Sleep and Breathing (2022) 26:1539–1550
https://doi.org/10.1007/s11325-021-02520-y

SLEEP BREATHING PHYSIOLOGY AND DISORDERS • REVIEW

Lateral pharyngoplasty vs. traditional uvulopalatopharyngoplasty for patients with OSA: systematic review and meta-analysis

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Received: 24 April 2021 / Revised: 19 September 2021 / Accepted: 27 October 2021 / Published online: 3 January 2022

Abstract

Objectives To compare the efficacy and success rates of lateral pharyngoplasty techniques (LP) vs. uvulopalatopharyngoplasty (UPPP) among adult patients surgically treated for obstructive sleep apnea.

Methods A systematic literature review of the last 20 years' papers was conducted using PubMed/Medline, Embase, Web of Science, Scholar, and the Cochrane Library until April 2021. Only full-text English articles comparing LP and UPPP outcomes in adult patients with objective outcomes were included in the study.

Results We included 9 articles for a total of 312 surgically treated patients with OSA. LP techniques for obstructive sleep apnea were used on 186 (60%) subjects, while 126 patients (40%) were treated with UPPP. Both surgical procedures resulted in significant improvements in apnea-hypopnea index (AHI), Epworth Sleepiness Scale (ESS) score, and lowest oxygen saturation (LOS) ($p < 0.001$ in all cases). Although better outcomes were reported with lateral pharyngoplasty, the differences were not significant compared to UPPP post-operative results ($p > 0.05$ in all cases).

Conclusions UPPP and LP are both effective surgical procedures in treating OSA in adults. Although not significant, LPs demonstrated improved post-operative outcomes. However, further evidence comparing the surgical effect on patients with OSA is needed to discriminate post-operative outcomes.

Keywords Obstructive sleep apnea · Barbed reposition pharyngoplasty · Expansion sphincter pharyngoplasty · Uvulopalatopharyngoplasty · OSA surgery

Introduction

Obstructive sleep apnea (OSA) is sleep-disordered breathing (SDB) characterized by the collapse of the upper airways during sleep, provoking a stop in airflow [1, 2]. Several anatomical component structures may cause a partial or total upper airway collapse, such as the soft palate, palatine tonsils, lateral pharyngeal walls, uvula, and tongue base [3–5]. Although the primary treatment for patients with moderate to severe obstructive sleep apnea (OSA) remains continuous positive airway pressure (CPAP), patients with poor CPAP compliance and tolerability may benefit from

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different therapeutic options [6, 7]. Uvulopalatopharyngoplasty (UPPP) was introduced by Fujita et al. in 1981 and quickly became the most performed surgical technique for soft collapse in adults with OSA [8–10].

Golbin et al. demonstrated a significant reduction in the average AHI of − 21.4/h in 25 patients treated with UPPP with a statistical significance of ($p < 0.001$) and a complication rate of 34.7% ($p < 0.001$) [11]. However, the literature has shown strongly conflicting results regarding UPPP-treated patients, with persistence of sleep apnea or severe long-term sequelae such as velopharyngeal insufficiency (VPI) and foreign body sensation [12–17].

For lateral pattern collapse, lateral expansion pharyngoplasty (LEP) was first described by Cahali et al. and then modified by Pang and Woodson in 2007 in expansion sphincter pharyngoplasty (ESP) [15, 16]. This technique has given excellent results in post-operative follow-up. A systematic review and meta-analysis of 5 articles (143 patients) by Pang et al. demonstrated that after surgery a pooled AHI reduction from 40.0 ± 12.6 to 8.3 ± 5.2 post-operatively and an overall pro-rated success rate of 86.3% [18]. Later, Vicini et al., modifying the lateral pharyngeal wall approach, introduced barbed repositioning pharyngoplasty (BRP), relocating palatopharyngeal muscle towards the pterygoid-mandibular raphe via a barbed suture [19–22].

Pharyngoplasty techniques may also present velopharyngeal insufficiency, mostly transient and self-resolving, as recently reported by Gulotta et al. [22]. The authors reported extrusion and exposure (E&E) rates of 18.4% and a significant difference between Stratafix and V-Loc wire ($p = 0.002$). In the literature, no clear concordance among authors is present regarding the best OSA velopharyngeal technique. To this end, our study aimed to compare the lateral pharyngoplasty techniques with the classic UPPP in the respiratory outcomes of patients with OSA. A metanalysis study was carried out considering only those papers in the literature that directly compared these two types of surgical techniques for OSA.

Materials and methods

Protocol data extraction and outcomes evaluated

The authors A.M and M.D.L. analyzed the data from the literature, solving any disagreements among the study members through discussion. All the studies included were examined, obtaining all available data and guaranteeing eligibility for all subjects. Main patient features, symptoms, diagnostic procedures, treatment modalities, outcome scores (AHI, ESS, ODI, LOS), and follow-ups were collected. Lateral pharyngoplasty and UPPP outcomes in OSA were evaluated, thus pre- and post-operative AHI, ESS, LOS, and ODI scores; the overall outcomes of the lateral pharyngoplasty procedures were compared with UPPP ones.

Electronic database search

According to the PRISMA checklist for review and meta-analysis, we performed a systematic review of the current literature (Fig. 1). PubMed/Medline, Embase, Web of Science, Scholar, and the Cochrane Library electronic databases were searched for studies on velopharyngeal and lateral pharyngoplasty surgical treatments in OSA patients over the last 20 years (from January 1, 2001 to March 1, 2021) by two different authors. The following search keywords were used: “upper airway surgery,” “obstructive sleep apnea surgery,” “palate surgery and sleep apnea,” “obstructive sleep apnea,” “lateral pharyngoplasty and obstructive sleep apnea,” “barbed suture and obstructive sleep apnea,” “uvulopalatopharyngoplasty and obstructive sleep apnea,” “tonsil surgery and sleep apnea,” “tonsil obstructive sleep apnea,” “barbed surgery and sleep apnea,” “sleep disordered breathing and uvulopalatopharyngoplasty,” and “sleep disordered breathing and barbed suture.” We also considered the “related articles option” on the PubMed and Scholar homepage. All the investigators examined the titles and abstracts of the papers available in English. Thus, the identified full-text articles were screened for original data, and related references were checked and retrieved manually, searching for other relevant studies.

Inclusion and exclusion criteria

Studies included met the following criteria:

1. Original article comparing post-operative outcomes of uvulopalatopharyngoplasty to one or more lateral wall techniques.
2. The article was published in the English language.
3. The studies performed velopharyngeal treatment only after confirmed obstructive sleep apnea at overnight polysomnography (PSG).
4. All the studies reported detailed information on pre-operative and post-operative OSA outcomes, such as apnea–hypopnea index (AHI), Epworth sleepiness scale (ESS), oxygen desaturation index (ODI), and lowest oxygen saturation (LOS).

We excluded:

1. Case report, editorial, letter to the editor, or review.
2. Studies with only qualitative outcomes.
3. Patients with central or mixed sleep apnea.
4. Papers missing pre- and post-operative continuous data.

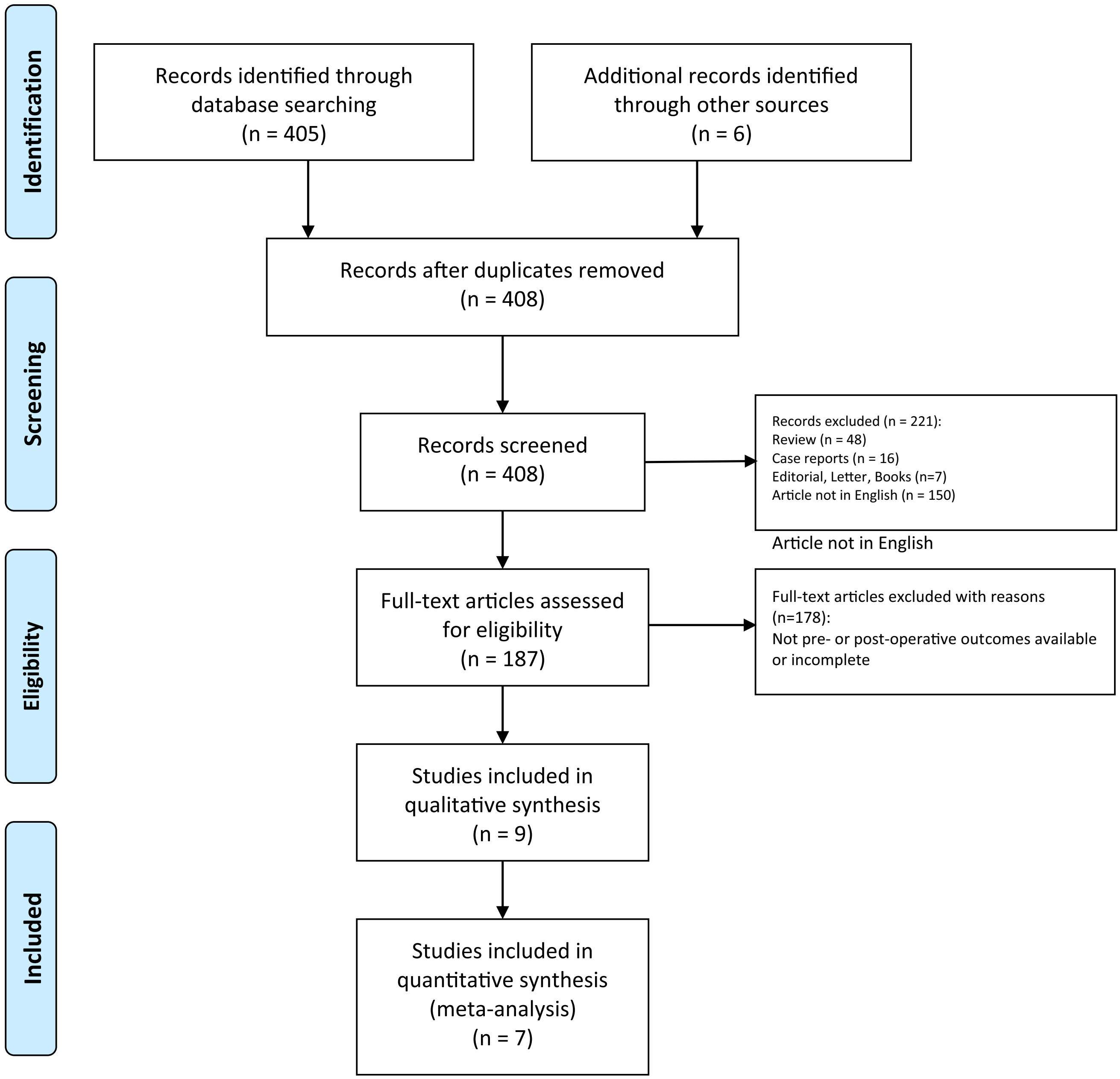


Fig. 1 Flow diagram according to PRISMA guidelines

Statistical analysis

We performed the search protocol according to the validated reporting items quality requirements for systematic review and meta-analysis protocols (PRISMA) declaration [23]. Furthermore, the study quality assessment (QUADAS-2) tool was used to evaluate the study design features of the included articles [24]. Statistical analysis was performed using statistical SPSS software (IBM SPSS Statistics for Windows, IBM Corp. Released 2017, Version 25.0. Armonk, NY, USA: IBM Corp). Furthermore, we adopted random-effects modeling (standard error estimate = inverse of the sample size) to estimate the summary effect measures by 95% confidence intervals (CI); subsequently, forest plots were generated via the Review Manager Software (REVMAN) version 5.4 (Copenhagen: The Nordic Cochrane Centre: The Cochrane Collaboration). Thus, the inconsistency (I2 statistic) was calculated and the values for low inconsistency = 25%, moderate inconsistency = 50%, and high inconsistency = 75% were established [25].

The calculation of the optimal total sample size was conducted using the G-Power statistical software. Foreseeing, based on data in the literature, an alpha error of 0.05, an average effect size of 0.50 and a power greater than 85%. To reduce clinical heterogeneity, studies with an overall sample size of fewer than ten patients were excluded from the analysis.

At the same time, funnel chart was used to evaluate the potential publication bias. The Duval and Tweedie's trim-and-fill method was adopted to assess missing studies due to publication bias in the funnel plot and to adjust the overall effect estimate[26].

Results

Retrieving studies

We identified 411 potentially relevant studies through the systematic review of the literature (Fig. 1). After removing duplicates and applying the criteria listed above, 408 records were potentially relevant to the topic. All the studies not matching inclusion criteria were excluded through record analysis and subsequent article full-text screening ($n = 399$). All the studies that reported inadequate or unclear patient selection criteria, partial or incomplete pre- and post-operative parameters both at baseline and follow-up, a lack of comparison between the two different surgical techniques or not homogeneous patients groups enrolled were excluded from the analysis.

The remaining 9 papers were included in the qualitative synthesis of papers for data extraction [15, 16, 27–33]. Moreover, because of the meta-analysis established criteria, we excluded two papers (partial or absent data) and thus considered 7 studies for quantitative analysis [15, 16, 27–31]. The possible risk of bias is summarized as a graphical QUADAS-2 outcome in Fig. 2. Excluding a study with high-risk of bias [33], the study bias analysis produced results similar to the overall analysis. Moreover, the certainty assessment in cumulative evidence evaluated by GRADE guidelines was considered very low (Tables 1 and 2).

Patients' features and surgery

We included 9 articles in our systematic literature review for a total of 312 OSA patients surgically treated, of which 186/312 (60%) were LP subjects while 126/312 (40%) were UPPP subjects. The patients' average age was 41.5 ± 8.0 years, of which the UPPP subjects were 48.3 ± 7.4, the BRP subjects were 48.2 ± 11.4, the ESP subjects were 46.3 ± 5.9 and the LEP subjects were 42.3 ± 1.2 [15, 16, 27–33].

All participants in the studies had undergone a home sleep apnea test, polysomnography type III (HSAT) as defined in the AASM rules [36]. The lateral wall techniques identified in the comparative analysis were ESP [16], BRP [19], and LEP [15]. The pooled BMI of the patients was 28.1 ± 0.9, of which UPPP 27.5 ± 1.3, BRP 28.8 ± 2.6, ESP 27.6 ± 0.7, and LEP 27.3 ± 1.41 (Table 1). A significant difference in sex ratio was found (75% men vs. 25% women; $p < 0.001$). Two papers reported a patient's neck diameter of 41.3 ± 3.3 cm [15, 29].

Lateral approaches

Nine papers, with a total of 186 patients, reported both pre-and post-operative mean value ± *SD* of the AHI scores (Table 1). In particular, the analysis of pooled AHI outcomes showed a significant reduction from the value of 35.8 ± 8.2 to 14.1 ± 4.5 at post-operative follow-up, of which from 32.5 ± 10.1 to 16.9 ± 8.6 for UPPP, from 29.8 ± 6.0 to 14.6 ± 1.6 for BRP, from 34.9 ± 8.5 to 11.5 ± 2.8 for ESP while from 28.6 ± 12.8 to 12.9 ± 2.1 for LEP ($p < 0.001$) (Fig. 3a). The analysis using random-effects modeling for 154 lateral procedures (7 papers) demonstrated a MD ranging from 11.0 to 24.4 [95% CI 0.04, 36.2] of the AHI score. BRP and ESP presented an overall effect Z score = 2.77 and 4.03, Q statistic $p = 010$, and $p < 0.00001$ (statistically significant heterogeneity), $I^2 = 63\%$ and $I^2 = 92\%$, respectively, as described in Fig. 4. Instead, the LEP procedure at random-effects modeling demonstrated an overall effect Z-score = 1.97, Q statistic $p = 0.006$ (statistically significant heterogeneity), $I^2 = 81\%$ (high inconsistency) [15, 29, 31].

Four papers analyzed the ESS outcomes after surgical treatment, demonstrating a significant reduction from 11.1 ± 1.8 to 4.5 ± 0.5 ($p < 0.001$) as shown in Fig. 3b [27, 28, 30, 31]. The ESS outcomes at random-effects modeling for 96 patients showed a MD ranging from 4.98 to 8.50 [95% CI 2.31, 10.29] as reported in Fig. 5. At subgroup analysis BRP demonstrated an overall overall effect Z-score = 3.66 ($p = 0.0003$), Q statistic $p = 0.11$ (no significant heterogeneity), $I^2 = 61\%$ (moderate inconsistency), with an overall Z-score = 4.35 ($p < 0.0001$), Q statistic $p = 0.07$ (no significant heterogeneity), $I^2 = 63\%$ (moderate inconsistency) for ESP patients.

The LOS were reported in 3 papers (52 patients), with a significant score improvement from the value of 77.0 ± 2.5 to 86.3 ± 6.0 ($p < 0.001$) (Fig. 3c). Furthermore, random-effects modeling showed an MD ranging from − 6.80 to 11.59 [95% CI − 18.76, − 2.74] as reported in Fig. 6. At subgroup analysis LEP demonstrated an overall effect Z-score = 3.17 ($p = 0.002$), Q statistic $p = 0.11$ (no significant heterogeneity), and $I^2 = 60\%$ (moderate inconsistency).

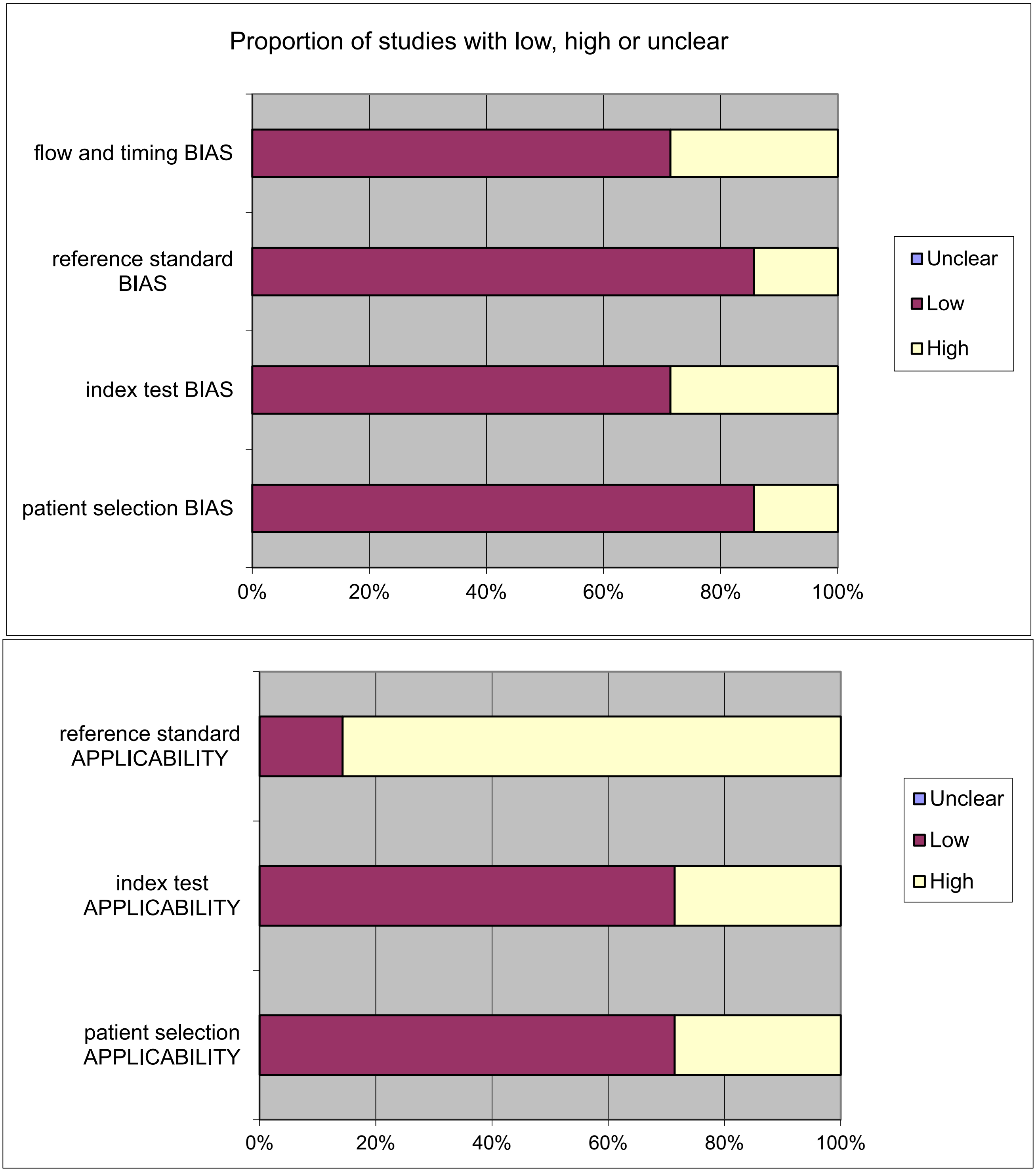


Fig. 2 QUADAS-2 risk of BIAS

Uvulopalatopharyngoplasty

AHI outcomes were reported in 9 papers (126 subjects), demonstrating a significant decrease from the value of 32.3 ± 9.5 to 16.2 ± 8.5 ($p < 0.001$)(Fig. 3a). We included in the quantitative analysis 97 OSA patients treated with UPPP [15, 16, 27–31]. Pre- and post-operative mean values ± *SD* of the AHI scores are summarized in Table 1. The analysis using random-effects modeling for the UPPP approach showed an MD of 16.64 [95% CI 12.81, 20.48] of

Table 1 Main demographic features and post operative surgical outcomes of the study included

References	Study design	Patients	BMI	Age	Pre-operative AHI	Post-operative AHI	Pre-operative ODI	Post-operative ODI	Pre-operative LOS	Post-operative LOS	Pre-operative ESS	Post-operative ESS
Cammaroto et al. *2017* [27]	Retrospective study	BRP (*n* = 10) UPPP (n = 10) ESP (*n* = 10)	28.77 ± 2.5 26.7 ± 3.7 27. ± 22.1	48.2 ± 11.3 58.4 ± 9.9 52.8 ± 11.3	34.04 ± 14.03 37.84 ± 21.60 35.59 ± 13.87	13.53 ± 7.76 22.92 ± 13.30 9.63 ± 9.25	nd nd nd	nd nd nd	nd nd nd	nd nd nd	10.4 ± 2.5 11.3 ± 4.24 13 ± 4.49	3.9 ± 3.57 4.9 ± 3.87 4.9 ± 3.47
Rashwan et al. *2017* [34]	Retrospective Study	BRP (n = 25) UPPP (*n* = 25) ESP (n = 25)	nd nd nd	nd nd nd	25.58 ± 14.6 18.96 ± 17.79 19.14 ± 9.66	15.76 ± 14.5 6.08 ± 5.5 10.13 ± 5.3;	24.3 ± 17.7 17.9 ± 16.6 16.3 ± 8.9	15. ± 17.6 7.1 ± 6.8 6.48 ± 7.9	80.5 ± 7.5 77.6 ± 12 86.5 ± 4.6	nd nd nd	9.28 ± 3.1 8.8 ± 3.23 8.96 ± 3.36	5.52 ± 4.1 1.36 ± 1.9 4.84 ± 3.3
Vicini et al. *2013* [30]	Retrospective study	TORS-UPPP (*n* = 12) TORS-ESP (*n* = 12)	27.34 28.19	54.16 49.5	38.38 ± 19.69 38.53 ± 14.35	19.81 ± 14.06 9.89 ± 8.59	Nd nd	nd nd	nd nd	nd nd	nd nd	nd nd
Carrasco-Llatas 2015 [29]	Retrospective study	UPP (*n* = 7) ESP (*n* = 10) LEP (*n* = 10)	28.5 ± 4.1 27.5 ± 3.5 27.3 ± 3.6	43.9 ± 9.7 40 ± 7.3 41.5 ± 8.4	47.3 ± 27.1 37.8 ± 21.5 48 ± 35.5	12 ± 7.1 10.5 ± 8.7 15.2 ± 12.3	30.4 ± 11.6 30.4 ± 11.6 30.4 ± 11.6	14.3 ± 21.8 14.3 ± 21.8 14.3 ± 21.8	79.5 ± 10.6 79.5 ± 10.6 79.5 ± 10.6	84.1 ± 12.5 84.1 ± 12.5 84.1 ± 12.5	9.7 ± 4.8 9.7 ± 4.8 9.7 ± 4.8	nd nd nd
Pang et al. *2007* [16]	Prospective study	UPP (*n* = 22) ESP (*n* = 22)	28.7 28.7	42.1 42.1	38.1 ± 6.6 44.2 ± 10.2	19.6 ± 7.9 12.0 ± 6.6	nd nd	nd nd	75.1 ± 5.9 78.4 ± 8.52	86.6 ± 2.2 85.2 ± 5.1	nd nd	nd nd
Steinbichler et al. *2017* [32]	Prospective clinical trial	UPPP (*n* = 4) ESP (*n* = 3)	nd nd	nd nd	19.75 ± 10.96 32.66 ± 37.54	5.75 ± 6.39 25 ± 39	nd nd	nd nd	nd nd	nd nd	nd nd	nd nd
Chi et al. *2015* [33]	Retrospective study	UPP (*n* = 29) UPPP + LP (*n* = 25)	28.4 ± 5.7 27.0 ± 4.6	36.4 ± 10.5 43.7 ± 9.9	30.6 ± 23.1 34.1 ± 25.8	21.3 17.3	nd nd	nd nd	80.2 ± 9.2 79.9 ± 8.3	84.7 84.5	11.2 ± 5.5 10.5 ± 5.2	nd nd
Cahali et al. *2004* [35]	Randomized trial	UPP (*n* = 12) LEP (*n* = 15)	30.1 29.3	nd nd	34.6 ± 16.25 14.38 ± 6.14	29.96 ± 21.58 12.07 ± 9.07	nd nd	nd nd	68.65 ± 22.33 74.13 ± 11.57	75.21 ± 12.94 80.96 ± 12.13	nd nd	nd nd
Dizdar et al. *2015* [31]	Retrospective study	UPP (*n* = 9) LEP (*n* = 14)	nd nd	43.1 ± 6.6 43.1 ± 6.6	25.1 ± 11.4 23.4 ± 9.9	8.0 ± 4.3 11.3 ± 5.6	nd nd	nd nd	92.8 ± 6.1 78.4 ± 4.4	94.9 ± 3.9 92.8 ± 6.1	15.1 ± 2.6 15.3 ± 2.9	5.1 ± 1.6 6.8 ± 1.8

BMI, body mass index; *AHI*, apnea–hypopnea index; *ODI*, oxygen desaturation index; *LOS*, lowest oxygen saturation; *ESS*, Epworth sleepiness scale; *BRP*, barbed reposition pharyngoplasty; *UPPP*, uvulopalatopharyngoplasty; *ESP*, expansion sphincter pharyngoplasty; *TORS*, transoral robotic surgery; *nd*, not defined

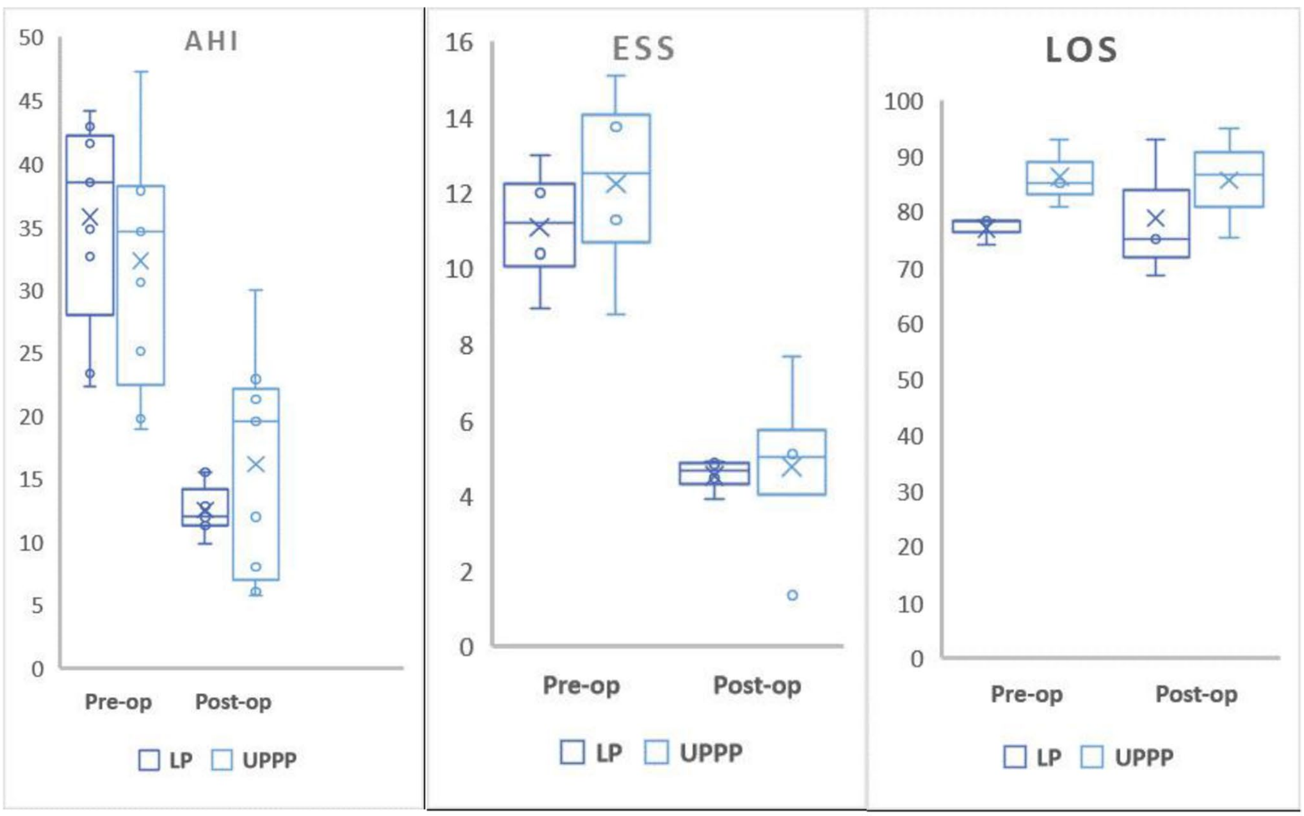
Table 2 GRADE summary of findings after systematic review

Certainty assessment							Certainty	
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations		
9	Observational Studies	Serious[a]	Not serious	Not serious	Not serious	None	⊕⊕◯◯	low

[a]Most studies do not identify confounding factors. Failure to identify these factors may lead to spurious interpretation of results

[b]Not different summary estimates across studies

[c]Not wide confidence intervals and ability to meta-analyze the results in seven of 9 papers



(A) (B) (C)

Fig. 3 **A**, **B**, **C** Overall mean of differences of AHI, ESS and LOS values between post-surgery time and pre-surgery time among two groups as visualized by the boxplots. The bottom and top of the box are the first and the third quartiles, and the band inside the box is the median; whiskers represent 1° and 99° percentiles; values that are lower and greater are shown as circles. Both surgical approaches resulted in a significant improvement in parameters ($p < 0.001$ in all cases). No significant differences were found between LP and UPPP post-operative outcomes ($p > 0.05$ in all cases)

the AHI score. The reported overall effect *Z*-score was 8.50 ($p < 0.0001$), *Q* statistic $p = 0.29$ (no significant heterogeneity), $I^2 = 18\%$ (low inconsistency) as described in Fig. 4. The ESS decreased after treatment from 12.2 ± 2.8 to 4.8 ± 2.6 ($p < 0.001$). The random-effects modeling for 56 patients showed an MD of 7.80 [95% CI 6.06, 9.55] as reported in Fig. 3b, Z = 8.75 ($p < 0.0001$), *Q* statistic $p = 0.09$, $I^2 = 53\%$ (moderate inconsistency).

UPPP patients reported a significant LOS improvement from a value of 78.9 ± 12.5 to 85.6 ± 9.9 ($p < 0.001$). The random-effects modeling demonstrated an MD of − 6.97 [95% CI − 14.65, 0.71], an overall effect *Z*-score = 1.78

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 UPPP								
Cahali 2004	34.6	16.25	12	29.96	21.58	12	4.5%	4.64 [-10.64, 19.92]
Cammaroto 2017	37.84	21.6	10	22.92	13.3	10	4.4%	14.92 [-0.80, 30.64]
Carrasco-Llatas 2015	47.3	27.1	7	12	7.1	7	3.3%	35.30 [14.55, 56.05]
Dizdar 2015	25.1	11.4	9	8	4.3	9	6.6%	17.10 [9.14, 25.06]
Pang 2007	38.1	6.6	22	19.6	7.9	22	7.5%	18.50 [14.20, 22.80]
Rashwan 2017	18.96	17.79	25	6.08	5.5	25	6.8%	12.88 [5.58, 20.18]
Vicini 2013	38.38	19.69	12	19.81	14.06	12	5.0%	18.57 [4.88, 32.26]
Subtotal (95% CI)			**97**			**97**	**38.2%**	**16.64 [12.81, 20.48]**
Heterogeneity: Tau² = 4.85; Chi² = 7.31, df = 6 (P = 0.29); I² = 18%								
Test for overall effect: Z = 8.50 (P < 0.00001)								
1.1.2 BRP								
Cammaroto 2017	34.04	14.03	10	13.53	7.76	10	6.0%	20.51 [10.57, 30.45]
Rashwan 2017	25.58	14.6	25	15.76	14.5	25	6.6%	9.82 [1.75, 17.89]
Subtotal (95% CI)			**35**			**35**	**12.6%**	**14.75 [4.31, 25.20]**
Heterogeneity: Tau² = 35.82; Chi² = 2.68, df = 1 (P = 0.10); I² = 63%								
Test for overall effect: Z = 2.77 (P = 0.006)								
1.1.3 ESP								
Cammaroto 2017	35.59	13.87	10	9.63	9.25	10	5.9%	25.96 [15.63, 36.29]
Carrasco-Llatas 2015	37.8	21.5	10	10.5	8.7	10	4.8%	27.30 [12.92, 41.68]
Pang 2007	44.2	10.2	23	12	6.6	23	7.4%	32.20 [27.23, 37.17]
Rashwan 2017	19.14	9.66	25	10.13	5.3	25	7.5%	9.01 [4.69, 13.33]
Vicini 2013	38.53	14.35	12	9.89	8.59	12	6.2%	28.64 [19.18, 38.10]
Subtotal (95% CI)			**80**			**80**	**31.8%**	**24.35 [12.51, 36.18]**
Heterogeneity: Tau² = 160.74; Chi² = 53.26, df = 4 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 4.03 (P < 0.0001)								
1.1.4 LEP								
Cahali 2004	14.38	6.14	15	12.14	9.07	15	7.3%	2.24 [-3.30, 7.78]
Carrasco-Llatas 2015	48	35.5	10	15.2	12.3	10	2.9%	32.80 [9.51, 56.09]
Dizdar 2015	23.4	9.9	14	11.3	5.6	14	7.2%	12.10 [6.14, 18.06]
Subtotal (95% CI)			**39**			**39**	**17.3%**	**11.03 [0.04, 22.02]**
Heterogeneity: Tau² = 65.55; Chi² = 10.28, df = 2 (P = 0.006); I² = 81%								
Test for overall effect: Z = 1.97 (P = 0.05)								
Total (95% CI)			**251**			**251**	**100.0%**	**17.91 [12.95, 22.87]**
Heterogeneity: Tau² = 80.11; Chi² = 101.68, df = 16 (P < 0.00001); I² = 84%								
Test for overall effect: Z = 7.08 (P < 0.00001)								
Test for subgroup differences: Chi² = 2.75, df = 3 (P = 0.43), I² = 0%								

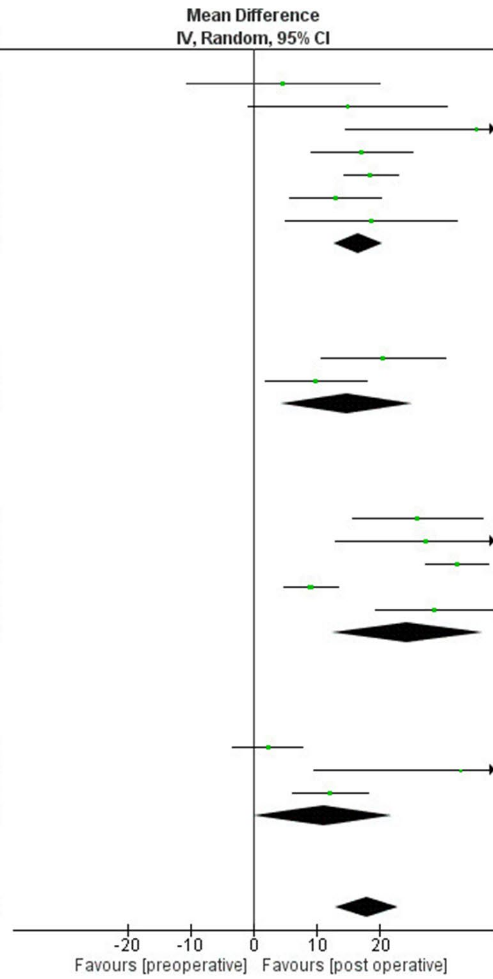
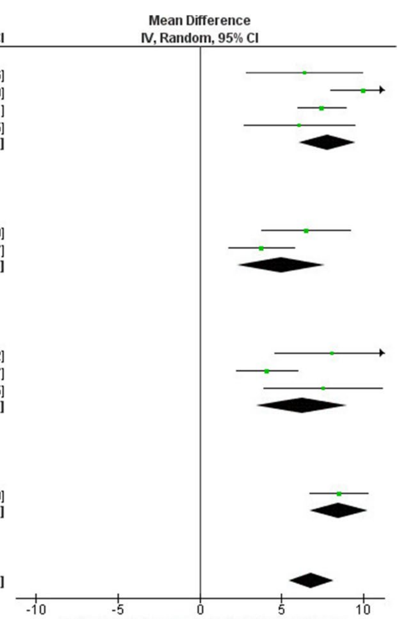


Fig. 4 Forest plot AHI comparison LP vs. UPPP

Fig. 5 Forest plot ESS comparison LP vs. UPPP

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.2.1 UPPP								
Cammaroto 2017	11.3	4.24	10	4.9	3.87	10	7.6%	6.40 [2.84, 9.96]
Dizdar 2015	15.1	2.6	9	5.1	1.6	9	11.5%	10.00 [8.01, 11.99]
Rashwan 2017	8.8	3.23	25	1.36	1.9	25	12.8%	7.44 [5.97, 8.91]
Vicini 2013	13.75	4	12	7.66	4.4	12	8.0%	6.09 [2.73, 9.45]
Subtotal (95% CI)			**56**			**56**	**39.9%**	**7.80 [6.06, 9.55]**
Heterogeneity: Tau² = 1.62; Chi² = 6.42, df = 3 (P = 0.09); I² = 53%								
Test for overall effect: Z = 8.75 (P < 0.00001)								
1.2.2 BRP								
Cammaroto 2017	10.4	2.5	10	3.9	3.57	10	9.6%	6.50 [3.80, 9.20]
Rashwan 2017	9.28	3.1	25	5.52	4.1	25	11.4%	3.76 [1.75, 5.77]
Subtotal (95% CI)			**35**			**35**	**21.0%**	**4.98 [2.31, 7.64]**
Heterogeneity: Tau² = 2.28; Chi² = 2.54, df = 1 (P = 0.11); I² = 61%								
Test for overall effect: Z = 3.66 (P = 0.0003)								
1.2.3 ESP								
Cammaroto 2017	13	4.49	10	4.9	3.47	10	7.7%	8.10 [4.58, 11.62]
Rashwan 2017	8.96	3.36	25	4.84	3.3	25	11.9%	4.12 [2.27, 5.97]
Vicini 2013	12	4.9	12	4.46	4.1	12	7.5%	7.54 [3.93, 11.15]
Subtotal (95% CI)			**47**			**47**	**27.0%**	**6.23 [3.43, 9.04]**
Heterogeneity: Tau² = 3.87; Chi² = 5.46, df = 2 (P = 0.07); I² = 63%								
Test for overall effect: Z = 4.35 (P < 0.0001)								
1.2.4 LEP								
Dizdar 2015	15.3	2.9	14	6.8	1.8	14	12.0%	8.50 [6.71, 10.29]
Subtotal (95% CI)			**14**			**14**	**12.0%**	**8.50 [6.71, 10.29]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 9.32 (P < 0.00001)								
Total (95% CI)			**152**			**152**	**100.0%**	**6.83 [5.43, 8.23]**
Heterogeneity: Tau² = 3.40; Chi² = 31.85, df = 9 (P = 0.0002); I² = 72%								
Test for overall effect: Z = 9.57 (P < 0.00001)								
Test for subgroup differences: Chi² = 5.50, df = 3 (P = 0.14), I² = 45.4%								



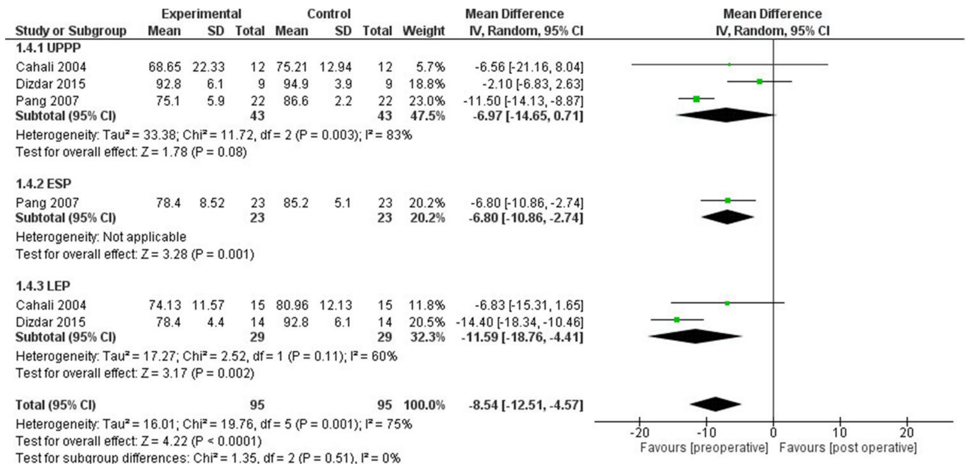


Fig. 6 Forest plot LOS comparison LP vs. UPPP

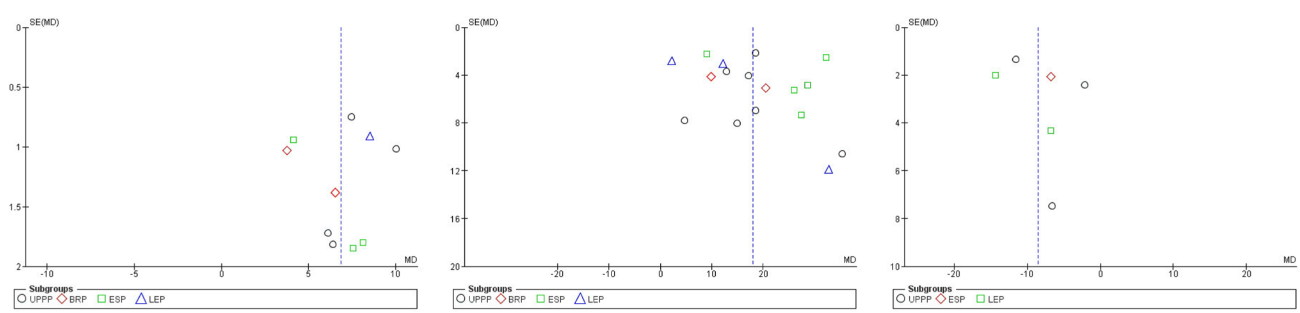
($p = 0.08$), Q statistic $p = 0.003$ (significant heterogeneity), $I^2 = 83\%$ (high inconsistency) (Fig. 6).

Assessment of publication bias

There was evidence of publication bias for studies reporting the association between AHI, ESS, and LOS outcomes at follow-up and surgical procedures. As analyzed in Fig. 7, asymmetry of the funnel plot was obtained for all the parameters assessed, suggesting that publication bias may exist (Fig. 7). For AHI outcomes and 17 imputed studies, under the random-effects model, the point estimate, and pseudo 95% CI for the combined studies was 1.48767 (1.06972, 1.90561); using the trim–fill method, the imputed point estimate was 0.98014 (0.50778, 1.4525) (Table 3). In addition, under the fixed-effects model, the point estimate and 95% CI for the combined studies was 1.32224 (1.12239, 1.52209); using the trim–fill method, the imputed point estimate was 0.94011 (0.76087, 1.11934). For ESS levels and 10 imputed studies, under the fixed-effects model, the point estimate and 95% CI for the combined studies was 1.67798 (1.39677, 1.95919), and using trim–fill method, the imputed point estimate is 1.29469 (1.04701, 1.54237). In addition, under the random-effects model, the point estimate and pseudo 95% CI for the combined studies was 1.88326 (1.34324, 2.42327); using the trim–fill method, the imputed point estimate was 1.33052 (0.72602, 1.93502).

Discussion

The introduction of drug-induced sleep endoscopy into clinical practice allowed the clear identification of velopharyngeal obstruction sites, in particular the collapse of the lateral pharyngeal wall, and led to more innovative surgical procedures aiming at less invasive palate surgery than classical UPPP surgery [15, 16, 19, 35, 37–46]. However, the current literature does not agree on the effective preeminence of a specific surgical treatment. Cammaroto et al., in 2017, demonstrated better post-operative AHI outcomes and surgical success rates in BRP and ESP techniques compared to the UPPP procedure [27]. Instead, Vicini et al. compared the ESP and UPPP techniques in a retrospective analysis, exhibiting a post-operative AHI of 9.9 ± 8.6 for patients undergoing ESP vs. 19.8 ± 14.1 for UPPP patients ($p < 0.04$) [30].



A) *AHI* **B)** *ESS* **C)** *LOS*

Fig. 7 **A**, **B**, **C** Funnel plots. Funnel plot for publication bias in studies on AHI, ESS and LOS outcomes after surgery. The asymmetry of the funnel plot suggests that publication bias may exist in all the parameters analyzed

Table 3 Duval and Tweedies trim-and-fill method was performed to assess publication bias

Value	Studies trimmed	Fixed effects			Random effects			Q value
		Point estimate	Lower limit	Upper limit	Point estimate	Lower limit	Upper limit	
AHI								
Observed		1.32224	1.12239	1.52209	1.48767	1.06972	1.90561	66.37436
Adjusted	6	0.94011	0.76087	1.11934	0.98014	0.50778	1.4525	147.45862
ESS								
Observed		1.67798	1.39677	1.95919	1.88326	1.34324	2.42327	26.5783
Adjusted	4	1.29469	1.04701	1.54237	1.33052	0.72602	1.93502	65.61042
LOS								
Observed		-1.15948	-1.47972	-0.83923	-1.24525	-2.04354	-0.44697	29.98487
Adjusted	0	-1.15948	-1.47972	-0.83923	-1.24525	-2.04354	-0.44697	29.98487

Although the pooled comparison between AHI results of 141 UPPP and 192 LP patients' follow-ups was not significant (0.07), our meta-analysis showed considerable heterogeneity ($p < 0.00001$; $Z = 7.08$; $I^2 = 84\%$), with better post-operative improvements in lateral procedures (Fig. 3a) (Fig. 4).

The relationship between the different techniques and the daytime sleepiness measured by the Epworth scale is also unclear. Rashawn et al., from a cohort of 75 OSA patients treated with two different surgical techniques, reported significantly better ESS improvements for UPPP with respect to LP patients (1.4 ± 1.9 vs. 5.5 ± 4.1; $p < 0.001$) [28]. In contrast, from the analysis of the surgical outcomes on daytime sleepiness follow-up, Cammaroto et al. did not find a significant difference between LP and UPPP procedures, and between the lateral approaches ($p < 0.44$) [27]. In this regard, our study confirmed a not relevant difference in the sleepiness improvement depending on the treatment used ($p = 0.86$). The test for subgroup differences demonstrated a low heterogeneity (Q statistic $p = 0.14$; I2 = 45.4%). However, the included studies often exhibited patient asymmetry within the different procedures, and not all authors included a sufficient patient number in their study to compare the different surgical modalities. Furthermore, prospective or randomized controlled observational studies were not sufficiently present in the literature, often limited to smaller retrospective studies. A crucial factor in OSAS is the partial or total closure of the airways during sleep, resulting in the lowest oxygen saturation [15, 31].

Our analysis confirmed the authors' hypothesis, demonstrating a post-operative improvement in LOS compared to pre-operative improvement in the absence of a significant difference between the two methods ($p = 0.91$) (Fig. 3c) and the test for subgroup differences showed a lack of sample heterogeneity ($Chi^2 = 1.35$; $p = 0.51$; $I^2 = 0\%$).

Although this meta-analysis has described several outcomes of the selected comparative studies, various limitations are present. Mainly, the literature to date lacks papers directly comparing the lateral pharyngoplasty procedures vs. the UPPP approach.

However, it should be considered that UPPP has recently shown a downward trend in frequency of use due to related post-operative complications such as nasal regurgitation and swallowing disorders [47–50]. A recent systematic review by Tang et al. reported long-term UPPP follow-up burdened with complications such as velopharyngeal insufficiency (VPI) and foreign body sensation, frequently expected after surgery. On the contrary, barbed pharyngoplasty techniques present only transient and self-resolving velopharyngeal insufficiency but could extrude the barbed sutures [17, 22].

Another limitation of the studies in the literature is the lack of the analysis of subjective post-operative results [20, 51]. The patient could perceive, with the same objective outcomes, an efficacy or a better quality of life according to the degree of satisfaction of patients with a score recommended by Rashwan et al. called "Score of the postoperative problems of the palate'' (PPOPS) [34].

Another limitation found is that the authors did not calculate statistical power in any of the identified papers, often due to a small sample size. This phenomenon leads to awareness and the need for future studies with larger samples.

Conclusion

This meta-analysis focused on recent trends in velopharyngeal techniques based on obstructive site assessment through DISE. Although promising results were shown for lateral pharyngoplasty techniques, to date, these constitute only partial data, and no significant difference with UPPP. However, UPPP-related post-operative complications must be considered when choosing the surgical approach. Much more evidence is needed to establish the validity and effectiveness of one procedure compared to the other.

Acknowledgements We thank Professor Antony Bridgewood for the significant guidance provided during the drafting of the manuscript.

Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Ethical approval All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication All authors give consent to the publication.

Conflict of interest The author declares no competing interests.

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