



## Nasal Septal Deviation: Pathophysiology, Management Strategies, and Emerging Approaches in Functional Nasal Surgery

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### Abstract:

Nasal septal deviation (NSD) is among the most frequently encountered structural abnormalities of the facial skeleton and stands as a primary etiology of chronic nasal obstruction. Crucially, symptom severity is rarely a direct reflection of isolated septal anatomy; rather, nasal airflow is governed by a dynamic, intricate interplay between the septum, the inferior turbinates, and the internal nasal valve. This narrative review synthesizes contemporary evidence surrounding the pathophysiology, clinical diagnostics, and therapeutic strategies for NSD, emphasizing a paradigm shift from purely morphological correction toward functional restoration. Comprehensive clinical evaluation increasingly pairs validated subjective patient-reported outcome measures (PROMs), such as the Nasal Obstruction Symptom Evaluation (NOSE) scale, with objective physiological assessments, including rhinomanometry and acoustic rhinometry, though correlation between these modalities often remains modest. Therapeutic interventions span a wide spectrum, from targeted medical regimens managing mucosal inflammation to precise surgical frameworks, including conventional and endoscopic septoplasty, inferior turbinate reduction, nasal valve stabilization, and advanced extracorporeal reconstructions. Furthermore, emerging modalities such as computational fluid dynamics (CFD) modeling and bioabsorbable implants represent a clear movement toward highly individualized, precision-guided patient care. Ultimately, modern rhinology recognizes NSD not merely as a static anatomical deformity, but as a complex, multifactorial functional airway disorder demanding a combined physiological and structural treatment approach.

**Keywords:** Nasal septal deviation; nasal obstruction; septoplasty; functional nasal surgery; nasal airflow dynamics; cartilage remodeling

## Introduction:

The nasal septum is a sophisticated osseocartilaginous architecture that splits the nasal vault into dual respiratory pathways. Nasal septal deviation (NSD) denotes the displacement of this partition away from the median plane, acting as one of the most prevalent structural drivers of chronic nasal obstruction. While a baseline degree of septal asymmetry is nearly ubiquitous across human populations, it frequently exists silently without clinical consequence unless intranasal airflow mechanics are fundamentally disrupted. Consequently, modern rhinology cautions against viewing NSD as a purely macroscopic or incidental anatomical finding; its clinical significance is dictated entirely by the degree to which it narrows the functional airway, elevates resistance, and compromises the ease of nasal respiration. This discrepancy highlights why an obvious structural deformity visualized on physical examination does not reliably mirror a patient's subjective symptom burden or dictate an immediate mandate for surgical intervention [1, 2, 11].

Functionally, this structural impairment translates into the clinical symptom of nasal obstruction, yet the subjective perception of this blockage varies drastically among individuals presenting with identical anatomical deviations. Patients navigate this impairment through descriptions of persistent nasal blockage, air hunger, localized fullness, or a distressing sensation that inspired air cannot seamlessly pass through the nasal passages. Beyond simple respiratory resistance, associated secondary complaints frequently arise, including an impaired sense of smell, rhinogenic headaches, chronic rhinosinusitis symptoms, audible nocturnal or diurnal breathing, snoring, and fragmented sleep architecture. These clinical manifestations carry immense weight, as unhindered nasal respiration is intimately bound to systemic sleep quality and overall physical wellbeing, reinforcing the modern clinical concept that NSD must be managed as a functional airway disorder rather than a static anatomical variant [1, 2, 6, 8].

An expanding grasp of upper airway physiology has demonstrated that the symptoms attributed to a deviated septum are rarely the product of an isolated septal deformity. Instead, mechanical airflow limitation reflects a combined, fluid interaction between the septal framework, the turbinate structures, and the delicate nasal valves, blending fixed structural barriers with reactive mucosal elements. Over recent decades, the conceptualization of NSD has undergone a profound evolution, transitioning from the simplistic correction of a crooked wall toward a comprehensive appreciation of a multifactorial airway system. This narrative review explores the underlying pathophysiology, diagnostic nuances, and evolving non-surgical and surgical management paradigms of NSD, highlighting the technical advancements and functional methodologies driving modern airway restoration.

## Pathophysiology of Nasal Obstruction:

In a subset of the population, minor septal deviation represents a physiological variation that preserves balanced airflow dynamics and remains entirely asymptomatic. Congenital and developmental septal variations classically present as smooth, sweeping C-shaped or S-shaped contours that accommodate normal mucosal adaptation. In stark contrast, post-traumatic deviations are typically sharp, irregular, and disruptive to the surrounding cartilaginous memory, drastically increasing the likelihood of

functional airway breakdown [1]. Thus, the clinical boundary separating a benign anatomical variant from a pathological deviation relies less on cosmetic severity and more on the quantitative and qualitative disruption of respiratory dynamics.

Normal nasal respiration depends entirely on a synchronized, homeostatic relationship between the septum, the inferior turbinates, and the internal and external nasal valves. Together, these structures act as a functional unit to regulate airflow velocity, direct laminar currents, maintain appropriate airway resistance, and optimize the warming and humidification of inspired air. Because intranasal fluid dynamics are highly sensitive to microscopic structural shifts, even minor septal deflections can abruptly alter airflow distribution between the paired nasal cavities, setting off a cascade of respiratory physiology disruptions [1,13]. As cross-sectional area becomes increasingly asymmetrical, total airway resistance rises within the narrowed cleft, while highly turbulent, inefficient airflow patterns develop within both the compressed and contralateral cavities, fueling the subjective sensation of suffocation or obstruction.

The pathophysiology underlying NSD is therefore inherently multi-tiered, extending far beyond a localized structural block. While the deviated segment directly narrows the ipsilateral lumen, a secondary phenomenon, compensatory hypertrophy of the contralateral inferior turbinate, frequently develops within the wider nasal chamber as an adaptive mucosal and bony response to altered shear stress and asymmetric airflow. Though initially a compensatory effort to balance bilateral airway resistance, this progressive enlargement eventually leads to a secondary, fixed narrowing of the opposite side. This creates a complex paradigm of combined structural and mucosal obstruction rather than an isolated, single-sided septal pathology [1,2,6,13]. Given that the inferior turbinate is a major physiological regulator of warming, humidification, and cyclic vascular resistance, its secondary hypertrophy plays a massive role in the overall symptom profile.

Furthermore, nasal obstruction is a highly dynamic process, particularly at the junction of the internal nasal valve, which constitutes the narrowest bottleneck of the entire upper respiratory tract. Because the physics of this region are exceptionally sensitive to subtle structural collapse, even minor caudal or dorsal septal deflections, laxity of the upper lateral cartilages, or loss of surrounding fibrofatty soft-tissue support can amplify resistance exponentially during inspiration. This disrupted airflow architecture contributes not only to the subjective experience of a blocked nose, but also precipitates downstream issues like turbulent, audible breathing, olfactory cleft bypass, chronic sinus stasis, and sleep-disordered breathing [1,13,15].

This intricate cross-talk between septal geometry, turbinate volume, and nasal valve dynamics explains why clinical severity regularly decouples from the raw anatomical grade of the deviation. A patient with a minor anterior septal spur located precisely at the nasal valve may present with debilitating airway distress, whereas another individual with a large, posterior osseous deviation may remain entirely asymptomatic [1, 2, 13]. Consequently, modern diagnostic tracking and surgical execution have discarded isolated septal straightening in favor of a holistic approach that evaluates and treats the septum, turbinates, and nasal valve as a single, interdependent functional continuum [13, 15].

## Clinical Evaluation and Diagnosis:

While septal deviation represents one of the most common structural drivers of airway compromise among individuals presenting with sinonasal disease, its diagnostic workup must reconcile the fact that structural severity does not automatically dictate clinical impairment. For instance, tiny caudal deviations can cause profound distress due to their impact on the nasal valve, whereas extensive posterior bony deflections are often well-tolerated. For this reason, a meticulous clinical history and detailed symptom tracking form the foundational pillar of evaluation, as the patient's lived experience is inherently subjective and cannot be deduced through passive anatomical inspection alone [12].

To bridge this gap between perception and anatomy, objective diagnostic tools are frequently deployed. Rhinomanometry stands as a widely utilized objective modality, measuring transnasal pressure gradients alongside simultaneous airflow volume to calculate definitive airway resistance. Acoustic rhinometry offers a complementary structural mapping, utilizing reflected sound waves to chart cross-sectional areas and nasal volumes across specific longitudinal zones. Together, these diagnostic systems evaluate nasal patency through both physiological and structural lenses.

Nevertheless, a persistent challenge in rhinology is that these objective measurements do not always show a linear or robust correlation with patient-reported symptoms. Systematic evaluations of surgical outcomes have repeatedly demonstrated an intriguing divergence between postoperative airflow data and subjective obstruction relief, proving that objective metrics alone cannot serve as a solitary metric for symptom severity or surgical efficacy. To capture the true clinical impact, validated patient-reported outcome measures (PROMs), specifically the Visual Analogue Scale (VAS) and the disease-specific Nasal Obstruction Symptom Evaluation (NOSE) scale, have become standard practice. The NOSE scale offers a rigorous, reproducible, and highly sensitive tool to quantify preoperative airway distress and track postoperative quality-of-life improvements [12]. Ultimately, the most accurate diagnostic profile is achieved by carefully weaving together these subjective symptom patterns with objective physiological data.

Advanced diagnostic imaging occupies a highly selective, secondary role within the routine workup. Computed Tomography (CT) of the paranasal sinuses is typically reserved for complex revision cases, multiplanar surgical navigation planning, or when looking for concomitant sinonasal diseases, rather than serving as a primary tool to diagnose functional airway blockages [12]. This conservative utilization reinforces the clinical understanding that nasal obstruction is fundamentally a functional, dynamic disorder rather than a static radiological abstraction.

## Non-Surgical Management:

Non-surgical intervention for nasal obstruction primarily aims to manage the secondary inflammatory and mucosal components of the airway rather than the underlying structural deformity itself. Intranasal corticosteroids represent the frontline medical strategy, particularly when coexisting mucosal conditions like allergic or non-allergic rhinitis exacerbate airway narrowing. These topical agents are highly effective at reducing mucosal edema, suppressing inflammatory cascades, and restoring a degree of reversible tissue volume [14]. However, their therapeutic ceiling is low when

facing structurally driven obstruction like a heavily deviated bone or cartilage, as medical therapies possess no capacity to remodel fixed anatomical narrowing.

In a similar vein, oral antihistamines and systemic or topical decongestants provide transient, symptomatic relief in acute inflammatory or allergic states but offer negligible utility in pure structural deviations. A critical study by Gillman et al. systematically evaluated the impact of structured preoperative medical optimization, including dedicated courses of intranasal steroids, and found that it exerted no statistically significant influence on long-term surgical outcomes [14]. This underscores the reality that topical medical regimens function as anti-inflammatory adjuncts rather than direct correctors of structural pathology.

In clinical reality, nasal obstruction is rarely an isolated phenomenon; it typically thrives at the intersection of coexisting structural blockages and mucosal inflammation. Fixed barriers like NSD and turbinate hypertrophy routinely overlap with seasonal or perennial rhinitis, creating an additive compounding effect on total airway resistance. Crucially, rhinology literature has demonstrated that both highly allergic and non-allergic cohorts experience profound, equivalent symptomatic relief following definitive surgical correction of their structural deviations, irrespective of their baseline inflammatory background [14]. This finding highlights that while medical management is essential to stabilize the mucosal environment, structural surgical correction remains the dominant and necessary pathway to achieve true airway restoration when a fixed anatomical block is present.

#### Surgical Management:

##### Conventional Septoplasty

Septoplasty is the definitive surgical intervention for symptomatic NSD, designed to alleviate the mechanical resistance responsible for disrupted nasal airflow. Tracing its roots back to the classic descriptions by Cottle in 1947, the procedural objective centers on correcting or resecting the obstructive segments of the osseocartilaginous septum while rigorously safeguarding structural dorsal-caudal support and mucosal flap integrity. Over the past several decades, the philosophy guiding septal surgery has progressively shifted from radical, destructive cartilage excision toward a conservative, functional, and structurally targeted intervention focused on optimizing airflow dynamics rather than merely chasing a perfectly straight midline image on a screen [2, 11].

Traditional endonasal septoplasty remains highly effective for mild-to-moderate deformities localized to the mid or posterior septal body. In these clinical contexts, targeted intranasal incisions and limited chondro-osseous reshaping provide excellent airway clearance while leaving the primary nasal support beams untouched. However, deviations involving the critical caudal septum, dorsal margin, or the L-strut framework present a far more formidable surgical challenge, as these specific regions serve as the dual arbiters of functional internal valve patency and external cosmetic projection. Consequently, correcting deviations within these zones demands a delicate balance between aggressive structural straightening and the absolute preservation of long-term mechanical stability [2, 4, 11]. This clinical necessity prompted the development of diverse, tailored reconstructive adjuncts designed to reinforce rather than weaken the nasal architecture.

## Reconstructive Techniques and Endoscopic Approaches

To address these complex deformities, modern surgeons frequently integrate specific reconstructive techniques tailored to the precise location of the structural flaw. Strategic cartilage scoring allows the surgeon to break the intrinsic cartilage memory and guide physical remodeling, while the placement of precise spreader grafts widens a collapsed internal nasal valve and reinforces dorsal continuity. In cases marked by profound structural instability, advanced techniques such as septal extension grafts, lateral batten grafts, tongue-in-groove caudal fixation, or total septal replacement grafts are utilized to secure the midline framework. Furthermore, when compensatory inferior turbinate hypertrophy acts as a secondary block, a synchronous turbinate reduction is performed. This multifaceted toolkit represents a paradigm shift toward tailored, comprehensive airway reconstruction over isolated septal manipulation [2, 4].

Despite its widespread global performance, quantifying septoplasty outcomes historically suffered from significant heterogeneity. While subjective functional success is routinely tracked using standardized validation tools like the NOSE and VAS scores, and objective changes are followed via acoustic rhinometry or rhinomanometry, the lack of consistent correlation between these dual endpoints remains a challenge [2,5]. This persistent variability has driven modern clinical trials to center patient-reported functional quality-of-life metrics alongside structural corrections as the true baseline for defining surgical success.

The intrinsic limitations of traditional headlight-driven septoplasty, namely, restricted deep visualization, poor illumination, and difficult access to isolated posterior or superior deflections, catalyzed the birth of endoscopic septoplasty, popularized by Lanza and Zinreich in 1991. By bringing high-magnification, high-definition visualization directly into the nasal cleft, the endoscope allows the surgeon to perform highly targeted, minimal-access septal corrections while sparing healthy surrounding tissues from unnecessary trauma. A rigorous systematic review by Besharah et al., analyzing 13 randomized clinical trials encompassing 735 patients, demonstrated that the endoscopic approach yielded significantly lower rates of intraoperative and postoperative hemorrhage, reduced mucosal adhesion formation, fewer instances of residual deviation, shorter overall operative times, and an accelerated postoperative recovery curve compared to conventional methods [11]. These data suggest that while the long-term functional airway outcomes may ultimately converge between the two techniques, the true superiority of the endoscopic approach lies in its enhanced surgical precision and minimized perioperative morbidity.

### Open and Extracorporeal Reconstruction

While mild-to-moderate septal deviations are easily managed via closed endonasal or endoscopic routes, severe, multiplanar deformities that disrupt the primary structural integrity of the nose routinely require an open rhinoplasty or an extracorporeal approach. The open approach grants unparalleled, direct visualization of the dorsal and caudal margins, making it the preferred route when functional airway restoration must be performed in lockstep with complex external structural reconstruction [4]. This evolution reflects a growing realization that advanced septal deformities are

rarely isolated; they are frequently tied to the collapse or severe distortion of the entire midvault support system.

Extracorporeal septoplasty, pioneered by King and Ashley in 1952, represented a major milestone in the management of severe, crooked dorsal and caudal septal deformities [3,4,5]. This advanced technique involves the near-total temporary excision of the distorted septal cartilage matrix, which is then reconstructed, flattened, and structurally reinforced completely outside the patient on a sterile workbench before being re-implanted and anchored back into the midfacial framework. This method became a crucial tool for resolving severe congenital or post-traumatic crooked noses where traditional internal corrections consistently resulted in persistent blockages or early structural failure [3,4].

However, early iterations of extracorporeal septoplasty raised valid clinical concerns regarding a risk of postoperative dorsal collapse, supratip depression, or disruption of the critical bony-cartilaginous keystone zone. To safeguard against these structural pitfalls, the technique underwent extensive modern refinements. Contemporary protocols emphasize subtotal resection styles that preserve a protective bridge at the keystone area, secure transosseous structural fixation, utilize protective bilateral spreader grafts, and incorporate bioabsorbable polydioxanone (PDS) plates as a temporary scaffold for the newly built cartilage wall [3,4,5]. These structural enhancements are specifically designed to maximize long-term mechanical stability while eliminating classic risks like graft warping, recurrent deviation, or airway collapse.

The published literature evaluating modern extracorporeal septoplasty demonstrates highly favorable subjective symptom relief and objective airflow metrics, paired with excellent cosmetic stability, including refinements in the nasolabial angle, nasofrontal alignment, and tip projection [3,5]. Nonetheless, because of the extensive nature of the dissection, complications such as septal perforations, partial graft resorption, localized hematomas, infections, or minor residual deviations can still occur, though their reported rates remain low in expert hands [3, 4, 5]. It must be noted, however, that current conclusions are somewhat constrained by a predominance of retrospective study models, diverse outcome tracking methodologies, and variable long-term follow-up windows. Moving forward, extracorporeal septoplasty remains an indispensable tool for severe structural deviations that lie beyond the reach of standard closed or endoscopic approaches, with ongoing technical iterations continuously improving both structural stability and functional success.

#### Inferior Turbinate Hypertrophy and Radiofrequency Ablation

Inferior turbinate hypertrophy represents a powerful secondary contributor to functional nasal airway obstruction. Under normal physiological conditions, the inferior turbinate acts as a dynamic radiator, constantly adjusting its vascular volume to regulate inspired airflow, humidify mucus, warm cold air, and filter particulate matter. In the presence of a chronic nasal septal deviation, a predictable compensatory hypertrophy routinely develops within the wider, contralateral nasal vault as a chronic tissue response to altered airflow shear stress and increased air micro-currents. Although initially an adaptive effort to normalize total nasal resistance, this progressive mucosal and bony overgrowth

eventually crosses a pathological threshold, narrowing the patent side and leaving the patient with a severe, paradoxically bilateral nasal obstruction [6, 13].

Therapeutic management is strictly dictated by whether the turbinate enlargement is primarily mucosal-inflammatory, purely structural-osseous, or a mixed manifestation. Initial management emphasizes structured medical regimens, such as intranasal corticosteroids, topical or oral antihistamines, and environmental control strategies aimed at reducing mucosal congestion. However, when a fixed structural or dense hypertrophic blockage persists despite exhaustive medical therapy, surgical reduction is indicated. Crucially, modern turbinate surgery has completely abandoned radical, destructive tissue clipping, shifting instead toward conservative, volume-reducing techniques that maximize airway clearance while scrupulously preserving the delicate overlying respiratory mucosa and its essential physiological properties [13].

Currently, a diverse array of surgical modalities is deployed, ranging from radiofrequency ablation (RFA), submucosal microdebrider resection, and conservative turbinoplasty to partial turbinectomies and laser-assisted reductions. Less invasive, mucosa-preserving interventions are intentionally prioritized to maintain normal warming and humidification functions while lowering baseline airway resistance. Conversely, aggressive or radical tissue resections achieve vast structural patency at the strict expense of normal nasal physiology. Current evidence heavily favors conservative, functional, submucosal approaches over radical tissue excision, as excessive turbinate removal can permanently disrupt normal laminar airflow, leading to debilitating long-term complications like chronic mucosal crusting, persistent dryness, paradoxical nasal obstruction, and the devastating clinical entity known as Empty Nose Syndrome [6, 13].

Radiofrequency ablation (RFA) has emerged as a premier, minimally invasive technique for treating inferior turbinate hypertrophy that has failed medical management. It achieves highly localized volume reduction while carefully insulating the overlying mucosal lining and its ciliary clearance mechanisms [13]. The procedure works by delivering precisely regulated, low-temperature radiofrequency thermal energy directly into the submucosal deep tissue via a specialized probe inserted at multiple targeted spots along the turbinate body. This targeted thermal injury induces localized coagulation necrosis, leading to deep tissue fibrosis, vascular thrombosis, and gradual scar contraction over subsequent weeks, effectively shrinking the turbinate volume while leaving the surface mucosa and underlying bone intact [13]. Prospective clinical studies consistently demonstrate significant post-procedural improvements in both subjective patient symptoms and objective airflow data, marked by drops in longitudinal NOSE scores and corresponding elevations in Peak Nasal Inspiratory Flow (PNIF) metrics, particularly during the early postoperative window [13]. While long-term outcomes over multiple years show a tendency to match the efficacy of other submucosal reduction techniques, and minor symptom recurrence can occasionally transpire based on individual patient exposures, RFA remains a highly effective, mucosa-preserving first-line option. It offers an ideal clinical compromise between immediate symptom relief and the preservation of long-term nasal function [13].

Turbinate reduction is most frequently performed as a synchronized adjunct to primary septoplasty, especially when managing a clear compensatory hypertrophy opposite a major septal deflection. This

combined surgical approach demonstrates excellent results, yielding concurrent drops in subjective obstruction scoring and marked improvements in objective airflow values. However, objective physiological parameters do not always show a tight statistical correlation with a patient's self-reported level of breathing comfort, highlighting the deeply subjective and multifactorial nature of nasal airway perception [6, 13]. Additionally, a notable subset of patients achieves completely adequate airway relief through isolated septoplasty alone as the contralateral turbinate naturally adapts over time. This suggests that turbinate surgery should not be performed as a mandatory, blanket addition to every septoplasty, but should instead be highly tailored based on exact pre-operative structural and functional findings.

While the vast majority of modern turbinate reduction techniques demonstrate highly favorable short- and intermediate-term clinical outcomes, a clear long-term clinical superiority of one specific method over another has not been definitively established. Furthermore, while combining a turbinate reduction with a septoplasty may slightly elevate immediate perioperative risks, such as self-limiting postoperative epistaxis, localized crusting, or temporary synechiae formation, the overall complication rates remain low [6]. Consequently, inferior turbinate intervention is best utilized as a highly selective, customized adjunctive procedure integrated into a holistic airway management strategy rather than a routine addition to septal surgery.

#### Nasal Valve Surgery

The internal nasal valve comprises the tightest structural segment of the entire intranasal airway, exerting a massive effect on total respiratory resistance according to Poiseuille's law. Because the physics of this small region are so unforgiving, even microscopic narrowing or structural weakness within this boundary can trigger severe, symptomatic airway blockages. Nasal valve dysfunction typically manifests in two distinct forms: a static insufficiency characterized by fixed anatomical narrowing of the valve angle, or a dynamic insufficiency where the lateral nasal wall lacks sufficient cartilaginous stiffness and collapses inward under the negative pressure of normal or forced inspiration [13, 15].

Surgical intervention at the nasal valve is typically indicated when a patient continues to experience significant airway obstruction despite the successful correction of a coexisting septal deviation, turbinate hypertrophy, or chronic inflammatory disease. The primary objective of valve surgery is to restore optimal cross-sectional patency and structurally reinforce the lateral nasal wall, enhancing airflow capacity while preserving natural external aesthetics and structural continuity [13].

A variety of elegant surgical techniques are currently used, each designed to address the specific mechanism causing the valve failure. Flaring sutures work by physically widening the internal valve angle through the lateral suspension of the upper lateral cartilages to the dorsal framework, whereas structural spreader grafts directly expand the cross-sectional area of the valve while restoring dorsal width. When dynamic lateral wall collapse is the primary driver, structural batten grafts are commonly placed to structurally reinforce weak lower or upper lateral cartilage zones, preventing inward collapse

during inspiration [15]. Selecting the ideal technique requires a meticulous pre-operative breakdown of the patient's anatomy, distinguishing between static narrowness and dynamic tissue laxity.

Contemporary clinical trials demonstrate substantial improvements in both patient-centered symptom tracking and objective airflow parameters following targeted nasal valve surgery. Studies consistently report dramatic drops in post-procedural NOSE scores alongside measurable improvements in rhinomanometry data and overall airflow velocity [13, 15]. However, establishing definitive comparative superiority between specific valve techniques remains challenging due to a lack of standardization in patient enrollment, heterogeneous surgical styles, and varied outcome reporting methods. Much like turbinate surgery, long-term subjective improvements can occasionally plateau over extended follow-up, causing the long-term outcomes of different valve interventions to eventually match.

Crucially, an increasing appreciation for the nuances of nasal valve dysfunction has driven a major shift in modern rhinological surgery away from isolated septal straightening toward a comprehensive, airway-first philosophy. Persistent, unresolved symptoms following a technically perfect septoplasty are frequently traced back to a previously undiagnosed or unaddressed nasal valve compromise. This reality underscores the absolute necessity of conducting a rigorous, functional evaluation of the valve region during every single preoperative assessment [8, 13, 15].

#### Revision Septoplasty

Revision septoplasty is indicated for patients dealing with persistent or recurrent nasal airway obstruction following a prior septal intervention. This secondary procedure is universally recognized as technically demanding and intricate compared to primary surgery due to the inevitable presence of dense submucosal scar tissue, altered tissue planes, distorted anatomical landmarks, and a significantly compromised local vascular supply [8, 9]. Surgical dissection through these scarred fields requires meticulous care, particularly when the patient has a history of aggressive cartilage resection or presents with significant structural collapse.

The structural flaws responsible for persistent failure after primary surgery most commonly involve the highly complex dorsal, caudal, and posterior bony segments of the septum. Large-scale clinical evaluations demonstrate that residual dorsal septal deviations are present in approximately 92% of all revision entries, followed by residual bony septal deformities in 79%, and direct caudal septal distortions in 72% of patients requiring a secondary operation [9]. These precise zones carry immense functional weight due to their direct structural relationship with the internal and external nasal valves, explaining why persistent or uncorrected deformities here result in severe, unyielding airway obstruction.

Corrective measures during revision surgery include the meticulous excision of remaining bony spurs, the placement of structural spreader grafts to restore midvault patency, cartilage traction or cross-suturing techniques to re-align the midline, and comprehensive reconstruction of the nasal valve region [9]. Prospective clinical trials have confirmed that appropriately selected patients experience significant, measurable improvements in their validated symptom and quality-of-life scores following

revision surgery, establishing it as a highly successful intervention when executed with precision [8,9]. Nonetheless, these secondary operations remain highly technically demanding, and the final clinical outcome is heavily influenced by the severity of the remaining deformity and the degree of tissue destruction left behind by the primary surgeon.

### Pediatric Septoplasty

Historically, pediatric septoplasty was approached with extreme caution or routinely delayed until adulthood due to a deeply held concern that any surgical manipulation of the cartilaginous septum could disrupt primary midfacial growth centers, leading to permanent craniofacial retrusion or severe dental malocclusions. However, modern pediatric rhinology evidence has fundamentally challenged this dogmatic delay, increasingly supporting carefully executed, conservative pediatric interventions when a child suffers from severe, debilitating functional airway obstruction. A landmark study by Ryan Bishop et al. conclusively demonstrated that pediatric septoplasty can be performed with an exceptional safety profile in children presenting with high-grade functional blockages, severe post-traumatic deformities, or progressive septal deviations [10].

Early, conservative surgical correction in appropriately screened pediatric candidates has been shown to rapidly restore normal nasal respiration, optimize nocturnal sleep quality, and dramatically improve overall childhood quality of life. Furthermore, timely intervention may play a preventative role, protecting the developing child from the well-documented, adverse long-term craniofacial and orthodontic consequences associated with chronic mouth-breathing and prolonged pediatric nasal obstruction. As a result of these findings, pediatric airway management has shifted away from a rigid, age-restricted delay toward an individualized, functional approach dictated by the severity of the child's clinical symptoms and anatomical impairment.

### Empty Nose Syndrome

Empty Nose Syndrome (ENS) represents a rare but profoundly debilitating iatrogenic complication that typically arises from excessive, over-aggressive surgical resection of the inferior or middle turbinates. Despite presenting with an anatomically wide-open, low-resistance nasal cavity on physical examination, these patients experience a severe, paradoxical sensation of complete nasal suffocation, paired with debilitating mucosal dryness, chronic crusting, loss of normal temperature perception, and a deeply distressing disruption of normal airflow sensation [8].

The clinical reality of ENS has served as a powerful catalyst for change within modern rhinology, driving a major shift away from destructive tissue ablation toward conservative, mucosa-preserving submucosal reductions. Rigorous preservation of normal turbinate micro-anatomy and its complex relationship with laminar airflow dynamics is absolutely essential to minimize these catastrophic functional failures and protect normal respiratory homeostasis.

### Bioabsorbable Implants

The contemporary literature analyzed within this review provides limited high-level evidence regarding the role of bioabsorbable implants in the management of nasal obstruction. None of the

included primary clinical trials or systematic reviews provide definitive data regarding their long-term efficacy, extended safety profiles, long-term complication rates, or clear comparative performance against time-tested, traditional cartilage grafting techniques. In modern rhinology practice, these synthetic bioabsorbable implants are occasionally used as a temporary lateral wall scaffold in select cases of severe internal nasal valve collapse, aiming to provide mechanical support and prevent dynamic collapse throughout the active postoperative healing window.

However, the proposed clinical benefits of these synthetic implants remain largely theoretical at this stage, with insufficient data to establish definitive surgical indications or prove a durable functional superiority over autologous reconstructive methods [6, 13, 15]. Consequently, within the current framework of functional nasal surgery, bioabsorbable implants must be classified as an emerging, unproven adjunct rather than a validated standard of care.

#### Outcomes, Complications, and Failures:

##### Quality of Life and Symptomatic Outcomes

The primary clinical objective of septoplasty is to alleviate chronic nasal obstruction and restore a patient's daily quality of life. Contemporary evidence demonstrates a high rate of subjective symptom relief following surgery, particularly regarding improved ease of nasal respiration and overall patient satisfaction. A comprehensive evaluation by Tsang et al. highlighted post-septoplasty patient satisfaction rates ranging from 69% to 100%, with approximately 88% of individuals reporting moderate to excellent satisfaction at their one-year postoperative milestone [7]. Multiple clinical trials utilizing validated patient-reported outcome measures (PROMs) have confirmed substantial, long-lasting postoperative drops in airway distress and corresponding boosts in functional wellbeing.

However, outcomes remain inherently variable, and septoplasty cannot be viewed as a universally guaranteed cure. A distinct subset of patients continues to struggle with persistent or recurrent airway obstruction despite a technically perfect, midline septal correction [7]. This clinical variation underscores the multifactorial nature of nasal obstruction, where a patient's symptoms are frequently driven by a complex combination of septal deflection, turbinate overgrowth, unrecognized nasal valve collapse, mucosal hyper-reactivity, or altered neurological airflow perception, rather than a single, isolated septal bend. Consequently, modern outcome assessment has moved away from purely structural alignment toward patient-centered quality-of-life markers as the true baseline of surgical success.

##### Short-Term and Long-Term Outcomes

The vast majority of clinical trials demonstrate a substantial, swift improvement in subjective and objective metrics during the early postoperative phase, a window that correlates with a steep drop in raw transnasal airflow resistance. However, the long-term durability of this initial symptomatic benefit over an extended multi-year follow-up period remains less predictable. Long-term tracking by Tsang et al. revealed that subjective patient satisfaction scores can experience a gradual decline over time in certain patient cohorts, serving as a reminder that early postoperative success does not automatically translate into a permanent lifetime cure [7].

Interpreting long-term outcomes across the rhinology literature remains challenging due to widespread heterogeneity in surgical styles, variable follow-up durations, and a lack of standardized outcome reporting metrics across different institutions. Furthermore, much of the available long-term data is derived from observational cohorts, with a scarcity of rigorous, randomized long-term comparative trials. This data gap has reinforced the critical role of validated PROMs, such as the NOSE scale, for conducting meaningful, longitudinal trackings of surgical efficacy over time [7]. Ultimately, while short-term airway relief is consistently achieved across the literature, long-term durability is more variable, heavily dependent on precise patient selection, the choice of surgical technique, coexisting airway pathologies, and the natural progression of underlying mucosal disease over time.

#### Failure Rates and Persistent Obstruction

Persistent nasal obstruction following a primary septoplasty remains a primary driver of patient dissatisfaction and a leading cause for revision surgery. Reported success rates for primary septoplasty span a wide spectrum from 43% to 85%, leaving an estimated 15% of patients experiencing minimal to no subjective symptom relief following their operation [8]. These data highlight the reality that surgical failure is an ongoing challenge in rhinology, despite septoplasty being one of the most frequently performed functional airway procedures worldwide.

A variety of distinct factors contribute to this failure rate. Incomplete or inadequate correction of the primary septal deviation remains a common culprit, particularly when the original surgeon fails to fully resolve complex deflections localized to the critical caudal or dorsal margins [8]. However, overlooked or undiagnosed nasal valve collapse, residual or recurrent inferior turbinate hypertrophy, uncontrolled allergic rhinitis, and progressive postoperative septal cartilage warping also play massive roles in driving persistent symptoms. An increasing awareness of these overlapping pathologies has fundamentally transformed modern functional nasal surgery, shifting the specialty away from isolated septal straightening toward a comprehensive, multi-level evaluation of the entire nasal airway.

#### Advancements and Future Directions:

The management of nasal septal deviation is rapidly moving away from a rigid, anatomy-only model toward a highly nuanced, individualized, and patient-centered framework of care. Rather than focusing solely on flattening a crooked structure, modern functional nasal surgery prioritizes the restoration of physiological airflow dynamics and the strict preservation of normal respiratory homeostasis. This conceptual evolution reflects a growing recognition that clinical nasal obstruction is rarely an isolated event; it is a multi-layered process driven by the dynamic cross-talk between septal geometry, turbinate volume, nasal valve stability, and underlying mucosal inflammation [6, 13, 15].

Among the most promising technological advancements in this field is the integration of Computational Fluid Dynamics (CFD). CFD utilizes advanced computer-based modeling and fluid mechanics equations to map out exact airflow patterns, localized pressure drops, shear wall stresses, and air ventilation characteristics within a specific patient's unique CT-derived nasal anatomy [1]. This virtual modeling has demonstrated that patients presenting with macroscopically identical septal deviations can experience completely different intranasal fluid dynamics and symptom profiles. In the

coming years, CFD modeling may allow surgeons to virtually simulate alternative surgical steps, such as a specific septal adjustment, turbinate reduction, or valve graft, preoperatively, predicting postoperative airflow improvements before making an incision. However, current data emphasize that CFD should function as an advanced, high-tech complement to, rather than a replacement for, classic clinical diagnostics, comprehensive history taking, detailed nasal endoscopy, and validated patient symptom scales [1,13,15].

Patient-specific surgical planning has established itself as an essential tenet of modern functional nasal surgery. Contemporary rhinology literature has made it clear that no single, standardized surgical combination can be universally applied to all patients. Structured evaluations of septoplasty combined with targeted maneuvers, such as radiofrequency turbinate ablation, submucosal turbinectomy, or functional valvuloplasty, have demonstrated clear subjective and objective success across multiple distinct approaches, confirming that the surgical plan must be meticulously customized to the patient's precise anatomical blockages and symptom profile [13]. Similarly, a deep appreciation for the role of the nasal valve has cemented the necessity of conducting a rigorous airway assessment prior to entering the operating room [15].

Data from revision studies further underscore the vital importance of this individualized planning and thorough preoperative screening. Persistent airway failure after primary surgery is overwhelmingly tied to uncorrected caudal or dorsal deflections, missed nasal valve insufficiency, unaddressed turbinate overgrowth, or unmanaged inflammatory mucosal disease [8, 9]. Consequently, an accurate, multi-level breakdown of every single factor contributing to a patient's obstruction is the single most effective way to minimize surgical failures and elevate long-term patient satisfaction.

Concurrently, minimally invasive and tissue-preserving modalities continue to expand their clinical footprint. Endoscopic septoplasty has raised the bar for surgical precision, offering high-magnification visualization that allows for selective, target-specific deviations to be resolved while minimizing overall tissue trauma and lowering classic rates of hemorrhage, postoperative adhesions, mucosal tears, and residual deformities [11]. In the same manner, radiofrequency turbinate reduction has earned widespread popularity because it achieves meaningful volume reduction while protecting the physiological integrity of the mucosal surface [13]. Balloon-assisted septoplasty has also emerged as a minimally invasive alternative, though current data remain sparse and insufficient to draw definitive, long-term comparisons against established, time-tested septoplasty frameworks [11, 13].

Importantly, this surge in minimally invasive technology has not eliminated the need for advanced, open structural reconstructions. High-grade caudal deflections, severe dorsal subluxations, and complex L-strut fractures continue to demand the exposure and reconstruction provided by open rhinoplasty or extracorporeal septoplasty [3, 5, 8]. Thus, technological innovation serves to expand the surgeon's choices, allowing conservative tools to be deployed for minor blockages while reserving complex reconstructive surgery for severe structural collapses.

Targeted biologic therapies are also poised to emerge as a powerful supportive adjunct for patients dealing with profound, systemic inflammatory mucosal disease. While these advanced monoclonal

antibodies have no capacity to remodel a fixed structural bone or cartilage deviation, they hold immense promise for stabilizing a hyper-reactive mucosal lining that would otherwise compromise a surgical result [1,14]. Contemporary evidence strongly advocates for the continuation of tailored medical therapies even after a successful surgical airway correction, reinforcing the core clinical truth that nasal obstruction is routinely a combined structural and inflammatory condition requiring a multi-modal management strategy [14].

Ultimately, the future progress of functional nasal surgery depends entirely on the design and execution of more rigorous, highly standardized research methodologies. The current rhinology literature continues to be limited by a high degree of heterogeneity in surgical execution, short or highly variable follow-up timelines, and inconsistent outcome reporting formats [2, 15]. A significant portion of studies evaluating functional rhinoplasty and advanced nasal valve techniques remain purely observational, lacking long-term, randomized comparative data [15]. To establish true evidence-based guidelines, future clinical trials must routinely combine validated subjective PROMs like the NOSE scale alongside precise, objective physiological parameters, including PNIF, acoustic rhinometry, and rhinomanometry [2,6,13]. Securing longer follow-up windows, keeping transparent tracking of revision rates, and standardizing global outcome metrics will be the essential steps required to build highly reliable, precision-guided treatment algorithms for functional nasal surgery.

#### Conclusion:

Nasal septal deviation must no longer be managed as an isolated, static structural deflection, but rather as a core component of a broader functional airway disorder shaped by a dynamic interaction between the osseocartilaginous septum, the inferior turbinates, the nasal valves, and the surrounding mucosal lining. This multifactorial nature explains the frequent mismatch observed between macroscopic anatomical severity and a patient's subjective symptom burden, highlighting the need for a comprehensive functional and physiological assessment during both diagnostic workup and surgical planning. A purely morphological approach focused on flattening a structure on a screen is insufficient to achieve true respiratory restoration.

Contemporary evidence strongly supports a structured, stepwise, and highly individualized treatment paradigm. Focused medical management remains indispensable for optimizing the mucosal environment and controlling secondary inflammatory edema, but it lacks the capacity to correct a fixed structural barrier. For symptomatic individuals, customized surgical intervention, centering on a precise septoplasty paired with highly selective adjunctive procedures, remains the gold standard of care. However, long-term outcomes are highly variable and easily compromised by unaddressed secondary factors like turbinate hypertrophy or nasal valve insufficiency, reinforcing the mandate for a complete, multi-level preoperative evaluation.

The future of NSD management lies at the intersection of precision medicine and function-oriented surgery. Technical breakthroughs such as high-definition endoscopic techniques, targeted nasal valve stabilization, and virtual computational fluid dynamics modeling reflect an industry-wide commitment to prioritizing airflow physiology over static anatomy. Nonetheless, current literature

limitations, namely, heterogeneous outcome tracking and a lack of randomized, long-term comparative data, continue to restrict definitive conclusions regarding the superiority of specific surgical techniques. Overcoming these methodological variations and systematically weaving together objective physiological metrics with patient-reported quality-of-life outcomes will be the essential pathway forward to optimize clinical decision-making and secure durable, long-term results for the airway patient.

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Abbreviations:

- **NSD:** Nasal Septal Deviation
- **PROMs:** Patient-Reported Outcome Measures
- **NOSE:** Nasal Obstruction Symptom Evaluation
- **VAS:** Visual Analogue Scale
- **CFD:** Computational Fluid Dynamics
- **RFA:** Radiofrequency Ablation
- **PNIF:** Peak Nasal Inspiratory Flow
- **ENS:** Empty Nose Syndrome