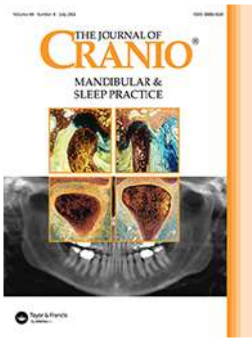

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The evolving landscape of sleep surgery: A state-of-the-art review

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SYSTEMATIC REVIEW

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The evolving landscape of sleep surgery: A state-of-the-art review

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ABSTRACT

Objective: To review the evolution of sleep medicine and surgical management of obstructive sleep apnea (OSA), focusing on anatomy-based and individualized treatment strategies.

Methods: This narrative review was developed by an expert panel of otolaryngologists and sleep medicine specialists. Landmark studies, consensus statements, and clinically relevant investigations were analyzed. Surgical approaches were classified according to anatomical target and functional mechanism, with particular attention to drug-induced sleep endoscopy (DISE), patient phenotyping, and multimodal treatment strategies.

Results: Sleep surgery has progressed from highly invasive procedures to minimally invasive, function-preserving, and multilevel approaches. Advances in understanding upper airway anatomy and collapse mechanisms have enabled targeted interventions, including barbed pharyngoplasty, transoral robotic surgery, maxillomandibular advancement, and hypoglossal nerve stimulation. DISE has improved identification of obstruction patterns and individualized surgical planning. Current OSA management increasingly combines surgical, dental, behavioral, and medical therapies within personalized care pathways.

Conclusion: Modern sleep surgery has evolved toward precision-based, multidisciplinary management. Individualized anatomical and functional assessment is central to treatment selection, while emerging diagnostic and therapeutic innovations may further improve outcomes.

KEYWORDS
Obstructive sleep apnea; sleep surgery; sleep medicine; drug-induced sleep endoscopy; hypoglossal nerve stimulation; sleep apnea treatment, precision medicine

Introduction

Sleep medicine and sleep surgery are highly specialized interdisciplinary fields that have undergone substantial development over the past decades. Initial surgical approaches to obstructive sleep apnea (OSA) were largely empirical and frequently associated with significant morbidity. Advances in the understanding of upper airway anatomy, collapse mechanisms, and sleep-related physiology have progressively reshaped surgical strategies. As a result, contemporary sleep surgery is increasingly characterized by targeted, function-preserving interventions guided by objective diagnostic tools and integrated within personalized treatment pathways. While non-surgical and dental approaches are briefly discussed to provide interdisciplinary context relevant to CRANIO readership, the primary focus of this review is the evolution of surgical strategies for OSA.

Materials and methods

This manuscript was developed as a narrative state-of-the-art review by an expert panel of national and international

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otolaryngologists and sleep medicine specialists. The literature was selected based on its relevance to the historical evolution, technical development, and clinical outcomes of surgical treatments for OSA. Landmark studies, consensus statements, and high-quality clinical investigations were preferentially considered. No formal systematic search strategy or quantitative synthesis was undertaken, in accordance with the narrative review design. Given the state-of-the-art nature of the review, surgical techniques were organized into dedicated subsections according to anatomical target and surgical principle, including palatal, lateral pharyngeal wall, tongue base, hypopharyngeal, epiglottic, skeletal, and neurostimulatory approaches. This structure was intentionally adopted to reflect both the historical and conceptual evolution of sleep surgery, to enhance clarity for the reader, and to enable a systematic yet non-quantitative comparison of techniques characterized by distinct indications, mechanisms of action, and clinical roles. Such anatomical and functional categorization is consistent with contemporary diagnostic frameworks, including drug-induced sleep endoscopy (DISE) and phenotypic classification of upper airway collapse. In addition, a historical – conceptual framework was deliberately incorporated to contextualize the evolution of surgical strategies within the broader development of sleep medicine. Key milestones in sleep physiology, diagnostic methodology, and pathophysiological understanding were therefore considered integral to the interpretative approach of this review, allowing surgical innovations to be analyzed in relation to advances in sleep medicine rather than as isolated technical developments.

• Sleep medicine

Although sleep and its disorders have been recognized for centuries, it was not until the mid-20th century that sleep was systematically classified using modern research techniques, particularly through the discovery of the electrophysiological basis of human sleep. In 1953, Aserinsky and Kleitman, in a landmark paper published in Science, described for the first time the presence of rapid eye movements during specific phases of sleep, in what is now known as REM sleep [1]. In 1957, Dement and Kleitman further differentiated REM and non-REM (NREM) sleep, identifying cyclical patterns that repeat throughout the night, an essential model that remains relevant today [2]. In 1960, Jouvet and Michel discovered that REM sleep is characterized by muscle atonia, a key feature in understanding sleep physiology [3]. Burwell et al., in 1956, described the "Pickwickian" syndrome, characterized by obesity-associated hypoventilation and hypersomnia. For several years, alveolar hypoventilation was thought to explain the excessive daytime sleepiness seen in Pickwickian patients. This view shifted in 1966, when Gastaut documented alterations in electroencephalographic activity occurring before and after apnea events in obese subjects, a phenomenon termed "respiratory-related arousal" [4]. In 1965, Jung and Kuhlo, neurologists at the University of Freiburg, demonstrated that weight reduction in obese, somnolent patients led to significant improvements in sleep and respiratory function, although the syndrome itself did not completely resolve [5]. Kuhlo et al. also reported a case of a Pickwickian patient who exhibited progressive and sustained decline in consciousness, requiring emergency tracheostomy. The intervention led to marked improvement in daytime alertness and elimination of respiratory pauses during sleep [6]. In 1970, Lugaresi et al. reported that tracheostomy in patients with hypersomnia and periodic breathing effectively resolved hypersomnia and normalized systemic and pulmonary blood pressures, as well as arterial blood gas levels [7]. Between 1970 and the early 1980s, tracheostomy emerged as the primary surgical treatment for individuals with severe OSA unresponsive to medical therapy. Around the same period, Kurtz and Lonsdorfer in Strasbourg identified a subset of patients who exhibited partial apnea events, later termed "hypopneas" [8]. In May 1972, a symposium held in Rimini, Italy, brought together neurologists and pulmonologists to classify the spectrum of sleep-related breathing disorders. During this meeting, three polygraphic patterns of sleep apnea, central, obstructive, and mixed, were identified, along with an additional incomplete obstructive pattern referred to as "hypopnea" [9]. Lugaresi and colleagues proposed that chronic snoring might represent a precursor to OSA [10]. In the 1970s, French researcher Christian Guilleminault joined the Stanford Sleep Clinic. Guilleminault and colleagues coined the term "obstructive sleep apnea syndrome" (OSAS) to describe sleep apnea in non-obese individuals, thereby challenging the prevailing belief that OSA was exclusive to obese patients. He also reported the first pediatric cases of OSA and helped define the emerging field of "sleep medicine". Together with William Dement, Guilleminault helped establish the apnea – hypopnea index (AHI), a key metric still used in the diagnosis and classification of OSA [11]. He also co-founded the journal Sleep, serving as its editor-in-chief until 1998. In 1974, Dr. Jerome Holland, also part of the Stanford group, introduced the term "polysomnography," which would become the standard term for the comprehensive sleep study [9].

- **Non-surgical therapies**

Although not the primary focus of this historical review, numerous non-surgical therapies play a central role in the treatment of sleep apnea either as stand-alone interventions or as part of multimodal treatment strategies. In 1981, Australian pulmonologist Colin Sullivan demonstrated that continuous positive airway pressure (CPAP) could effectively prevent upper airway collapse in patients with sleep apnea. Since then, CPAP has become the first-line and most widely used treatment for OSA [12]. In 1982, a clinical study evaluating a tongue-retaining device reported outcomes comparable to those of uvulopalatopharyngoplasty (UPPP) [13]. In 1985, Soll and George described the successful use of a mandibular advancement oral appliance in a patient with Class II malocclusion and severe OSA [14], laying the foundation for an important approach for non-surgical treatment that has been well studied in the past forty years [15–18]. In 1984, Cartwright described the influence of sleep position on OSA severity, noting that symptoms worsened in the supine position compared to side-sleeping, and that this effect was inversely related to body weight [19]. That same year, a brief correspondence in the Chest Journal reported the benefits of a simple positional therapy method: placing a plastic ball in a sewn pocket on the patient's back to discourage supine sleeping [20]. Myofunctional therapy (MFT) has also shown potential in improving muscle tone and reducing upper airway collapse in sleep-disordered breathing. In 2007, Guimarães et al. were the first to report the use of targeted oropharyngeal muscle exercises as a therapeutic approach [21]. Behavioral therapies, such as physical activity and proper nutritional intake, represent simple, globally accessible strategies that are widely recognized and primarily aimed at promoting weight loss [22–24]. Finally, pharmacological therapies have been proposed to address various aspects of OSA, including weight and visceral fat reduction, modulation of respiratory rate, and preservation of upper airway dilator muscle tone during sleep [25,26]. All these medical developments have contributed to make OSA a well-known condition with imbricated interests in several disciplines, such as, among the others, otorhinolaryngology, maxillofacial surgery, neurology, psychology, internal medicine, and dentistry.

Concerning dentistry, increasing attention has been directed toward sleep bruxism and its relationship with sleep-disordered breathing [27–29]. Seminal contributions by Lavigne and colleagues, subsequently expanded by Lobbezoo and Manfredini, have clarified the multifaceted interactions between bruxism, arousal mechanisms, circadian regulation, and OSA [30–45].

Evolution of surgery

This state-of-the-art review outlines the historical development of OSA surgery, highlighting key innovations, the role of anatomical understanding, and the emergence of precision surgical approaches. Emphasis is placed on the transition from isolated oropharyngeal surgeries to multilevel and neurostimulation strategies. The aim is also to highlight the most significant surgical strategies developed for the treatment of OSA, many of which remain clinically relevant today. It also outlines the key milestones in sleep surgery over recent decades, reflecting on the challenges encountered, the lessons learned, and the ongoing contribution to the growing body of knowledge available to surgeons treating patients with OSA.

Before the 1980s, tracheostomy was the only surgical option available for treating OSA [6]. In 1981, Fujita et al. introduced uvulopalatopharyngoplasty (UPPP) for the surgical management of OSA, an adaptation of a technique originally described by Ikematsu in Japan in 1964 for treating snoring. Over time, UPPP fell out of favor due to its significant postoperative side effects and relatively low long-term efficacy in resolving OSA [46,47]. Growing awareness of the serious health consequences of untreated OSA has driven exponential growth in research and the development of new surgical techniques over recent decades. This evolution has marked a shift from predominantly ablative procedures toward functional surgeries that better preserve pharyngeal anatomy, thanks in part to technical innovations such as barbed sutures, robotic-assisted approaches, and neurostimulation, many of which have been adapted from other medical and surgical fields. Technological advances aimed at preventing upper airway collapse during sleep have played a central role in shaping the current and evolving landscape of sleep surgery.

Uvulopalatopharyngoplasty (UPPP)

Uvulopalatopharyngoplasty (UPPP) was initially described by Ikematsu in 1964 as a surgical treatment for snoring [46]. In 1981, Fujita et al. introduced the technique in the United States as a surgical option for managing OSA [47]. Fujita's original UPPP technique involved complete tonsillectomy combined with excision of the palatine arches and uvula. Over the following three decades, numerous variations of the procedure were developed to improve outcomes, primarily aimed at increasing the lateral dimensions of the oropharyngeal airway. Subsequent refinements expanded upon the classical approach. In the early 2000s, Han proposed a revised version that preserved the uvula, a method that remains in use today and has demonstrated favorable outcomes [48]. Further advancements in modified UPPP techniques emerged in Australia, notably with Robinson's approach, which demonstrated effectiveness in multilevel treatment protocols when combined with coblation-assisted tongue base surgery [49]. However, despite improvements in clinical symptoms, the use of UPPP has declined in recent years due to significant postoperative pain, a high complication rate, and limited long-term efficacy in controlling OSA [50]. Although historically pivotal, traditional UPPP highlighted the limitations of non-selective palatal surgery, reinforcing the need for anatomically and functionally targeted approaches based on collapse pattern and patient-specific characteristics.

Laser-assisted uvulopalatoplasty (LAUP)

In the 1980s, the introduction of advanced technologies such as the CO_2 laser paved the way for the development of new surgical techniques, including Laser-Assisted Uvulopalatoplasty (LAUP) [51]. The widespread adoption of UPPP during the same period contributed to the refinement of LAUP techniques throughout the 1990s and early 2000s. However, clinical outcomes demonstrated only partial efficacy, primarily in cases of snoring and mild OSA, with benefits often diminishing over time. These limitations prevented LAUP from gaining widespread adoption despite initial enthusiasm [52]. To date, LAUP remains unapproved by the American Academy of Sleep Medicine for the treatment of OSA, although it has shown efficacy comparable to UPPP in the management of snoring [53].

Radiofrequency and palatal implants

Radiofrequency was introduced in the late 1990s as a form of interstitial thermotherapy targeting the soft palate, offering a minimally invasive approach with a low complication rate [54]. While effective in reducing snoring, radiofrequency is generally not recommended for patients with severe sleep-disordered breathing (SDB). The technique can be applied to both the soft palate and the tongue base to reduce tissue vibration during sleep. Its safety and efficacy in the treatment of mild to moderate OSA have been supported by randomized controlled trials (RCTs) demonstrating short-term improvements in snoring, apnea severity, and daytime sleepiness [55,56]. In 2006, Romanow introduced palatal implants as a method to stiffen the anterior portion of the soft palate [57]. Made of biocompatible materials, these implants have shown efficacy in reducing snoring and alleviating daytime symptoms in patients with mild to moderate OSA. An additional advantage is that they can be inserted under local anesthesia. However, the use of palatal implants remains controversial due to limited medium- and long-term data on their efficacy and tolerability, as well as the risk of implant extrusion. This is particularly relevant considering newer and more effective techniques offering comparable procedural risks. Despite these limitations, palatal implants are still used in select centers for the treatment of snoring and mild to moderate OSA [58]. They remain a theoretically valid option in cases where other treatments are contraindicated or less feasible.

Anterior pharyngeal wall surgery

Numerous variants of palatal surgery have been developed, marking a conceptual shift from aggressive resection of the palate and uvula to functional, reconstructive techniques aimed at improving pharyngeal function by reshaping its structure. Following anatomical and physiological investigations into palatal collapse, Ellis introduced the "anterior palatal stiffening operation" in 1994, a technique considered a precursor to modern anterior palatoplasty [59]. It involved removing a rectangular section of mucosa from the uvular and anterior palatal region. Around the year 2000, Mair refined the technique by introducing the cautery-assisted palatal stiffening operation (CAPSO) [60]. Pang subsequently adapted the procedure for use in an office-based setting, initially renaming it the modified CAPSO technique [61]. In 2009, Pang formally introduced the term "anterior palatoplasty" to describe the modified CAPSO technique [62]. Today, anterior palatoplasty remains a valid option for the personalized treatment of simple snoring and mild to moderate OSA, particularly in cases of isolated anterior soft palate collapse or as part of multimodal or multilevel surgical strategies. LAUP, radiofrequency-based procedures, and palatal implants underscored the importance of balancing minimal invasiveness with durable clinical efficacy, ultimately accelerating the transition toward function-preserving and multilevel surgical concepts.

Lateral pharyngeal wall surgery

In 2003, Cahali described lateral pharyngoplasty, a surgical technique aimed at stabilizing the lateral pharyngeal walls through microdissection of the superior pharyngeal constrictor muscle, thereby reducing lateral wall collapse [63]. In 2007, Pang and Woodson further introduced expansion sphincter pharyngoplasty, a procedure involving tonsillectomy, rotation of the palatopharyngeus muscle, partial uvulectomy, and closure of the anterior and posterior tonsillar pillars to generate lateral wall tension [64]. In 2008, Hur proposed the "sling snoreplasty with a permanent thread" (SST), a three-dimensional retention suture technique applied to redundant segments of the soft palate, typically in triangular, tetragonal, or pentagonal configurations, designed to shorten and anteriorly elevate the soft palate, thereby widening the oral cavity and nasopharyngeal space [65]. In 2012, Sorrenti and Piccin refined the approach with functional expansion pharyngoplasty, in which the cranial portion of the palatopharyngeal muscle is suspended to the pterygoid hamulus using resorbable sutures placed through a submucosal tunnel [66]. In 2016, Pang et al. proposed combining anterior pharyngoplasty with lateral expansion pharyngoplasty for patients exhibiting concentric pharyngeal collapse [67]. Also in 2012, Mantovani et al. introduced the velo-uvulo-pharyngeal lift, also known as the "Roman blinds" technique. This procedure involves anchoring the palatopharyngeal fibromuscular tissue and the soft palate to bony landmarks, the posterior nasal spine and the pterygoid hamulus bilaterally, using a continuous transmucosal suture along a semicircular path from the uvula to the posterior tonsillar pillars [68].

Pharyngeal barbed snore surgery

A major innovation in palatal surgical techniques came in 2013, when Mantovani et al. introduced the use of barbed sutures, which allow for knotless tissue fixation. Barbed sutures offer improved tension distribution and enable anchoring to rigid anatomical structures such as the pterygoid hamulus, palatine aponeurosis, and pterygomandibular raphe. Several pharyngoplasty techniques incorporating barbed sutures have since been developed. In 2014, the barbed anterior pharyngoplasty (BAPh) procedure was introduced. This technique integrated barbed sutures and newly defined anatomical landmarks within the framework of anterior pharyngoplasty [69]. In 2015, Vicini et al. modified the Roman blinds technique into what they termed "barbed reposition pharyngoplasty" (BRP), expanding its indications to include patients with moderate to severe OSA and concentric collapse patterns. The procedure begins with bilateral tonsillectomy, followed by the insertion of a barbed suture through the center of the soft palate. The suture is then advanced laterally around the pterygomandibular raphe using continuous submucosal zigzag stitching toward the tonsillar bed, where it incorporates the palatopharyngeal muscle and exits through the mucosa of the posterior pillar [70]. In 2017, the Alianza pharyngoplasty technique was introduced as a combination of anterior and lateral pharyngoplasty using barbed sutures. After tonsillectomy, a rectangular mucosal area is excised to expose the muscular plane. The posteroinferior nasal spine and pterygoid hamulus serve as anchor points, and a palatal suture, similar to that used in BRP, is placed without transecting or isolating the palatopharyngeal muscle [71].

Tongue base surgery

The base of the tongue is a common site of airway obstruction in OSA, but it presents significant challenges for surgical access and intervention. In 1999, Chabolle proposed open tongue base resection; however, due to the high risk of complications, its use was limited and largely replaced by less invasive, although less effective, techniques such as radiofrequency [72]. In 2010, Vicini et al. demonstrated the feasibility of tongue base reduction via transoral robotic surgery (TORS) in patients with moderate to severe OSA [73]. Indications for the procedure included airway obstruction due to anteroposterior collapse caused by hypertrophy of the lingual tonsils or by epiglottic collapse. The robotic approach offers enhanced visualization of the surgical field, enabling precise transoral resection of the tongue base and the mucosa overlying the lingual surface of the epiglottis. This procedure can be combined with tonsillectomy and barbed pharyngoplasty during the same surgical session [74]. In addition to TORS, tongue base reduction using coblation was also described as early as 2010 [75]. Both coblation and TORS have demonstrated comparable surgical outcomes and similar rates of postoperative complications, making them viable alternatives for addressing tongue base hypertrophy.

Hypopharyngeal collapse

The hypopharynx is a complex site of upper airway collapse, posing significant challenges for both accurate diagnosis and effective surgical management. In 1986, Riley et al. first proposed hyoid suspension surgery, performed in combination with mandibular osteotomy and myotomy of the infrahyoid muscles, as a treatment for hypopharyngeal obstruction [76]. In 2004, Hörmann and Baisch introduced a less invasive variation of hyoid suspension, which could be performed under local anesthesia. Their technique involved anchoring the hyoid bone to the thyroid cartilage using a steel wire [77]. In 2005, den Herder introduced hyoidthyropexy, a technique involving anterocaudal mobilization of the hyoid bone followed by its fixation to the thyroid cartilage, resulting in increased retrolingual space. Compared to Riley's original approach, hyoidthyropexy was less invasive while achieving comparable effects on the hypopharyngeal airway [78]. In 2013, Piccin et al. described a modified hyoid suspension technique that employed a titanium miniplate to reinforce the thyroid cartilage [79].

Epiglottic collapse

At the hypopharyngeal level, epiglottic collapse is a frequently underrecognized cause of airway obstruction. Its prevalence among patients with OSA is estimated to range from 27% to 44%, particularly among those with poor CPAP adherence or failed upper airway surgeries [80]. DISE enables more accurate diagnosis of epiglottic collapse by allowing direct visualization of the collapse during obstructive events and identification of specific collapse patterns [81].

Epiglottoplasty – Laser or robotic

Various strategies have been proposed for the treatment of epiglottic collapse. These include reducing the size of the epiglottis through partial epiglottectomy, stabilizing it by anchoring to adjacent structures with suture wires, and stiffening it through demucosalization and cauterization of its lingual surface combined with demucosalization of the corresponding area of the tongue base. Total or partial epiglottectomy was the earliest strategy adopted. However, total epiglottectomy was soon abandoned due to postoperative swallowing difficulties, including aspiration. Partial epiglottectomy, involving the removal of either one half of the epiglottis or a midline V-shaped section, remains an option, although newer techniques that preserve anatomy while maintaining efficacy are increasingly preferred [82]. In 2018, Roustan et al. proposed a transoral glossoepiglottopexy using a CO_2 laser to stiffen the lingual surface of the epiglottis, which was then stabilized with a transcutaneous suture [83]. This technique proved effective and safe, with minimal impact on swallowing and phonatory function, and is currently considered a valid option for managing epiglottic collapse. In 2019, Salamanca et al. introduced the Epiglottic Stiffening Operation (ESO), a minimally invasive technique performed under microlaryngoscopy. ESO involves cauterization of the lingual surface of the epiglottis using an aspirator and cauterizer, while preserving both the free margin and anatomical integrity of the epiglottis [84].

Skeletal surgery

The first study to evaluate the effectiveness of maxillomandibular advancement (MMA) for treating OSA was conducted in 1986 by Riley et al. Despite its invasiveness, the unmatched efficacy of this technique contributed to its success, and it remains a valid therapeutic option today [85]. For many years, MMA has been considered the most effective surgical treatment for OSA. Since the development of the Stanford protocol, it has served as a second-line intervention for patients unresponsive to palatal and nasal surgical techniques. In 1993, the Stanford group introduced a staged surgical protocol for dynamic upper airway reconstruction based on OSA severity. Phase I, a conservative approach, includes UPPP, mandibular osteotomy with genioglossus advancement, hyoid myotomy and suspension, tonsillectomy, and nasal surgery. Patients with persistent OSA following Phase I are considered candidates for Phase II, which includes maxillomandibular advancement and temperature-controlled radiofrequency ablation of the tongue base. The surgical success rate for Phase I was 61%, while Phase II achieved a reported success rate of 100% [86]. Recognition of the interplay between anatomical and dynamic factors in upper airway collapse during sleep has sustained interest in skeletal surgery as a valuable therapeutic option. In 2017, the Stanford group introduced a new technique: Distraction Osteogenesis Maxillary Expansion (DOME). This approach has shown effectiveness in treating patients with a narrow maxilla and high-arched palate, a phenotype often associated with OSA. Patients undergoing DOME have demonstrated improvements in nasal obstruction, a reduction in apnea events, and decreased levels of excessive daytime sleepiness [87].

Hypoglossal nerve stimulation (HNS)

The first clinical application of hypoglossal nerve stimulation (HNS) in patients with OSA dates back to 2011 [88]. In 2014, results from the first clinical trial, known as the STAR trial, demonstrated the objective and subjective effectiveness of HNS in treating OSA. These findings laid the foundation for the adoption of HNS as a second-line therapy to CPAP in carefully selected patients following thorough diagnostic evaluation [89]. Today, long-term follow-up data are available from patients treated with HNS, allowing assessment of its medium- to long-term efficacy. The sustained reduction in apneas and the low incidence of complications even years after implantation support HNS as a feasible and effective treatment that merits increasing consideration in the management of OSA [90]. HNS, along with other surgical interventions targeting the nose, tongue base, palate, and maxillomandibular skeleton, represents part of a broad spectrum of surgical therapies currently available for OSA. These evolving options call for a revision of the original Stanford protocol to align it with the current therapeutic landscape. Such a revision is essential in modern clinical practice, which increasingly emphasizes personalized treatment strategies tailored to the individual patient's characteristics [91].

The role of drug induced sleep endoscopy (DISE)

Any surgical or prosthetic decision-making should be preceded by a sleep endoscopy evaluation. Sleep nasendoscopy was first introduced by Croft and Pringle in 1991 as a tool to assess upper airway (UA) collapse in patients with OSA during drug-induced sleep. Originally referred to as sleep nasendoscopy, the procedure is now commonly known as DISE. DISE enables real-time assessment of the various levels of airway collapse, including their severity and collapse patterns, and is typically performed in the operating room or endoscopy suite using standard anesthetic equipment. After inducing sleep with agents such as Midazolam, Propofol, or Dexmedetomidine, a flexible endoscope is inserted through the patient's nostril to visualize the different levels of the upper airway (soft palate, tonsils, tongue base, and epiglottis) during sleep-related phenomena such as snoring and apneas. Several DISE-based scoring and classification systems have been described in the literature, with the VOTE classification currently being the most widely used. The information obtained through DISE is essential for guiding the therapeutic approach and, when applicable, for tailoring medical or surgical planning in accordance with the principles of personalized medicine [16].

Future perspectives in targeting surgical therapy for OSA

The pathogenesis of OSA is closely linked to upper airway collapse, a phenomenon that clearly has an anatomical basis. In 2013, Eckert et al. identified four key contributors to the pathophysiology of OSA. The first, critical closing pressure (Pcrit), reflects the anatomical tendency of the upper airway to collapse. The remaining three are arousal threshold, loop gain, and muscle responsiveness. Based on the predominance of specific pathophysiological traits in each patient, individualized profiles can be established. This has led to the emergence of patient "endotyping" and "phenotyping," enabling the targeting of both surgical and non-surgical therapies. The PALM classification was introduced for this purpose [92]. Widespread adoption of this classification is currently limited by the challenges involved in measuring its defining parameters. The gold standard requires polysomnographic evaluation in a controlled setting using advanced, and often invasive, monitoring technologies available primarily in highly specialized research centers. To address this limitation, several surrogate indices have been proposed [93]. Currently, the treatment of OSA involves a variety of options that can be delivered either as standalone therapies or in combination, depending on the patient's endotype, phenotype, and disease severity. Therapies targeting anatomical traits include CPAP, weight loss, mandibular advancement devices (MADs), and positional therapy. In contrast, treatments addressing non-anatomical traits include pharmacotherapy, MFT, and HNS. Multimodal treatment strategies and precision diagnostics for preoperative planning are becoming increasingly integrated into clinical practice, though they remain under ongoing development. Surgical therapy for OSA primarily aims to reduce upper airway collapsibility. Some data in the literature suggest that surgical outcomes may vary depending on the patient's Pcrit values [94]. Furthermore, three potential outcomes following surgical treatment have been described in relation to the patient's PALM classification: complete resolution of OSA, a significant improvement in collapsibility resulting in mild residual disease, or, in the worst case, no significant improvement and persistence of OSA. This variability in surgical outcomes underscores the importance of evaluating a patient's endotypic and phenotypic traits before proposing a surgical approach. While this approach is still under investigation, future developments may include new assessment tools and improved use of surrogate indices. Broader implementation of preoperative DISE could enhance patient selection by identifying characteristic patterns or abnormal sites of airway collapse amenable to surgical intervention [95]. In the future, DISE may be complemented, or even surpassed, by minimally invasive tools such as real-time sleep videomanometry. This technique involves inserting a catheter equipped with pressure, temperature, and video sensors directly into the patient's upper airway during sleep studies [96]. Other advanced imaging modalities, such as dynamic MRI, have also been proposed to aid in surgical planning [97]. Recent advances in artificial intelligence (AI) and machine learning (ML) have shown promising potential in improving the diagnosis and management of OSA. It is plausible that soon, large-scale validation of AI-based diagnostic systems will further enhance their reliability and integration into clinical workflows, ultimately improving patient selection and fostering the development of precision medicine in sleep surgery and sleep medicine [98,99].

Synthesis

The reviewed literature demonstrates a progressive transition from isolated palatal and skeletal procedures toward multilevel and precision-based surgical approaches. Less invasive techniques, including barbed suture pharyngoplasty, transoral robotic surgery, and neuromodulation procedures represent highly effective options in carefully selected patients, particularly when guided by anatomical and functional assessment for the treatment of OSA. Diagnostic refinement through DISE has enabled improved identification of upper airway collapse patterns, thereby supporting more accurate patient selection. Neuromodulation and skeletal advancement remain highly effective therapeutic options in carefully selected patients.

Discussion

Sleep apnea surgery has evolved from empirical and often invasive procedures into a sophisticated field guided by detailed anatomical and physiological understanding. The integration of DISE, emerging concepts of endotyping and phenotyping, and multimodal treatment strategies has redefined the role of surgery within contemporary OSA management. Rather than representing a standalone intervention, surgical therapy is now best viewed as one component of individualized care, aimed at reducing upper airway collapsibility while complementing non-surgical treatments. Despite significant progress, heterogeneity in outcome measures and limited long-term data for some newer techniques remain important limitations. Ongoing advances in diagnostics, imaging, and artificial intelligence are expected to further refine patient selection and optimize surgical outcomes. In this context, sleep surgery should be regarded not as an isolated intervention, but as one component of an integrated, multidisciplinary care pathway that includes dental, behavioral, and medical expertise.

Take-home message

From a practical standpoint, contemporary sleep surgery is increasingly driven by patient selection rather than procedural choice alone. Tools such as DISE, combined with phenotypic and endotypic assessment, currently play a central role in guiding surgical decision-making and tailoring interventions within multimodal treatment strategies.

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Rosario Marchese-Ragona conceived and supervised the study, coordinated the expert panel, and led manuscript drafting and revision.

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