



Advances in Rhinoplasty: Techniques, Outcomes, and Evolving Approaches

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Abstract:

Rhinoplasty is one of the most commonly performed facial plastic surgical procedures and has evolved significantly over recent decades from a primarily cosmetic operation to a more functional, patient-centred and evidence-based procedure. Modern rhinoplasty focuses not only on aesthetic refinement, but also on airway preservation, functional restoration and individualized surgical planning. This review discusses the fundamentals of rhinoplasty including open and closed techniques, osteotomies, grafting methods and dorsal preservation approaches, along with associated complications and revision surgery. Current evidence regarding patient-reported outcome measures, particularly the Rhinoplasty Outcome Evaluation (ROE) scale, highlights the increasing importance of patient satisfaction and functional outcomes in determining surgical success. Technological advances such as piezosurgery, artificial intelligence (AI), machine learning and 3D simulation have further transformed rhinoplasty planning and perioperative management by improving precision, visualization and patient communication. Despite these developments, limitations remain regarding long-term evidence, cost-effectiveness and standardized outcome reporting. Overall, rhinoplasty continues to progress towards a more predictable, minimally invasive and personalized procedure driven by both technological innovation and patient-centred care.

Keywords: Rhinoplasty; nasal surgery; functional rhinoplasty; aesthetic rhinoplasty; open rhinoplasty; preservation rhinoplasty

Introduction:

Rhinoplasty is the surgical manipulation of the nose, primarily for aesthetic perfection and airway preservation. Historically, it was developed to serve a purely cosmetic purpose as a means for aesthetic improvement, however, recently there has been a gradual shift towards a patient-centered, functional, and evidence-based procedure. This shift was driven by the rising patient needs for better breathing, as observed by various studies analysing rhinoplasty approaches' endpoints. Additionally, multiple meta-analyses provided evidence and optimised evaluating tools, helping drive rhinoplasty in the direction of dorsal preservation and refined septoplasty [1, 2]

Reliable evidence has been minimal in rhinoplasty, staying around 5%, though the technique has undergone drastic and dynamic improvements over the past decade in the aspect of diagnostics, pre and post-operative outcomes and techniques. Significantly, in the past, dorsal hump removal was focused on, even occasionally at the cost of nasal valve integrity, and long-term contour regularity. With advances in Preservation Rhinoplasty (PR), the focus has shifted to maintaining dorsal and keystone anatomy while stabilizing airway function and achieving natural lines. Additionally, the indications for surgery have also seen change to the guidelines, as a result of the recent surge of patient-reported outcome measures (PROMs), becoming a benchmark to measure success rates of rhinoplasty. Inclusion of personalized surgical planning, taking the patient's symptoms into consideration have also shown promise in surgical outcomes and overall patient approval [1,2]. This highlights that the field of rhinoplasty is not only transforming in a purely objective and technique-driven manner, but also in the expectations and desired outcomes from the procedure. Overall, modern rhinoplasty can be understood as a convergence of structural preservation, outcome quantification through PROMs, and increasing technological augmentation through simulation and AI-based planning. This reflects a broader shift from technique-centred surgery to outcome- and patient-defined success.

Fundamentals of Rhinoplasty:

Rhinoplasty consists of multiple minor surgical procedures to ensure better nasal functions and aesthetics. This can be achieved using either the open or closed technique. In open rhinoplasty, the surgeon lifts both skin and subcutaneous tissues revealing the cartilage underneath, allowing precise structural modifications, using transcolumnar and intranasal incisions which allows a clear view of the nose, so there can be precise changes made. This technique provides increased visibility and access, allowing precise modification in complicated cases [7].

Meanwhile closed rhinoplasty is done by intranasal incision with limited visibility. The surgical access is gained through a cut placed within the nostrils, protecting the external soft tissue and avoiding scars. Even though this approach limits direct visualization of the framework, it enables dorsal reshaping and osteotomies to be carried out with minimal external disruption, resulting in reduced soft tissue trauma [7].

Further, rhinoplasty also includes tip modification, dorsal hump reduction, and adjustments of nasal valves to achieve complete nose reshaping. Tip modification refers to surgical modification of the nasal tip to enhance its shape, projection and overall modification. This is attained by careful maneuvering of the cartilaginous framework underneath, often involving reshaping or repositioning the tip of cartilage, and when needed, the use of graft to enhance structural support and contour [7,12]. The aim here is to construct a balanced and aesthetically pleasing tip while preserving or improving normal function and remains one of the most challenging parts of rhinoplasty, demanding careful adjustment of cartilage for maximum definition and projection. This is achieved through reshaping and repositioning of cartilage and graft till desired results are achieved [7,12]. Diced cartilage grafts play a role here, in correcting small irregularity and improving aesthetic appearance [12]. The best results rely on accurate understanding of nasal anatomy, and an approach that balances both the functional and aesthetic goals in a stable and proportional way [7,12].

Dorsal hump reduction entails the removal or reduction of excess bone or cartilage along the nasal dorsum to achieve a smoother profile. However, this procedure requires nasal bone realignment and osteotomies, to close the open roof deformities created during this procedure, ensuring structural steadiness and aesthetic continuity of the nasal dorsum [7]. Adjustment of nasal valves include surgical alteration of external or internal nasal valve area to improve airflow and sustain functional integrity of the nose. The valves play a crucial role in regulating breathing, and during rhinoplasty, adjustment might be necessary to prevent or fix airway obstruction which may arise from structural alterations, especially after dorsal hump reduction or tip modification [7].

Osteotomies are defined as controlled surgical fractures to reshape the bony vault, used for repositioning the nasal bone to achieve desired results and correct any present deformities. They are usually performed with mechanical osteotomes, forming fractures enabling structural realignment. There are multiple osteotomy techniques, including endonasal, percutaneous, perforating, and the continuous approach. They all defer in bone division and placement of the incision. The choice of technique depends on multiple factors including desired structural outcomes, stage of the surgery and preference of the surgeon. Conventional mechanical osteotomies can produce irregular bone cuts and might cause mucosal and soft tissue injury. This trauma contributes to complications such as postsurgical oedema, and ecchymosis, which are common because of the highly vascular nature of the nasal area and blood vessel disruption during the surgical process [7].

Grafting is a core part of rhinoplasty, used to give structural support and enhance nasal contours. Most commonly, cartilage for grafting, is sourced from the septal and the auricular cartilage, while the costal cartilage is preferred for complicated cases. This cartilage is diced to increase flexibility and ease of molding, which makes them ideal for smoothening and fixing irregularities, especially for dorsal augmentation and contour refinement [12].

Regardless of these benefits, grafting carries risk of visibility, distortion, and resorption. Grafting might be visible under the skin, especially in patients with thinner skin. Graft can shift, bend, or even heal unevenly causing distortion. The body can also break down and absorb the graft material Septal and

auricular cartilage, though commonly used, might be insufficient in quantity especially in revision cases, making it necessary to use costal cartilage leading to additional surgical morbidity [12]. Harvesting cartilages from donor sites can cause pain, scarring & structural compromise at the donor location. Additionally, the behaviour of graft itself after implantation, is cause for concern. Cartilage grafts can become visible under the skin, go through distortion over time, or even move from the intended position, compromising aesthetic appearance [12].

Infections, and the need for reoperation are significant complications. Even though the rates of infections are reported to be low, they still contribute to graft failure and further complications like reabsorption and deformities. Reoperation might be needed due to issues such as overcorrection, irregular contours or other unfavorable aesthetic results, highlighting importance of careful handling of graft and precise surgical techniques [12].

Preservation Versus Structural Rhinoplasty:

The transformation of modern rhinoplasty displays a paradigm shift from traditional approaches towards one that highlights natural preservation and conserves natural structure. Structural rhinoplasty (SR) is based on dorsal reduction by humpectomy, which involves reduction of mid-vault using techniques such as spreader's graft to maintain structural and aesthetic integrity. This reconstructive requirement emerges because dorsal resection destroys the natural support mechanism of the nasal framework, which increases the risk of complications such as internal nasal valve collapse and inverted 'v' deformity. On the other hand, Preservative Rhinoplasty (PR) is based on the principle of keeping the osteocartilaginous dorsum as a continuous structure, therefore avoiding unnecessary disruption to native anatomy. Through prioritizing tissue mobilization instead of excision, PR pursues the preservation of dorsal aesthetic lines and protection of the keystone area, which is essential for both structural stability and long-term outcomes. This philosophy fundamentally minimizes the probability of dorsal irregularities and functional compromise, which are usually associated with traditional reduction techniques [2,4,5,6].

Dorsal preservation is mainly achieved through two surgical procedures: the Push Down (PD) and the Let Down (LD) technique, both involving mobilization of the nasal pyramid with carefully planned lateral and transverse osteotomies. The PD technique lowers the nasal dorsum by removing the osteocartilaginous vault inferiorly into the piriform aperture without removing the bone, whereas the LD technique involves a controlled resection of bone at the nasofacial groove, which allows more precise descent of the dorsum. Both techniques mutually share the advantages of conserving the dorsal roof, hence avoiding the 'open roof' deformity usually experienced in traditional resection of the hump. Comparative data suggests that in certain circumstances, the PD technique may generate more advantageous results, exhibiting lower revision rate (PD 0% vs LD 5%) and decreased recurrence rate (PD 1.3% vs LD 4.6%) compared to the LD technique. These results emphasize subtle yet clinically relevant differences in stability between the two techniques [4,5].

Present evidence shows that PR attains outcomes that are at least comparable, and in some cases, even superior to structural rhinoplasty in maintaining nasal airway patency. Even though early concerns suggested that inferior removal of the nasal pyramid might compromise the internal valve, contemporaries do not support this supposition. PROMs including NOSE & SCHNOS & the Visual analog scale (VAS), consistently exhibit considerable postoperative improvements in nasal breathing following PR. Objective assessment using acoustic rhinoplasty and rhinomenometry validates these findings, demonstrating preservation or even enhancement of nasal airflow parameters, including increased minimum cross-sectional area and nasal cavity volume. The main factor underlying these advantageous outcomes is the preservation of the anatomical relationship between the upper lateral cartilage and the septum. As a result, PR offers a functionally protective approach that decreases the risk of airway compromise that's commonly associated with more invasive dorsal resection techniques [2,4,6].

The choice between PR and SR is immensely dependent on individual patient anatomy, as well as the surgeon's experience and familiarity with the techniques. PR is indicated in patients with a straight nasal dorsum, well defined dorsal hump, & a favorable soft tissue envelope allowing redraping after mobilization. With this context, the PD technique is preferred for smaller humps, whereas the LD technique is better for larger hump reduction that requires greater structural fixing. Regardless of its advantages, PR has major limitations, and is not universally applicable. It is normally contraindicated in cases with severe nasal trauma and septal deviation (such as crooked nose). The possibility of dorsal hump recurrence also stays a concern, further strengthening the need for careful patient selection and surgical expertise when considering a preservation technique [4, 5].

Complications and Revision Surgery:

Complications of rhinoplasty can range from minor contour irregularities to post-operative infections and functional obstruction. They are generally categorized into early and late complications, although this distinction is often indirect due to overlap with common post-surgical effects such as edema, pain and transient obstruction [11]. Most morbidity reported in literature is related to structural changes that eventually require revision surgery.

Early complications are usually mild and uncommon, including infection, graft displacement and contour irregularities. In a review of 3,252 patients undergoing diced cartilage grafting, infection was observed in only 0.06% of cases [12]. Late complications include graft resorption, long-term deformities and persistent cosmetic or functional dissatisfaction, often resulting in revision rhinoplasty. These secondary surgeries are mainly performed to correct residual airway dysfunction or unsatisfactory aesthetic outcomes after the primary surgery. Most revisions focus on the valve-dorsum-pyramid complex, reflecting the importance of nasal contour and symmetry in determining patient satisfaction [11,12].

The choice of graft material also plays a major role in post-operative outcomes and revision rates. A meta-analysis involving 1,233 patients from seven controlled trials compared autologous cartilage with silicone prostheses and demonstrated higher patient satisfaction with autologous cartilage grafts (RR = 1.11; 95% CI 1.02-1.21), along with significantly lower complication rates (RR = 0.34; 95% CI 0.22–0.52) [3]. Additionally, autologous cartilage was associated with fewer secondary surgeries, further supporting its preference in rhinoplasty [3].

Free diced cartilage grafts also showed favourable safety outcomes. Across 4,044 patients, reoperation rates remained low at 1.51%, mainly due to overcorrection or dorsal irregularities [12]. Other complications such as infection (0.06%), displacement and partial resorption (0.67%) were uncommon [12]. Comparisons between open and closed rhinoplasty techniques showed only minimal differences in revision rates, with reoperation observed in 2.73% and 1.56% of patients respectively, suggesting that surgical approach alone may not be a major determinant for revision surgery [11].

Evaluation of rhinoplasty outcomes has increasingly shifted towards patient-reported outcome measures, particularly the Rhinoplasty Outcome Evaluation (ROE) scale. The ROE evaluates both functional and aesthetic outcomes through a structured questionnaire, allowing standardized assessment of patient satisfaction [14]. Meta-analytic evidence demonstrated significant post-operative improvement, with ROE scores increasing from 35.04 ± 11.20 preoperatively to 76.80 ± 5.54 postoperatively [14]. These findings show that successful rhinoplasty outcomes depend not only on technical precision and functional restoration, but also on achieving patient-specific aesthetic expectations.

Intraoperative bleeding occurs frequently during rhinoplasty and septorhinoplasty due to which the surgical procedure becomes significantly complicated as it reduces the surgeon's visibility and prolongs operative time. Excessive bleeding can lead to further increase in the risk of postoperative complications such as edema and ecchymosis leading to a negative outcome affecting the surgery and recovery of the patient. They are minimised effectively by peri and postoperatively using several pharmacological and non-pharmacological strategies.

Several approaches used to manage bleeding in rhinoplasty and septorhinoplasty procedures, including pharmacologic agents such as TXA, steroids, desmopressin, magnesium sulfate, clonidine, and remifentanyl, in addition to non-pharmacologic measures like patient positioning, were evaluated by Zamani et al. incorporating the results of 16 randomized controlled trials involving 933 patients. The pooled result concluded that TXA (Mean Difference: -1.31 ; 95% CI) and steroids (Mean Difference: -1.07 ; 95% CI) were the most effective interventions for reducing intraoperative bleeding [13]. Additional findings imply that TXA not only decreases intraoperative bleeding but also minimises postoperative edema and ecchymosis, hence facilitating an improved recovery and patient satisfaction during the preliminary postoperative period. Moreover, corticosteroids have established substantial efficacy in reducing postoperative swelling and bruising, predominantly within the first 24 hours after surgery, with studies suggesting that perioperative administration may improve early postoperative results in a dose-dependent process [1].

Patient positioning, particularly the reverse Trendelenburg position, also contributed to a substantial reduction in bleeding, on the other hand desmopressin showed a positive but statistically irrelevant effect. Collectively, these findings highlight that combining pharmacological agents with supportive surgical approaches may promote improvement in perioperative bleeding management during rhinoplasty procedures [13]. Efficacious pain management also remains a critical component of recovery. Non-steroidal anti-inflammatory drugs have been shown to substantially lower postoperative pain and rescue analgesic prerequisites while also lowering postoperative nausea without increasing bleeding risk. Prophylactic antibiotics are also a common part of post-operative care following rhinoplasty, though current evidence demonstrates lack of statistically significant reduction in postoperative infection rates with prophylactic use, suggesting that antibiotics should be reserved for selected high-risk cases rather than prescribed globally. Besides bleeding control, perioperative management in rhinoplasty also emphasizes reducing postoperative discomfort, mitigating inflammation, elevating recovery, and augmenting overall patient satisfaction through adjunctive pharmacologic treatments. Advanced perioperative care therefore assimilates both surgical and pharmacological approaches to optimize operative conditions and postoperative healing [1].

Overall, rhinoplasty outcomes are determined by a combination of surgical precision, graft selection, perioperative management and patient expectations. Although complications such as graft resorption, contour irregularities and revision surgeries remain concerns, reported complication rates were generally low across multiple studies [3,11,12]. The increasing use of validated patient-reported outcome measures such as the ROE scale has also shifted focus towards both functional restoration and aesthetic satisfaction [14]. Additionally, improved perioperative care and preference for autologous grafts have shown promise in reducing morbidity and improving long-term patient satisfaction following rhinoplasty [1,3].

Clinical Decision-making Framework:

The choice between PR and SR is primarily guided by nasal anatomy, deformity severity and functional baseline. Patients with relatively preserved dorsal lines, mild to moderate dorsal hump and good soft tissue envelope are more suitable for preservation techniques, whereas severe deformity, post-traumatic noses and significant septal deviation often necessitate structural approaches. In practice, the decision is rarely binary and often exists on a spectrum, with hybrid techniques commonly employed depending on intraoperative findings.

Within PR, technique selection between PD and LD is determined by the extent of dorsal reduction required and skeletal rigidity. PD is generally preferred for smaller, more controlled dorsal modifications, whereas LD is more suited for larger humps requiring greater structural descent. In SR, the requirement for reconstruction of mid-vault support, often using spreader grafts or equivalent structural reinforcement, becomes a defining step. Thus, reconstruction is not incidental but an expected consequence of dorsal resection-based techniques.

Beyond anatomy, surgical decision-making is strongly influenced by surgeon familiarity, experience with preservation techniques, and patient-specific expectations regarding aesthetic outcome and recovery profile. Revision cases often default towards structural approaches due to altered anatomy and scar burden, even if preservation principles are theoretically applicable. Therefore, technique selection reflects a combined interaction of anatomy, surgical philosophy, and predictability of outcome rather than purely procedural preference.

Advances in Rhinoplasty:

In recent years, we have seen rhinoplasty grow by two major technological streams: the integration of Artificial Intelligence (AI) and the development of refined bone-cutting tools, aimed at providing a precise and more predictable experience [7, 8, 9].

3D simulation and AI are transforming how rhinoplasty is planned, communicated and evaluated. 3D systems are now utilized to predict implant size in augmentation rhinoplasty, suggest nasal shapes that match the individual's face, and rebuild 3D facial models from simple two-dimensional images, allowing shared visual decision making between surgeon and patient, further improving pre-operative communication and expectation alignment rather than proven outcome superiority. Machine learning models can learn an individual surgeon's style from perioperative images and estimate likely surgical outcomes, and can recognise facial features like changes in the nasofrontal and nasolabial angles that are linked to improve outcomes and recommend the selection of specific techniques to optimise the results desired by the patient [9]. However, most current applications remain in preoperative simulation and predictive modelling, with limited translation into validated improvements in long-term surgical outcomes.

Piezosurgery uses high-frequency ultrasonic microvibrations to cut bone with great precision while leaving soft tissue unharmed, thus reducing the trauma associated with osteotomies. Safia A et al. systematically reviewed 12 randomized controlled trials, to find that piezosurgery resulted in significantly lower post-operative edema (Mean Difference = -0.45; 95% CI) most pronounced on the second and seventh days; reduced ecchymosis (Mean Difference = -1.22), especially when paired with an outer osteotomy approach, most pronounced on the second, fourth and seventh days; and reduced post-operative pain (Mean Difference = \sim -0.80) compared to a traditional osteotomy [8]. This conclusively demonstrates fewer complications with piezosurgery, and lesser dependence on pain medication. They also reported recovery that was visibly less bruised and swollen and is mostly more comfortable for patients. Selection between conventional & piezoelectric methods comes down to availability and costs, with the upfront cost of acquiring the machinery for piezosurgery being expensive [7,8]. However, this cost is expected to come down significantly with widespread adoption of the technique owing to its apparent advantages.

Limitations, Future Directions and Emerging Concepts

Despite significant advances across techniques, outcomes and technology, the evidence base in rhinoplasty remains limited by heterogeneity in study design, patient selection and outcome reporting. A major proportion of current literature is still observational or short-term, with relatively few high-quality long-term randomized comparisons between preservation and structural approaches. In addition, variability in PROM usage and lack of standardized objective outcome definitions makes cross-study comparison difficult. Even with emerging AI and 3D simulation tools, most evidence is still centred around prediction and visualization rather than validated long-term functional and aesthetic outcomes. This creates a persistent gap between technological promise and clinically verified benefit.

Artificial intelligence (AI) and advanced imaging are increasingly influencing how rhinoplasty is planned, performed and evaluated, with a stronger shift towards individualized care and shared decision-making [1,10]. Alongside this, the evidence base surrounding rhinoplasty continues to expand, although significant gaps and heterogeneity still remain within the literature [9,10].

AI-driven personalization is emerging through simulation systems and machine learning models capable of predicting nasal shape, selecting implant size in augmentation rhinoplasty and generating 3D facial images from standard 2D photographs. Machine learning has also been used to analyse surgeon-specific rhinoplasty styles, estimate likely outcomes and identify facial features associated with improved attractiveness and younger appearance after surgery [1]. These developments suggest a future where preoperative planning and postoperative evaluation become increasingly data-driven and patient-specific.

Three-dimensional imaging and simulation technologies have also improved preoperative assessment and patient communication. Studies have shown improved surgeon satisfaction and better planning precision, particularly in complicated revision cases [10]. Additionally, patients reported better understanding of procedures and increased involvement in surgical planning through 3D simulation, supporting a more patient-centred and shared decision-making approach [10]. However, these systems remain expensive and currently show limited benefit in reducing operative time or revision rates, limiting widespread adoption [10].

Despite these advances, major evidence gaps persist. Meta-analytic reviews continue to highlight the need for standardized diagnostics, stronger patient-reported outcome measures and more long-term data evaluating both functional and cosmetic outcomes. Similarly, although AI and simulation technologies show significant promise, most current evidence remains focused on prediction and planning rather than long-term safety, clinical outcomes and cost-effectiveness, owing to the aforementioned lack of long-term studies [1,9,10]. Future research in rhinoplasty should focus on closing the gap between technological innovation and clinically validated outcomes. There is a clear need for long-term, high-quality comparative studies between preservation and structural techniques, particularly assessing both functional airway outcomes and aesthetic stability over time. Standardization of outcome reporting using consistent PROMs, alongside objective airflow and

structural metrics, is essential to allow meaningful cross-study comparison. In addition, AI and 3D simulation tools require external validation across diverse populations and surgical settings, with emphasis on real-world impact rather than predictive accuracy alone. Cost-effectiveness and integration into routine surgical workflow also remain underexplored and will determine whether these technologies move from adjunct tools to standard practice.

Future advances in rhinoplasty will likely be driven by AI-based personalization, 3D-assisted planning and more minimally invasive, patient-centred approaches. However, stronger long-term evidence and standardized outcome reporting will be necessary before these technologies can become routinely integrated into clinical practice.

Conclusion:

Rhinoplasty has evolved significantly from a procedure focused primarily on cosmetic alteration to one that increasingly balances both functional restoration and aesthetic outcomes. Advancements in preservation techniques, grafting methods and PROMs have contributed towards a more evidence-based and patient-centred approach. The growing emphasis on individualized surgical planning and airway preservation reflects this shift in modern rhinoplasty practice.

At the same time, complications and revision surgeries continue to remain important considerations. Although most reported complications are uncommon, issues such as graft resorption, contour irregularities and residual functional defects still contribute to secondary procedures. The increasing use of validated tools such as the ROE scale has also improved the assessment of patient satisfaction and surgical success, further supporting personalized outcome evaluation.

Recent technological advances including piezosurgery, AI-assisted planning and 3D simulation continue to reshape the future of rhinoplasty by improving surgical precision, patient communication and perioperative recovery. However, despite promising early results, stronger long-term evidence and standardized reporting remain necessary to fully establish their role in routine clinical practice. Overall, rhinoplasty continues to progress towards a safer, more predictable and increasingly patient-specific procedure.

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Abbreviations:

PR - Preservation Rhinoplasty

Patient-reported Outcome Measure - PROMs

Structural rhinoplasty - SR

Visual analog scale - VAS

Let Down - LD

Push Down - PD

Rhinoplasty Outcome Evaluation - ROE

Tranexamic Acid - TXA