2016)[24]	93 patients with OSA and 92 controls	To compare objective measures of minimal cross-sectional area, nasal cavity volume and peak nasal inspiratory flow between patients with OSA and a group of healthy individuals	Prospective case–control study	The mean minimal cross-sectional area in the OSA group was smaller than that in controls (p<0.01). The mean nasal cavity volume was correspondingly smaller than that in controls (p<0.01). The peak nasal inspiratory flow was lower in the OSA group than in the control group (p<0.01)

Continued

Table 1: Continued

Author (year)	Study participants	Objective	Study design	Primary outcomes
Nguyen et al. (2021)[25]	8 studies including 228 patients	To assess how topical nasal treatments affect OSA outcomes	Systematic review and meta-analysis	Topical nasal sprays do not significantly impact AHI in adult patients with OSA, but they may improve minimum oxygen saturation, oxygen desaturation index, respiratory distress index and subjective quality-of-life measures in this population. Allergic patients may have more improvement in OSA measures with the use of topical nasal sprays when compared with nonallergic patients
Park et al. (2014)[26]	25 patients with OSA	To evaluate the outcomes of nasal surgery alone in patients with OSA	Prospective cohort study	AHI reduced from 23.9 ± 14.9 events per hour preoperatively compared with 12.2 ± 6.4 events per hour postoperatively ($p<0.05$) and RDI reduced from 28.8 ± 14.4 to 17.1 ± 7.5 ($p<0.05$)
Schoustra et al. (2022)[27]	21 studies including 727 patients	To determine whether isolated nasal surgery can improve OSA subjectively (ESS) and/or objectively (PSG)	Systematic review and meta-analysis	There was no significant reduction in the AHI after isolated nasal surgery in patients with OSA. The ESS was significantly lower after nasal surgery in 18 studies
Yeom et al. (2021)[28]	11,238 individuals with DNS and 22,476 controls (no DNS)	To determine whether there is an association between septal deviation and OSA diagnoses	Prospective case–control study	From long-term follow-up, the prevalence of OSA was 4.39 times higher in the septal deviation group compared with the control group. This phenomenon was more pronounced with increasing body mass index and decreased significantly after septoplasty
Wu et al. (2017)[29]	18 studies included	To determine the role of nasal surgery alone in treating OSA	Systematic review and meta-analysis	Statistically significant improvement in AHI with a WMD of 4.15 less events per hour following nasal surgery. Significant reduction in ESS with a WMD of -4.08

AHI = apnoea–hypopnoea index; AR = allergic rhinitis; CI = confidence interval; CPAP = continuous positive airway pressure; DNS = deviated nasal septum; ESS = Epworth Sleepiness Scale; h = hours; OSA = obstructive sleep apnoea; PAP = pulmonary arterial pressure; PSG = polysomnography; RDI = respiratory disturbance index; WMD = weighted mean difference.

specific echocardiogram parameters, including a statistically significant reduction in the E/e′ ratio, a marker of diastolic dysfunction when elevated, statistically significant improvement in right ventricular systolic myocardial function and tricuspid annular plane systolic excursion as summarized in *Table 2*.[32,33,36–39] Recent studies evaluated N-terminal pro-b-type natriuretic peptide (NT-proBNP), an inactive hormone that has been reported to provide information on cardiovascular disease and has shown to have a prognostic value in chronic heart failure, and found that it was elevated in those with septal deviation compared with controls.[39,41] After surgical correction of the DNS, NT-proBNP levels were significantly reduced.[39]

Other studies examined the impact DNS may have on pulmonary function more directly. Five studies examined the effects DNS has on pulmonary function tests (PFTs).[40,42,43,45] Of these, three found a significant increase in forced vital capacity and forced expiratory volume in 1 s in patients with postoperative septoplasty.[40,42,43] These findings of improved PFT outcomes were also seen with a reduction in inferior turbinates.[45] One study found a significant increase in tracheobronchial resistance among patients with DNS and a significant reduction in resistance following surgery.[44] This particular study did not find any functional residual capacity differences between the DNS population and control patients (*Table 2*). When extrapolating the above-mentioned findings to asthma, there is a more limited conclusion. Ahn et al. conducted a review of 8,865 patients and found that 44.8% of patients had DNS. They found no association between DNS and any general health problems apart from asthma.[46] A retrospective database study by You et al. examined 29,853 patients divided into those with and without DNS. They found that the hazard ratio for asthma in the DNS group was 2.43 (95% CI: 2.31–2.56) and the hazard ratio for asthma after septoplasty was 0.83 (95% CI: 0.75–0.93).[47] Interestingly, Jura-Szoltys et al. investigated the impact of performing a turbinate reduction using argon plasma coagulation on 47 patients and found that this technique decreased the prevalence of patients with insufficient bronchial asthma control from 79 to 4% with a significant reduction in nasal resistance (*Table 3*).[48]

Discussion

Inflammatory diseases of the upper and lower airways are known to impact one another. The unified airway theory is a concept that has been examined over the past 20–30 years and suggests that the nasal passages, paranasal sinuses, middle ear and lungs all exist as one functional unit. What is less clearly understood is the relationship between anatomical variations or abnormalities of the upper airway and the subsequent impact on the respiratory system as a whole. This review sought to identify the existing literature that investigates this question and to offer insight into clinically impactful interventions that may aid in patient care.

OSA is a multilevel disease with obstruction occurring most commonly at the velum but also at the level of the epiglottis, tongue base and oropharynx.[49] Each of these sites is a target for surgical correction, which has been shown to relieve obstruction and improve AHI and symptoms

Table 2: Studies investigated the effect of nasal anatomical abnormalities on cardiopulmonary functions[30,32–45]

Author (year)	Study participants	Objective	Study design	Primary outcomes
PAP				
Avcı et al. (2021)[32]	35 patients with moderate and severe DNS who underwent septoplasty	Investigate cardiovascular effects of septoplasty by comparing pre- and postoperative echocardiography findings in patients with DNS undergoing septoplasty	Prospective cohort study	The NOSE questionnaire scores, systolic PAP values and the E/e' ratios decreased significantly after septoplasty ($p<0.05$ for all), whereas no significant difference was found in other transthoracic echocardiography parameters ($p>0.05$)
Caglar et al. (2018)[33]	44 patients with obstructive septum deviation and 30 healthy individuals with no nasal-related problems	To study the cardiological functions of patients with obstructive septum deviation	Prospective case–control study	In the patient group with septum deviation, the PAP and the size of the right heart chambers were increased. Tricuspid annular plane systolic excursion, pulmonary acceleration time, ejection fraction and RV outflow tract-fractional shortening were found to be lower than those in the normal group
Fidan et al. (2011)[34]	51 patients with DNS and 35 controls who underwent septoplasty	To determine the effect of septoplasty on the PAP	Prospective case–control study	The mean preoperative PAP value of the study group was statistically significantly higher than that of the control group. There was a significant decrease in mean PAP 3 months after the operation
Kayapinar et al. (2019)[35]	32 patients with upper airway obstruction secondary to DNS who underwent septoplasty	To evaluate the effect of nasal septoplasty on atrial electromechanical features	Prospective cohort study	Upper airway obstruction secondary to DNS causes a significant increase in mean PAP and a significant delay in atrial conduction time, which improved after nasal septoplasty (6-month postoperation)
Luke et al. (1966)[30]	4 patients with severe nasopharyngeal obstruction	To observe cardiorespiratory complications	Observational study	Patients with severe nasopharyngeal obstruction have cardiorespiratory complications ranging from moderate cardiac enlargement and RV hypertrophy to cor pulmonale and pulmonary oedema
Ozkececi et al. (2016)[36]	25 patients with marked DNS and 27 healthy volunteers	To study the effect of septoplasty on PAP and RV function in DNS	Prospective case–control study	The mean PAP increased and right ventricular function worsened in patients with DNS. However, the mean PAP decreased and RV function tended to recover 3 months after septoplasty
Sahin et al. (2017)[37]	76 patients who underwent septoplasty	To determine whether septoplasty improves PAP and right heart functions in patients with DNS	Prospective cohort study	The mean PAP reduced and tricuspid annular-plane systolic excursion increased 3 months after surgery. The right heart functions improved postoperatively ($p<0.001$)
Simsek et al. (2018)[38]	58 patients with symptoms of nasal obstruction and snoring	To determine changes in RV myocardial functions at the tissue level before and after surgery in patients with DNS	Observational study	There was a significant decrease in pulmonary artery systolic pressure in the postoperative period ($p=0.001$). Postoperative peripheral arterial oxygen saturation values, measured at room temperature, also increased significantly ($p=0.001$). There was a significant improvement after surgery in RV systolic functions
Ulusoy et al. (2020)[41]	40 patients with a nasal obstruction for at least 1 year	To study the utility of NT-proBNP in demonstrating the probable negative effects of markedly DNS on cardiac function	Prospective cohort study	NT-proBNP level and pulmonary artery pressure are higher in patients with markedly nasal septal deviation compared with healthy individuals, which eventually improved after septoplasty. Pulmonary arterial pressure also increased in patients with markedly DNS

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Table 2: Continued

Author (year)	Study participants	Objective	Study design	Primary outcomes
Yigit et al. (2022)[39]	30 adult patients who underwent septoplasty due to DNS	To evaluate the impact of septoplasty on cardiopulmonary functions in patients with DNS	Prospective cohort study	The PAP significantly decreased in 3-month postoperative outcomes. There were also significant increases in trans-mitral early diastolic rapid filling, peak systolic velocity, tricuspid annular plane systolic excursion and right ventricle stroke volume
PFT				
Bulcun et al. (2010)[42]	14 patients with DNS and 20 controls who underwent septoplasty	To study the effects of septoplasty on PFT in patients with DNS	Prospective cohort study	The 8- to 12-week postoperative values of FEV1, FVC and PEFR percentages were significantly higher than preoperative values
Mandour et al. (2019)[43]	90 patients underwent septoplasty with turbinectomy due to nasal obstruction and sleep problems	To compare PSG and PFT before and after septoplasty	Prospective cohort study	The postoperative pulmonary function values; FVC, FEV1, PEFR and postoperative polysomnographic values and AHI, snoring index/hour and oxygen saturation were significantly higher than the preoperative values
Öğreden et al. (2018)[40]	53 patients with DNS	To determine whether septoplasty affects cardiopulmonary functions in patients with DNS	Prospective cohort study	The mean FVC, the mean FEV1 and the mean FEV1/FVC values were higher in 6-month postoperatively than preoperatively ($p<0.001$)
Schumann et al. (1981)[44]	247 patients with septal deviations and 387 patients without septal deformities	To study the effect of septal deviations on pulmonary function	Prospective case–control study	Comparative measurements of PFT before and after septal surgery showed a decrease in tracheobronchial resistance in 66.7% of the patients
Unsal et al. (2019)[45]	27 patients with bilateral persistent inferior turbinate hypertrophy without septal deviation	To evaluate the effects of the radiofrequency ablation of persistent inferior turbinate hypertrophy on nasal and PFT	Prospective cohort study	There was a statistically significant increase in the mean cross-sectional area and volume of the nose, FEV1, FVC, and PEFR of the patients after inferior turbinate ablation. The post-ablation visual analogue scale scores were significantly lower when compared with the pre-ablation scores

AHI = apnoea–hypopnoea index; DNS = deviated nasal septum; FEV1 = forced expiratory volume in 1 s; FVC = forced vital capacities; NOSE = Nasal Obstruction and Septoplasty Effectiveness Scale; NT-proBNP = N-terminal pro-b-type natriuretic peptide; PAP = pulmonary artery pressure; PEFR = peak expiratory flow rate; PFT = pulmonary function tests ; PSG = polysomnography; RV = right ventricular.

in the patient.[50] This review suggests that anatomical obstruction in the nasal cavity may provide another source of obstruction in certain patients. This correlation becomes less clear when looking at isolated nasal surgery for the treatment of OSA, which is best highlighted by the four meta-analyses discussed earlier.[7,12,27,29] While some of the literature cited reports statistically significant results, the clinical significance is less clear. The success of surgical interventions for OSA is traditionally defined as a >50% postoperative reduction in AHI and an AHI <20.[51] It

Table 3: Studies investigated the effect of nasal anatomical abnormalities on asthma

Author (year)	Study participants	Objective	Study design	Primary outcomes
Asthma				
Ahn et al. (2016)[46]	8,865 patients with DNS	To determine the association between DNS and general health problems	Retrospective database study	A significant association was found between obstructive DNS and asthma (odds ratio 2.648 [95% CI: 1.211–5.791])
Jura-Szoltys et al. (2014)[48]	47 patients with bronchial asthma and allergic rhinitis	To determine whether turbinate reduction may improve asthma symptoms	Prospective cohort study	Subjective improvement of nasal congestion 3 months after the procedure was observed in 87% of patients. Rhinomanometry showed 219 ± 19 cm^3/s increased flow. Insufficient bronchial asthma control decreased from 79% to 4%
You et al. (2022)[47]	29,853 individuals with or without septal deviation	To determine the incidence of asthma in the septal deviation group compared with the matched controls	Retrospective database study	The incidence of asthma was 2.43 times higher in the DNS group compared with the control group

CI = confidence interval; DNS = deviated nasal septum.

is unlikely that a modest decrease in AHI as described in these studies meets such criteria. Notably, however, all four of the meta-analyses report a significant decrease in ESS scores, which suggests that patients are attaining a noticeable, subjective improvement in their sleep quality, as the minimal clinically important difference for the ESS is estimated to be a change of 2–3 points.[52] While this change is positive, patient-reported outcome measures such as ESS are susceptible to placebo and bias, particularly in retrospective studies that do not include a control arm.

While AHI may not be demonstrably impacted by nasal obstruction, ventilatory burden, a novel metric, may be affected. This is a recently described measure that more accurately predicts long-term sequelae of OSA, such as all-cause or cardiovascular disease mortality, when compared with AHI.[53] Ventilatory burden is a breath-by-breath measure of inspiratory flow rate, which is independent of physiological consequences such as hypoxia similar to AHI. These findings suggest that OSA may have many components that are relevant to long-term OSA outcomes that are not accurately captured by AHI, such as decreased inspiratory nasal flow. Patients with OSA have reduced peak nasal inspiratory flow and increased nasal resistance compared with healthy controls.[11,24] Other studies have noted that decreased inspiratory flow is associated with particular sites of pharyngeal, tongue and epiglottic obstruction among patients with OSA and that reduction in nasal airway resistance also decreases resistance at the palatopharyngeal cavity.[9,19] A potential mechanism would be that improvement in inspiratory flow may improve the total ventilatory burden while reducing respiratory effort-related arousals that do not meet the criteria for apnoea or hypopnoea but still result in improved sleep quality and ESS.

Furthermore, though nasal surgery alone is not likely to provide a clinically significant improvement in a patient's AHI, it has been shown to provide benefits to CPAP tolerance. Increased CPAP tolerance following nasal surgery continues to be supported by literature published since the findings noted by Camacho et al. and others.[29,54,55] Kempfle et al. found that both septoplasty and rhinoplasty are cost-effective methods to improve CPAP tolerance when compared with non-surgical management.[56]

This review highlights the relationship between nasal anatomical obstruction and cardiopulmonary function, with numerous studies demonstrating an improvement in PFTs and PAP following surgical correction of nasal obstruction. While the studies cited are either of small sample size or population-based observational studies, their results do demonstrate the need for a mechanistic explanation of their findings. It has been suggested that long-term nasal obstruction as evident through septal deviation, for example, could increase nasal resistance creating reduced lung ventilation, resulting in hypoxia, hypercapnia, pulmonary vasoconstriction and increased intrathoracic pressure, causing increased pulmonary arterial pressure.[32] This mechanism has been described in children with adenotonsillar hypertrophy impacting cardiopulmonary function.[30,57] However, more studies will need to be performed to fully investigate this phenomenon and the mechanism behind these findings in adults with nasal anatomical abnormalities. In addition, one hypothesis is that relieving the nasal obstruction allows the nasal cavity to more effectively protect the lower airway. Physiologically, the nasal cavity acts as the primary entry point for inhaled air, providing a physical barrier from the distal airway.[1,58] An inability to protect the distal airway may lead to insufficiently warmed or humidified air or inflammatory agents entering into the lungs, causing bronchoconstriction and consequently decreased pulmonary performance.[59]

The impact of anatomical abnormalities in the nasal airway and its role in respiratory conditions remain largely understudied with data of varying quality. While the above-mentioned studies provide valuable insight into the benefits of nasal surgery for OSA and cardiopulmonary function, future areas of research should focus on producing high-quality studies that demonstrate the interplay between nasal anatomy and respiratory conditions. These studies should work to further elucidate the mechanisms by which the nasal airway impacts the distal airway.

Conclusion

This review highlights the relationship between nasal anatomy and respiratory pathology. While there are mixed data on the impact of nasal obstruction on OSA, surgical correction of that obstruction leads to a clear improvement in patient quality of life, CPAP tolerance and subjective sleep quality. Limited data suggest that nasal obstruction may play a significant role in the pathology of the distal airway and a negative impact on pulmonary and ultimately cardiac function. A comprehensive evaluation of the nasal airway is warranted in patients presenting with numerous respiratory conditions, including OSA, pulmonary hypertension and asthma. ❑

1. Flint PW, Haughey BH, Robbins KT, et al. *Cummings Otolaryngology-Head and Neck Surgery e-Book*. Elsevier Health Sciences, 2014.
2. Lin DC, Chandra RK, Tan BK, et al. Association between severity of asthma and degree of chronic rhinosinusitis. *Am J Rhinol Allergy*. 2011;25:205–8. DOI: 10.2500/ajra.2011.25.3613.
3. Bose S, Stevens WW, Li N, et al. Unified airway theory: Association of bronchiectasis and chronic rhinosinusitis. *J Allergy Clin Immunol*. 2016;137(Suppl.):AB284. DOI: 10.1016/j.jaci.2015.12.1176.
4. Rajan JP, Wineinger NE, Stevenson DD, et al. Prevalence of aspirin-exacerbated respiratory disease among asthmatic patients: A meta-analysis of the literature. *J Allergy Clin Immunol*. 2015;135:676–81. DOI: 10.1016/j.jaci.2014.08.020.
5. Stachler RJ. Comorbidities of asthma and the unified airway. *Int Forum Allergy Rhinol*. 2015;5(Suppl. 1):S17–22. DOI: 10.1002/alr.21615.
6. van Egmond MMHT, Rovers MM, Hannink G, et al. Septoplasty with or without concurrent turbinate surgery versus non-surgical management for nasal obstruction in adults with a deviated septum: A pragmatic, randomised controlled trial. *Lancet*. 2019;394:314–21. DOI: 10.1016/S0140-6736(19)30354-X.
7. Camacho M, Riaz M, Capasso R, et al. The effect of nasal surgery on continuous positive airway pressure device use and therapeutic treatment pressures: A systematic review and meta-analysis. *Sleep*. 2015;38:279–86. DOI: 10.5665/sleep.4414.
8. Clarenbach CF, Kohler M, Senn O, et al. Does nasal decongestion improve obstructive sleep apnea? *J Sleep Res*. 2008;17:444–9. DOI: 10.1111/j.1365-2869.2008.00667.x.
9. Genta PR, Sands SA, Butler JP, et al. Airflow shape is associated with the pharyngeal structure causing OSA. *Chest*. 2017;152:537–46. DOI: 10.1016/j.chest.2017.06.017.
10. Hisamatsu K, Kudo I, Makiyama K. The effect of compound nasal surgery on obstructive sleep apnea syndrome. *Am J Rhinol Allergy*. 2015;29:e192–6. DOI: 10.2500/ajra.2015.29.4254.
11. Hoel HC, Kvinnesland K, Berg S. Outcome of nasal measurements in patients with OSA–mounting evidence of a nasal endotype. *Sleep Med*. 2023;103:131–7. DOI: 10.1016/j.sleep.2023.01.028.
12. Ishii L, Roxbury C, Godoy A, et al. Does nasal surgery improve OSA in patients with nasal obstruction and OSA? A meta-analysis. *Otolaryngol Head Neck Surg*. 2015;153:326–33. DOI: 10.1177/0194599815594374.
13. Kerr P, Millar T, Buckle P, Kryger M. The importance of nasal resistance in obstructive sleep apnea syndrome. *J Otolaryngol*. 1992;21:189–95.
14. Kim ST, Choi JH, Jeon HG, et al. Polysomnographic effects of nasal surgery for snoring and obstructive sleep apnea. *Acta Otolaryngol*. 2004;124:297–300. DOI: 10.1080/00016480410016252.
15. Kim S-D, Jung D-W, Lee J-W, et al. Relationship between allergic rhinitis and nasal surgery success in patients with obstructive sleep apnea. *Am J Otolaryngol*. 2021;42:103079. DOI: 10.1016/j.amjoto.2021.103079.
16. Koutsourelakis I, Georgoulopoulos G, Perraki E, et al. Randomised trial of nasal surgery for fixed nasal obstruction in obstructive sleep apnoea. *Eur Respir J*. 2008;31:110–7. DOI: 10.1183/09031936.00087607.
17. Leitzen KP, Brietzke SE, Lindsay RW. Correlation between nasal anatomy and objective obstructive sleep apnea severity. *Otolaryngol Head Neck Surg*. 2014;150:325–31. DOI: 10.1177/0194599813515838.
18. Li H-Y, Wang P-C, Chen Y-P, et al. Critical appraisal and meta-analysis of nasal surgery for obstructive sleep apnea. *Am J Rhinol Allergy*. 2011;25:45–9. DOI: 10.2500/ajra.2011.25.3558.
19. Li L, Han D, Zang H, London NR. Aerodynamics analysis of the impact of nasal surgery on patients with obstructive sleep apnea and nasal obstruction. *ORL J Otorhinolaryngol Relat Spec*. 2022;84:62–9. DOI: 10.1159/000516243.
20. Magliulo G, Iannella G, Ciofalo A, et al. Nasal pathologies in patients with obstructive sleep apnoea. *Acta Otorhinolaryngol Ital*. 2019;39:250–6. DOI: 10.14639/0392-100X-2173.
21. Michalska J, Olszewski J. Polysomnographic evaluation of sleep apnea in patients with unilateral or bilateral impaired nasal patency. *Otolaryngol Pol*. 2016;70:31–7. DOI: 10.5604/00306657.1193067.
22. Miljeteig H, Hoffstein V, Cole P. The effect of unilateral and bilateral nasal obstruction on snoring and sleep apnea. *Laryngoscope*. 1992;102:1150–2. DOI: 10.1288/00005537-199210000-00009.
23. Moxness MHS, Nordgård S. An observational cohort study of the effects of septoplasty with or without inferior turbinate

reduction in patients with obstructive sleep apnea. *BMC Ear Nose Throat Disord*. 2014;14:1–5. DOI: 10.1186/1472-6815-14-11.
24. Moxness MHS, Bugten V, Thorstensen WM, et al. A comparison of minimal cross sectional areas, nasal volumes and peak nasal inspiratory flow between patients with obstructive sleep apnea and healthy controls. *Rhinology*. 2016;54:342–7. DOI: 10.4193/Rhino16.085.
25. Nguyen DK, Liang J, Durr M. Topical nasal treatment efficacy on adult obstructive sleep apnea severity: A systematic review and meta-analysis. *Int Forum Allergy Rhinol*. 2021;11:153–61. DOI: 10.1002/alr.22658.
26. Park CY, Hong JH, Lee JH, et al. Clinical effect of surgical correction for nasal pathology on the treatment of obstructive sleep apnea syndrome. *PLoS One*. 2014;9:e98765. DOI: 10.1371/journal.pone.0098765.
27. Schoustra E, van Maanen P, den Haan C, et al. The role of isolated nasal surgery in obstructive sleep apnea therapy—A systematic review. *Brain Sci*. 2022;12:1446. DOI: 10.3390/brainsci12111446.
28. Yeom SW, Kim MG, Lee EJ, et al. Association between septal deviation and OSA diagnoses: A nationwide 9-year follow-up cohort study. *J Clin Sleep Med*. 2021;17:2099–106. DOI: 10.5664/jcsm.9352.
29. Wu J, Zhao G, Li Y, et al. Apnea–hypopnea index decreased significantly after nasal surgery for obstructive sleep apnea: A meta-analysis. *Medicine*. 2017;96:e6008. DOI: 10.1097/MD.0000000000006008.
30. Luke MJ, Mehrizi A, Folger GM, et al. Chronic nasopharyngeal obstruction as a cause of cardiomegaly, cor pulmonale, and pulmonary edema. *Pediatrics*. 1966;37:762–8.
31. Ferris BG Jr, Mead JV, Opie LH. Partitioning of respiratory flow resistance in man. *J Appl Physiol*. 1964;19:653–8. DOI: 10.1152/jappl.1964.19.4.653.
32. Avcı D, Hartoka Sevinç A, Güler S. The systolic pulmonary artery pressure and the E/e’ ratio decrease after septoplasty in patients with grade 2 and 3 pure nasal septal deviation. *Braz J Otorhinolaryngol*. 2021;87:497–504. DOI: 10.1016/j.bjorl.2020.10.006.
33. Caglar O, Aksit E. Evaluation of heart functions with detailed echocardiogram in patients with septum deviation. *J Craniofac Surg*. 2018;29:2148–52. DOI: 10.1097/SCS.0000000000004742.
34. Fidan V, Aksakal E. Impact of septoplasty on pulmonary artery pressure in patients with markedly deviated septum. *J Craniofac Surg*. 2011;22:1591–3. DOI: 10.1097/SCS.0b013e31822e5e21.
35. Kayapinar O, Kaya A, Ozde C, et al. Evaluating the effect of nasal septoplasty on atrial electromechanical features. *Am J Otolaryngol*. 2019;40:179–82. DOI: 10.1016/j.amjoto.2018.12.007.
36. Ozkececi G, Akci O, Bucak A, et al. The effect of septoplasty on pulmonary artery pressure and right ventricular function in nasal septum deviation. *Eur Arch Otorhinolaryngol*. 2016;273:3747–52. DOI: 10.1007/s00405-016-4042-1.
37. Sahin MS, Ozmen OA, Yalcin MU. Does septoplasty improve heart functions of patients with septum deviation in terms of echocardiography findings *J Craniofac Surg*. 2017;28:1803–5. DOI: 10.1097/SCS.0000000000003814.
38. Simsek Z, Simsek E. Does nasal surgery affect right ventricular myocardial functions at the tissue level in patients with nasal septum deviation. *J Clin Med*. 2018;7:186. DOI: 10.3390/jcm7080186.
39. Yigit E, Manav A, Ture M, et al. The impact of septoplasty on cardiopulmonary functions in patients with nasal septal deviation: A prospective comprehensive analysis of echocardiographic outcome and serum N-terminal pro BNP levels. *J Craniofac Surg*. 2022;33:35–40. DOI: 10.1097/SCS.0000000000007801.
40. Öğreden Ş, Tansuker HD, Cengiz AB, et al. Effect of septoplasty on cardiopulmonary functions in the patients with nasal obstruction. *J Craniofac Surg*. 2018;29:e706–8. DOI: 10.1097/SCS.0000000000004955.
41. Ulusoy B, Tunçez A, Gül O, et al. NT-proBNP as a new marker in the investigation of nasal septum deviation impacts on cardiopulmonary functions. *Am J Otolaryngol*. 2020;41:102671. DOI: 10.1016/j.amjoto.2020.102671.
42. Bulcun E, Kazkayasi M, Ekici MA, et al. Effects of septoplasty on pulmonary function tests in patients with nasal septal deviation. *J Otolaryngol Head Neck Surg*. 2010;39:196–202.
43. Mandour YMH, Abo Youssef SM, Moussa HH. Polysomnographic and pulmonary function changes in patients with sleep problems after septoplasty with turbinectomy. *Am J Otolaryngol*. 2019;40:187–90. DOI: 10.1016/j.amjoto.2018.12.003.
44. Schumann K, Laniado K. [The influence of septum deviation on lung function (author's transl)] [Article in German]. *HNO*. 1981;29:6–9.
45. Unsal O, Ozkahraman M, Ozkarafakili MA, et al. Does the reduction of inferior turbinate affect lower airway functions? *Braz J Otorhinolaryngol*. 2019;85:43–9. DOI: 10.1016/j.bjorl.2017.10.007.
46. Ahn J-C, Lee WH, We J, et al. Nasal septal deviation with obstructive symptoms: Association found with asthma but not with other general health problems. *Am J Rhinol Allergy*. 2016;30:e17–20. DOI: 10.2500/ajra.2016.30.4277.
47. You YS, Kim JS, Jeong JS, et al. Septal deviation could be associated with the development of bronchial asthma: A nationwide cohort study. *J Allergy Clin Immunol Pract*. 2022;10:1099–101. DOI: 10.1016/j.jaip.2021.11.002.
48. Jura-Szołtys E, Ficek R, Ficek J, et al. Bronchial asthma control after argon plasma coagulation turbinectomy in patients with chronic rhinitis. *Eur Arch Otorhinolaryngol*. 2014;271:1581–7. DOI: 10.1007/s00405-013-2762-z.
49. Kezirian EJ, Hohenhorst W, de Vries N. Drug-induced sleep endoscopy: The VOTE classification. *Eur Arch Otorhinolaryngol*. 2011;268:1233–6. DOI: 10.1007/s00405-011-1633-8.
50. Won CHJ, Li KK, Guilleminault C. Surgical treatment of obstructive sleep apnea: Upper airway and maxillomandibular surgery. *Proc Am Thorac Soc*. 2008;5:193–9. DOI: 10.1513/pats.200708-121MG.
51. Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. *Sleep*. 1996;19:156–77. DOI: 10.1093/sleep/19.2.156.
52. Patel S, Kon SSC, Nolan CM, et al. The Epworth Sleepiness Scale: Minimum clinically important difference in obstructive sleep apnea. *Am J Respir Crit Care Med*. 2018;197:961–3. DOI: 10.1164/rccm.201704-0672LE.
53. Parekh A, Kam K, Wickramaratne S, et al. Ventilatory burden as a measure of obstructive sleep apnea severity is predictive of cardiovascular and all-cause mortality. *Am J Respir Crit Care Med*. 2023;208:1216–26. DOI: 10.1164/rccm.202301-0109OC.
54. Reilly EK, Boon MS, Vimawala S, et al. Tolerance of continuous positive airway pressure after sinonasal surgery. *Laryngoscope*. 2021;131:E1013–8. DOI: 10.1002/lary.28968.
55. Poirier J, George C, Rotenberg B. The effect of nasal surgery on nasal continuous positive airway pressure compliance. *Laryngoscope*. 2014;124:317–9. DOI: 10.1002/lary.24131.
56. Kempfle JS, BuSaba NY, Dobrowski JM, et al. A cost-effectiveness analysis of nasal surgery to increase continuous positive airway pressure adherence in sleep apnea patients with nasal obstruction. *Laryngoscope*. 2017;127:977–83. DOI: 10.1002/lary.26257.
57. Attia G, Ahmad MA, Saleh AB, et al. Impact of obstructive sleep apnea on global myocardial performance in children assessed by tissue Doppler imaging. *Pediatr Cardiol*. 2010;31:1025–36. DOI: 10.1007/s00246-010-9755-0.
58. Shin SH, Heo WW. Effects of unilateral naris closure on the nasal and maxillary sinus mucosa in rabbit. *Auris Nasus Larynx*. 2005;32:139–43. DOI: 10.1016/j.anl.2005.01.015.
59. Licari A, Castagnoli R, Denicolò CF, et al. The nose and the lung: United airway disease. *Front Pediatr*. 2017;5:44. DOI: 10.3389/fped.2017.00044.