


**Research Article**

## Systematic Review of the Effect of Upper Airway Surgery based on DISE findings in Adults with Obstructive Sleep Apnea

Bertelsen JB<sup>1\*</sup>, Ovesen T<sup>1,2</sup>, Zainali-Gill K<sup>1</sup>

### Abstract

**Introduction:** Obstructive sleep apnea (OSA) is common among adults worldwide and is associated with an increased risk of both cardiac, metabolic, and mental disease and an increased risk of traffic accidents. However, evidence of the different types of upper airway surgery to relieve OSA symptoms is sparse. Whether Drug induced sedation endoscopy (DISE) can improve the outcome of the various surgical techniques in the upper airways (UA) is uncertain. The objective of this review was to evaluate the effectiveness of UA surgery in adults with OSA by change in apnea-hypopnea index (AHI) with minimum three months follow-up in studies where DISE was used.

**Methods:** Cochrane, PubMed, CINAHL and Embase were systematically searched on March the 22<sup>nd</sup> 2022. Relevant studies were selected on abstracts and full texts were obtained for critical appraisal. Relevant data was extracted for data synthesis. The reference list of all studies selected for critical appraisal was screened for additional studies. Studies included were randomized controlled trials, prospective and retrospective studies, case-control studies and cohort studies of one or a combination of surgeries on the upper airways in adults diagnosed with OSA and obstruction verified by DISE before surgery published from January 1<sup>st</sup> 2000 to 31<sup>th</sup> of December 2021. AHI was reported prior to and minimum three months after surgery by polysomnography or home sleep apnea test and a minimum of 40 participants were included. Surgery in the upper airways such as soft tissue of the retropharyngeal space, velum, tonsils and base of tongue (BOT) were included. Cartilage and osseous surgery as septoplasty, turbinoplasty, mandibular advancement surgery, epiglottoplasty and tracheostomy were included plus studies of hypoglossal nerve stimulation implant insertion.

**Results:** Studies were excluded due to small sample size, lack of postoperative AHI or if DISE was not a part of preoperative evaluation. Eighteen studies were finally eligible for review with a total of 1182 patients. The studies could be divided into four segments, comprised by six studies of surgery of the velum and oropharynx (401 patients), one study addressing BOT (70 patients), and seven studies of multilevel surgery (388 patients). Four studies with upper airway stimulation by hypoglossal nerve stimulation implant (323 patients) were also included. Velum and oropharynx surgery led to an average decrease in AHI of 14.0 events per hour (e/h), 95% CI (12.6; 15.4). Epworth Sleep Scale (ESS) was reduced with 7.62, 95% (6.95; 8.30). In BOT surgery, AHI was reduced with 17.7 e/h, 95% CI (15.7; 19.7), ESS was reduced with 7.90, 95% CI (7.15; 8.64). Multilevel surgery reduced AHI with 25.0 e/h, 95% (22.8; 27.2) and ESS with 5.51, 95% (4.62; 6.39) 5. Upper airway stimulation showed a decrease in AHI of 21.1 e/h, 95% CI (18.9, 23.3), and a reduction in ESS of 4.98, 95% CI (4.25; 5.71).

### Affiliation:

<sup>1</sup>University Clinic for Balance, Flavour and Sleep, ENT Department, Godstrup Hospital, 7400 Herning, Denmark

<sup>2</sup>Department of Clinical Medicine, Aarhus University, Denmark

### \*Corresponding author:

Bertelsen JB, University Clinic for Balance, Flavour and Sleep, ENT Department, Godstrup Hospital, 7400 Herning, Denmark.

**Citation:** Bertelsen JB, Ovesen T, Zainali-Gill K. Systematic Review of The Effect of Upper Airway Surgery based on DISE findings in Adults with Obstructive Sleep Apnea. *Journal of Surgery and Research*. 6 (2023): 49-65.

**Received:** November 07, 2023

**Accepted:** November 16, 2023

**Published:** March 09, 2023









**Table 1:** General characteristics of included studies in upper airway surgery for obstructive sleep apnea

General study characteristics									
Author, year	Type of study	Follow-up in months	Mean age of patients (no. of patients)	Mean BMI (sd)	Inclusion criteria	Exclusion criteria	Outcomes analyzed	LOE	Comments
<b>Velum / Oropharynx</b>									
Amali 2017	Randomized controlled trial	6	37.4 ± 10.07 (40)	27.7 (4.3)	Age>18, Symptomatic OSA with 5≤AHI30, No prior treatment, BMI≤35, ASA ≤3	AHI≥30, Tongue base or epiglottis obstruction, previous history of palatal surgery, severe comorbidities, depression	AHI, Nadir O2, Mean O2, ESS, SAQLI	2	Polysomnography
Babademez 2019	Retrospective cohort study	12-18	Barbed palatoplasty 37.3 ± 8.9 (45) ESPwAP 41.6 ± 9.4 (53)	Barbed palatoplasty 29.3 (3.1) ESPwAP 28.8 (4.2)	AHI 5- 30 Tonsillectomy + isolated palatal surgery	Lost to follow-up < 6 months, revision surgery, multilevel obstruction, patients operated for tonsillar disease	AHI, ESS, surgical success, AHI reduction ratio, surgical time, time to oral diet, analgesic requirement	4	Polysomnography
Elzayat 2020	Prospective cohort study	6	39.2 ± 6.66 (40)	N/A	Age>18, OSA, CPAP failure, no history of previous sleep surgery	Previous palatal surgery, craniofacial anomalies	AHI, STOP-BANG, Snoring Index, nadir O2, mean O2, Operation time, Complications,	3	Polysomnography
Hong 2019	Cohort study	6	42.1 range 20 -54 (63)	27.58 (range 19-32.1)	AHI>15, retropalatal circumferential narrowing above DISE grade II (>75% narrowing), narrowed oropharynx due to lateral pharyngeal collapse	None mentioned	AHI, Nadir O2, VAS snoring, surgical success, CT-scan	3	Polysomnography. Patients underwent different surgical treatments such as septoplasty and UP-flap prior treatment.
Plaza 2019	Prospective multi-center cohort study	12	46.7 ± 10.5 (75)	28.1 (2.7)	CPAP failure, age between 18 and 75, BMI≤35, ASA≤2, AHI 5-70, lateral wall collapse on oropharynx	Age ≥75, severe medical illness, limited mouth opening ≤2cm Tonsil size ≥3, FTP≥3, LTH≥3 and follow-up under 12 months.	AHI, ESS, Surgical success	3	Polysomnography
Süslü 2021	Retrospective case series	3-4	44 range 22-65 (85)	30.12 (4.02)	Isolated first-step surgery for treatment of OSA. CPAP failure	MAD, multi-level surgery	AHI, ODI, mean O2, nadir O2, supine AHI and non-supine AHI ratio	4	Polysomnography
<b>BOT</b>									
Babademez 2019	Randomized controlled trial	6	TORS 40.9 ± 9.2 (37) Coblation 39.4 ± 8.5 (33)	TORS 27 (4.4) Coblation 28.3 (3.9)	CPAP failure, moderate to severe OSA, BMI≤35, tonsil size 1-2	Limited mouth opening, severe comorbidities, known bleeding disorder, previous tonsillectomy, lost to follow-up	AHI, ESS, VAS snoring, surgical success, time to oral diet, analgesic requirement	2	Polysomnography
<b>Multilevel</b>									
Baghat 2020	Randomized controlled trial	6	Ablation 42.36 ± 9.087 (25) Robo-Cob 41.36 ± 8.727 (25)	Ablation 31.28 (2.965) Robo-Cob 30.48 (3.885)	AHI >15, age 18-65, BMI<35, CPAP failure, collapse of tongue base during DISE	Serious psychiatric disease, cardiopulmonary or neurological disease, ASA 3-4, previous OSA surgery, mainly palatal or lateral wall collapse	AHI, surgery time, complications, pain VAS, volume of tissue removed	2	Polysomnography
Cammaroto 2018	Retrospective cohort study	12	55.47 ± 11.56 (51)	29.12 (8.9)	CPAP failure, moderate to severe OSA (AHI > 20)	Prior airway surgery, postoperative PSG shorter than 12 months	AHI, tongue volume (cc) Lymphatic/soft tissue ratio, total thickness, surgical success	4	Unattended type 3 home sleep study and Polysomnography used.
El-Anwar 2018	Prospective (non-randomized) case-control	6-14	Group A 47.1 ± 9.2 (20) Group B 46.0 ± 4.7 (20)	Group A 33.4 (2.5) Group B 33.4 (2.01)	Moderate to severe OSA (AHI>15) BMI<35	Prior airway surgery, lost to follow-up.	AHI, ESS, nadir O2, Snoring score	3	Sleep registration type not stated.
Hwang 2017	Retrospective case-control study	4	Lat. Pharyngoplasty + TORS 45.1 ± 13.4 (16) Lat. Pharyngoplasty + Coblation 39.8 ± 10.8 (29)	Lat. Pharyngoplasty + TORS 25.8 (3.4) Lat. Pharyngoplasty + Coblation 26.8 (2.8)	AHI > 15 Retroglossal obstruction	Previous OSA surgery	AHI, ESS, Improvement rate, success rate, nadir O2, operation time, hospital stay, adverse events	4	Polysomnography DISE not performed in all patients.

Thaler 2016	Prospective non-randomized trial with historical controls.	3	49.7 (SD not stated) (n=75) Prior surgery N = 31 No prior surgery N = 45	32.3 (5.61)	CPAP failure, moderate to severe OSA (AHI > 20)	None stated	AHI, ESS, Nadir O2, % of TST with O2<90%,	3	Polysomnography.
Tsou 2021	Retrospective case series with two comparative groups	6	TORS + UPPP 39.61 ± 11.63 (31) TORS + BRP 37.51 ± 9.42 (31)	TORS + UPPP 28.20 (3.62) TORS + BRP 28.22 (3.19)	Age >20, AHI > 15, Tonsils > 2, Mallampati > III, DISE: above 50% collapse of velum and oropharynx and tongue base	Tonsil < 2, tongue base reduction by coblation, loss of data	AHI, ESS, nadir O2, Arousal Index, cumulative time spent below 90%, surgical success, comorbidities	4	Polysomnography
Turhan 2019	Prospective observational cohort study	6	45.93 ± 10.40 (64)	30.50 (3.94)	AHI > 15 or positional AHI > 5 and supine AHI > 2 x non-supine AHI, tongue base collapse, CPAP failure	Unfit for general anesthesia, presence of retrognathia or mandibular hypoplasia, poor mouth opening	AHI, ESS, mean O2, nadir O2, ODI, adverse events, surgical success	3	Polysomnography
<b>Upper airway stimulation</b>									
Huntley 2017	Multi-center cohort study	3	TJUH 60.88 ± 11.12 (48) UPMC 62.84 ± 10.81 (49)	TJUH 29.29 (3.72) UPMC 27.74 (3.66)	CPAP failure, AHI > 15 No concentric collapse in oropharynx during DISE	BMI > 32, neuromuscular disease, hypoglossal nerve palsy, pulmonic disease, moderate-to-severe hypertension, NYHA 3-4, recent myocardial infarction or severe cardiac arrhythmias, active psychiatric disease, non-respiratory sleep disorder.	AHI, ESS, Nadir O2, surgical success	3	Polysomnography
Mulholland 2020	Prospective case series	3-6	64.4 ± 15.2 (46)	28.5 (3.7)	Age > 21, AHI > 15, BMI > 35, CPAP failure,	Lack of improvement of mandibular advancement during DISE, loss to follow-up, previous cleft palate or major reconstructive surgery in the oral cavity	Ahi, ESS, ODI, association between mandibular advancement during DISE and surgery	4	Polysomnography
Steffen 2018	Prospective multi-center cohort study	12	56.8 ± 9.1 (60)	28.8 (3.6)	CPAP failure, (AHI 15-65). No concentric collapse in oropharynx during DISE	Tonsil size 3-4 Additional anatomical abnormalities, such as long soft palate.	AHI, ODI, nadir O2, mean O2, ESS, FOSQ, % of TST with O2<90%,	3	2-night type3 home sleep test.
Strollo 2014	Prospective multi-center cohort study	12	54.5 ± 10.2 (126)	28.4 (2.6)	CPAP failure, AHI > 15. No concentric collapse in oropharynx during DISE	BMI > 32, neuromuscular disease, hypoglossal nerve palsy, pulmonic disease, moderate-to-severe hypertension, NYHA 3-4, recent myocardial infarction or severe cardiac arrhythmias, active psychiatric disease, non-respiratory sleep disorder.	AHI, ODI, FOSQ, ESS, % of TST with O2<90%, surgical success	3	Polysomnography. STAR-trial funded by implant company.

LOE (level of evidence) is based on Levels of Evidence for Oxford Centre for Evidence-Based Medicine 2011 OCEBM Levels of Evidence Working Group\*. "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine. <http://www.cebm.net/index.aspx?o=5653>

\* OCEBM Table of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson.

AHI = Apnea hypopnea Index

ASA = American Society of Anesthesiology score

BMI = Body Mass Index

CPAP = Continuous Positive Airway Pressure

DISE = Drug Induced Sedation Endoscopy

ESS= Epworth Sleepiness Scale

FOSQ = Functional Outcomes of sleep questionnaire.

ODI = Oxygen Desaturation Index

OSA = Obstructive Sleep Apnea

TST = Total sleep time

**Table 2:** Changes in AHI and ESS in the included studies in upper airway surgery for obstructive sleep apnea.

Study results							
Author, year	Pre-OP AHI Mean - sd	Post-OP AHI Mean - sd	Pre-OP ESS Mean - sd	Post-OP ESS Mean - sd	Sher's surgical success	Other outcomes	Comments and conclusions
<b>Velum / Oropharynx</b>							
Amali 2017	UPPP 20.15 ± 6.92 MRFTA 19.42 ± 6.04	UPPP 10.03 ± 3.28 MRFTA 13.39 ± 4.36	UPPP 12.07 ± 3.89 MRFTA 13.4 ± 6.02	UPPP 6.87 ± 1.99 MRFTA 7.67 ± 1.71	UPPP 73% MRFTA 40%	Mean SpO2 nadir in the UPPP group improved from 84.2% ± 3.96 to 88.47% ± 3.5 (p<0,01) and in the MRFTA group improved from 85.33% ± 2.79 to 87% ± 2.61 (p<0,01) with no significant differences between the two groups. SAQLI improved in both groups and reported higher in MRFTA group in two domains including social interaction and treatment-related symptoms.	Authors conclude that that for mild OSA, MRFTA is comparable to UPPP and can be considered as the first surgical treatment operation in patients with oropharyngeal lateral wall obstruction.
Babedemez 2019	Barbed Palatoplasty 25.9 ± 13.6 ESPwAP 28.5 ± 16.8	Barbed Palatoplasty 7.4 ± 5.5 ESPwAP 9.1 ± 6.9	Barbed Palatoplasty 11.2 ± 3.7 ESPwAP 12.6 ± 4.9	Barbed Palatoplasty 3.4 ± 1.4 ESPwAP 4.1 ± 1.8	Barbed Palatoplasty 86.6% ESPwAP 84.9%	Barbed palatoplasty (BP) required less analgesics and surgical time were also lower (statistically significant) No significant differences between the AHI reduction ratios between the two treatments.	The study showed similar success rates for BP and ESPwAP. The authors suggest that BP may be superior to ESPwAP in terms of less surgical time, no potential mucosal damage, absence of knots, and probably a faster recovery with less pain
Elzayat 2020	34.73 ± 12.81	16.59 ± 9.35	N/A	N/A	70%	Clinical variables such as Stop Bang score and snore index were significantly reduced. Nadir SpO2 improved from 79% ± 5.73 to 88.05% ± 3.46 (p<0.001) and baseline SpO2 improved from 96.23% ± 0.92 to 96.5% ± 0.91 (p=0.00004) Univariate analysis showed that high preoperative AHI and snore index predict operation failure.	The new Cahali lateral pharyngoplasty can be used as a stand-alone procedure in the absence of lateral wall collapse at the level of the hypopharynx, high tongue base collapse, laryngeal collapse or tongue palate interaction
Hong 2019	45 ± 10.7	17.3 ± 8.9	17.1 ± 5.4	7.2 ± 5.4	N/A	Mean SpO2 nadir improved from 78.2% ± 21.3 to 86.4% ± 10.6 with reported mean difference (95%) 8.6% (6.6%-10.6% Cohen d = 1,16).	ESP appears to be a promising surgical technique to reduce lateral pharyngeal collapse in patients with moderate or severe OSA. Clinical data suggest that both severe palatal circumferential narrowing and bulky lateral pharyngeal tissue are favorable surgical indications for ESP in patients with OSA.
Plaza 2019	22.1 ± 12.2	8.6 ± 6.7	11.5 ± 4.7	4.6 ± 6.6	90%	33,3% were cured (AHI<5, ESS<10 and AHI reduction>50%), 82,66% patients did not need CPAP after surgery. Using Sher's criteria 90% obtained AHI < 20. Seven patients failed surgery with two cases whose AHI worsened postoperative. Patients without a suitable PSG postoperatively or follow-up time under 12 months were excluded.	ESP technique can be done with good results as stand-alone procedure for patients with OSA, when proper patient selection based upon DISE.
Süslü 2021	48.7 ± 27.99	26.37 ± 21.16	N/A	N/A	51.8%	Both supine and non-supine apnea decreased significantly with the surgery, but the decrease was significantly higher in non-supine apnea (20.6% to 39.1% respectively, p = 0.016)	Non-supine apneas and hypopneas respond better to the surgery than supine apneas.
<b>Base of tongue</b>							
Babademez2019	TORS 29.7 ± 9 Coblation 27.2 ± 6.4	TORS 10.7 ± 3.9 Coblation 10.3 ± 4	TORS 12.1 ± 2.7 Coblation 11.4 ± 2.6	TORS 4.1 ± 1.9 Coblation 3.6 ± 1.6	TORS 75.6% Coblation 78.7%	Time to oral diet were significantly better for coblation group than TORS 4.2 days ± 1.2 vs 5.78 ± 0.91 (p=0.000). Time of analgesic requirement were significantly worse in the TORS group than in the Coblation 5.8 days ± 1.8 vs 4.1 ± 1.1 (p = .000) TORS preoperative snoring VAS 7.5 ± 1.3 improved to 2.9 ± 1.4 (p=0.000) Coblation preoperative snoring VAS 6.9 ± 1.4 improved to 2.6 ± 1 (p=0.000)	Overall, the results show promising results for treatment of OSA in patients with moderate to severe OSA and isolated tongue base obstruction based upon DISE findings with low risk of complications after 6 months of follow-up.



Multi-level							
Bahgat 2020	Ablation 36.96 ± 10.44 Robo-Cob 33.84 ± 10.55	Ablation 12.8 ± 6.47 Robo-Cob 11.52 ± 5.42	N/A	N/A	N/A	Mean surgical time in the Robo-Cob group was 35.8 ± 10.27 min while in the ablation group mean surgical time was 47.6 ± 7.37 min (p = 0.001). The study showed that resection of at least 10 cm3 of tongue base tissue was associated with better outcomes in terms of postoperative AHI (postoperative AHI was 9.8 ± 4.5 if the resected tissue volume was >10 cm3, otherwise it was 23.25 ± 2.8, p = 0.001)	Robo-Cob was found to be feasible and effective and well tolerated by patients undergoing multilevel surgery for severe OSA. Robo-Cob appears to be quicker than standard ablation technique.
Cammaroto 2018	39.97 ± 16.78	15.10 ± 11.36	N/A	N/A	74.5%	No correlations were observed in postoperative AHI and anatomical measures of removed base of tongue tissue.	Although the study did not show any differences in the primary measured outcomes, the observed reduction of AHI and the rate of surgical success reported, concur with previous studies published.
El-Anwar 2018	Group A 48.8 ± 31.6  Group B 68.4 ± 25.3	Group A 24.5 ± 10.9  Group B 25.6 ± 9.52	Group A 12.6 ± 5.6  Group B 13.8 ± 5.4	Group A 4.1 ± 2.7  Group B 5.2 ± 1.6	N/A	SpO2 nadir improved in both groups: Group A from 73.5% ± 14.8 to 84% ± 5.3 Group B from 66.8% ± 11.3 to 83.2% ± 2.9. The difference between preoperative and postoperative values in both groups was nonsignificant.  Change in snoring score in group A 3.8 ± 0.4 to 2.3 ± 0.51 Change in snoring score in group B 3.4 ± 0.54 to 2 ± 0.  The preoperative snoring score was reported to be significantly more in patients who had associated nasal obstruction (group A) (p=0.0113). But after surgery the difference in postoperative values were nonsignificant (P=0.1296)	The authors conclude that treatment of nasal obstruction should be considered a crucial component in the comprehensive management plan as it has significant impact on the patients' AHI and snoring.
Hwang 2017	Group 1 45.0 ± 19.3  Group 2 45.6 ± 20.6	Group 1 17.0 ± 9.2  Group 2 16.2 ± 14.1	Group 1 8.5 ± 5.2  Group 2 9.7 ± 4.0	Difference ESS shown: Group 1 3.5 ± 5.3 Group 2 2.1 ± 3.7	Group 1 56.3%  Group 2 62.1%	Nadir SpO2 was significantly improved in both the TORS and coblation groups. Nadir SpO2 increased from 79.8 ± 6.6% to 85.0 ± 5.6% (p = 0.005) in the TORS group and from 78.5 ± 7.4% to 85.3 ± 5.0% (p < 0.0001) in the coblation group  Surgical time and blood loss were not significantly different between the two groups. Mean hospital stay was in the two groups 8.2 ± 5.1 days and 4.4 ± 2.4 days, respectively. TORS patients had significantly longer hospital stays compared to coblation patients (p = 0.004)	Group 1: N =16. TORS with lateral pharyngoplasty Group 2: N = 29. Coblation with lateral pharyngoplasty  TORS was comparable to endoscope guided coblation tongue base resection. Group 1 showed non-inferior PSG outcomes, comparable complication rates, and prolonged hospitalization stay
Thaler 2016	57.5 ± 23.9	31.4 ± 28.6	12.8 ± 6.5	5.8 ± 4.9	45%	SpO2 Nadir improved from 78.8% ± 9.6 to 83.1% ± 7.3 % of TST with SpO2<90% improved from 16.9 ± 21.3 to 7.2 ± 15.3	The authors conclude that prior surgery did not appear to make any difference in the outcome of the study. Combined TORS and UPPP is suitable for selected patients in a multi-level approach.
Tsou 2021	Group 1 46.21 ± 22.03  Group 2 45.13 ± 19.31	Group 1 21.6 ± 21.54  Group 2 28.75 ± 23.09	Group 1 9.03 ± 4.52  Group 2 11.01 ± 4.52	Group 1 6.6 ± 3.82  Group 2 7.82 ± 3.45	Group 1 67.74%  Group 2 38.71 %	Group 1 was superior to group 2 when AHI reduction, AHI reduction rate and surgical success was compared (p <0.05). No significant differences were found in postoperative pain, length of hospital stay or complication rates.	Group 1: N = 31 TORS + BRP Group 2: N = 31 TORS + UPPP  TORS + UP3 seems inferior to TORS + BRP

Turhan 2019	Total n = 64 41.72 ± 21.28  Group 1 n = 7 37.31 ± 11.62  Group 2 n = 42 45.94 ± 21.48  Group 3 n = 15 32 ± 21.53	Total n = 64 18.82 ± 14.91  Group 1 n = 7 25.27 ± 15.22  Group 2 n = 42 20.63 ± 16.04  Group 3 n = 15 10.77 ± 6.88	Total n = 64 10.49 ± 5.19  Group 1 n = 7 12.28 ± 5.87  Group 2 n = 42 10.64 ± 5.56  Group 3 n = 15 9.14 ± 3.37	Total n = 64 4.09 ± 2.66  Group 1 n = 7 4.14 ± 2.60  Group 2 n = 42 3.92 ± 1.95  Group 3 n = 15 4.57 ± 4.29	Total n = 64 75%  Group 1 n = 7 42.9%  Group 2 n = 42 73.8%  Group 3 n = 15 93.3%	Surgical responders had significantly lesser total volume of tongue-base tissue removed (13.5 mL vs. 19.9 mL), lower AHI (38.8 vs. 50.4 events/hour), arousal index (34.9 vs. 47.4 events/hour), number of obstructive apneas during non-rapid eye movement (111.5 vs. 213.4), total apnea duration (58.8 vs. 114.5 minutes), total apnea index (18.9 vs. 33.7 events/hour), mean O2 desaturation (5.5% vs. 7.3%), O2 desaturation index (30.4 vs. 42.2), and ST90 (39.1 vs. 62.6 minutes), and significantly higher lowest SaO2 (82.0% vs. 75.6%) Multivariate analysis revealed that none of those variables was an independently significant predictor of the treatment success.	Group 1: TORS TBR with modified TBS Group 2: TORS TBR + modified TBS + UPPP Group 3: TORS TBR + modified TBS + ESP  TORS-TBR combined with modified TBS is a feasible, safe, and efficient procedure for OSA with tongue base collapse. The study was not designed to compare these three groups.
UAS							
Huntley 2017	TJUH group 35.88 ± 20.88  UPMC group 35.29 ± 15.33	TJUH group 6.34 ± 11.50  UPMC group 6.28 ± 6.10	TJUH 11.08 ± 3.77  UPMC 10.94 ± 4.89	TJUH 5.77 ± 3.35  UPMC 6.60 ± 4.51	≈ 91% (figure 1*)	TJUH group Preoperative SpO2 nadir 80.96% ± 7.90 Postoperative SpO2 nadir 88.04% ± 3.40  UPMC group Preoperative SpO2 nadir 79.58% ± 7.18 Postoperative SpO2 nadir 84.35% ± 4.74	The study shows a significant and clinically meaningful improvement in both subjective and objective OSA outcome measures. There were no permanent or serious adverse events because of the implant procedure, and therapy-related side effects were mild, infrequent, and transient. Furthermore, adherence rates were high. No differences were observed in the two centers. All data were statistically significant.
Mulholland 2020	39.4 ± 17	21.1 ± 17.7	11.1 ± 6.5	7.3 ± 6.4	N/A	Patients in group 1 had better AHI mean decreases 21.1 compared to group 2: 4.9 (p=0.02) Patients who had complete collapse at the velum and lateral walls (n = 11) had poorer response compared to patients who had partial collapse of the soft palate and lateral walls (n = 35), AHI reduction of 5.6 vs. 22.3 (p = 0.02). Patients with partial collapse of the lateral walls (n = 32) had better AHI reductions compared to those with complete collapse (n = 14), AHI reduction of 22.4 vs 9.0 (p = 0.05).	Group 1: N = 36, minimal opening of collapse due to mandibular advancement (MA) during DISE Group 2: N = 10 robust opening of the soft palate and lateral wall in response to MA  The study concludes that a robust response to MA on DISE for the soft palate and lateral wall correlates with worse outcomes for UAS
Steffen 2018	31.2 ± 13.2	13.8 ± 14.8	12.8 ± 5.3	6.5 ± 4.5	68%	Mean ODI was at baseline 27.6 ± 16.4, at 6 months follow-up 13.5 ± 10 (p<0.05) and 12 months follow-up 13.7 ± 14.9 (p<0.05). Mean SpO2 was 71.4% ± 11.4, at 6 months follow-up 80.4% ± 7.6 (p<0.05) and 12 months follow-up 80.9% ± 6.4 (p<0.05). Mean FOSQ improved from 13.7 ± 3.6 to 17.5 ± 2.8 (p<0.05) to 17.5 ± 3 (p<0.05). At the end of the study, 30% showed an AHI<5, 55% showed an AHI <10 and 68% showed an AHI < 15. Nadir SpO2 improved from 71.4% ± 11.4 to 80.9% ± 6.4. Changes in mean SpO2 TST < 90% were not statistically significant.	At the end of the study, 30% showed an AHI<5, 55% showed an AHI <10 and 68% showed an AHI < 15.  Upper airway stimulation reduced OSA severity and improved patient-reported quality-of-life outcome measures. Therapy adherence was high after 12 months of follow-up.
Strollo 2014	32.0 ± 11.8	15.3 ± 16.1	11.6 ± 5	7.0 ± 4.2	66%	Mean ODI (SD) decreased from 28,9 (12) to 13,9 (15,7) (p<0.001). Surgical success based upon ODI reduction > 25% was 94 of 126 patients (75%)	The study concludes that UAS showed a reduction in the severity of obstructive sleep apnea, and the adverse-event profile was acceptable.

31 patients of 75 patients completed ESS measurements, hence the data was not included in the meta-analysis. Some studies included additional PRO measurement tools such as the Calgary Sleep Apnea Quality of Life Index (SAQLI) or Funtional Outcomes of Sleep Questionnaire (FOSQ) or merely Visual Analog Scale (VAS) snoring scale. This review found an overall statistically significant improvement in ESS. Lee et al. reported that ESS should not be used as a screening method in a population with sleep disorders since the method is unreliable [51]. However, this measurement of daytime sleepiness is frequently used among sleep surgeons and in CPAP therapy. Kendzerska et al. published in a systematic review evidence on the psychometric properties

of ESS for describing the level of daytime sleepiness in adults and reported only high-quality studies on correlation between ESS and psychometric properties [52]. They suggested that ESS could be recommended for a group but not for individual-level comparisons. Our review found that ESS was comparable between the studies and that postoperative ESS improved. We suggest that other validated patient reported outcome questionnaires should be included in the evaluation of patients undergoing sleep surgery.

All studies included in this study reported mean values for AHI and ESS, as well for other secondary outcomes. However, the nature of surgical intervention compelled that

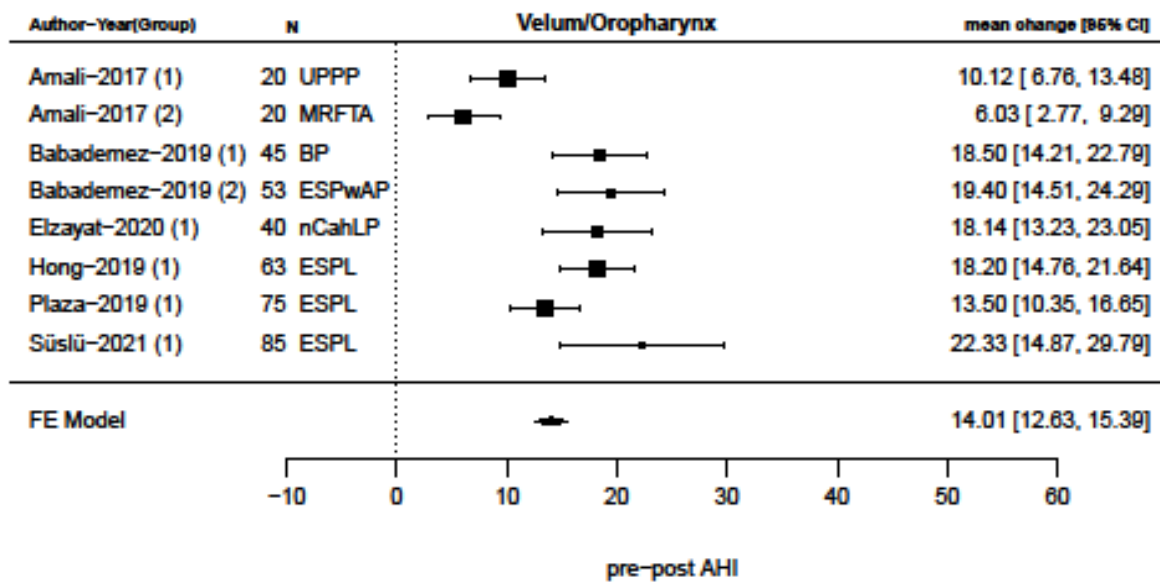


Figure 2: Reduction i AHI after surgery directed at velum/oropharynx

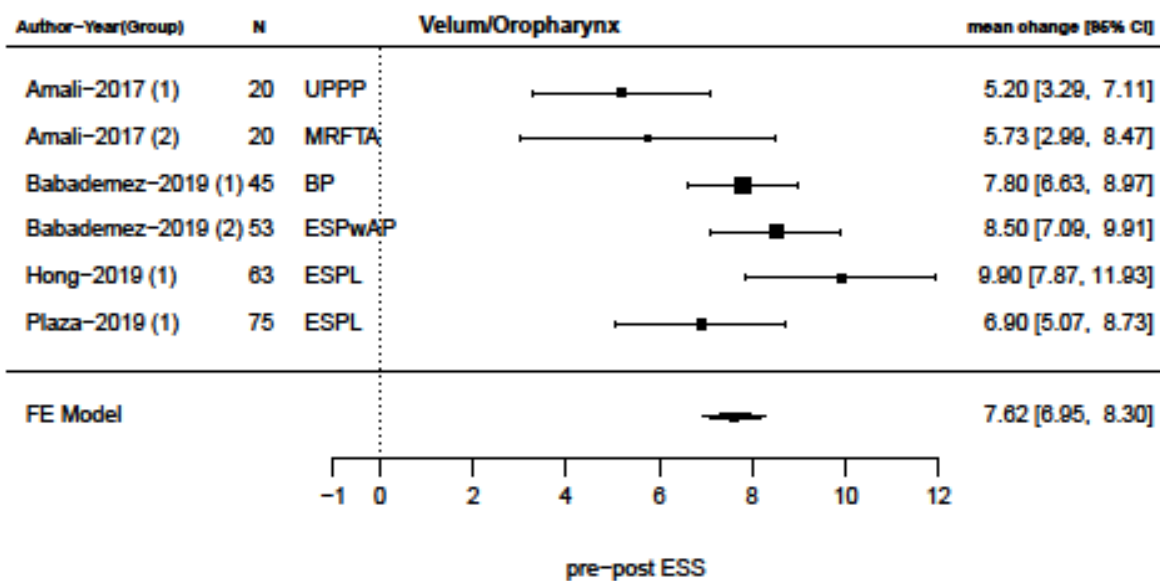


Figure 3: Reduction i ESS after surgery directed at velum/oropharynx

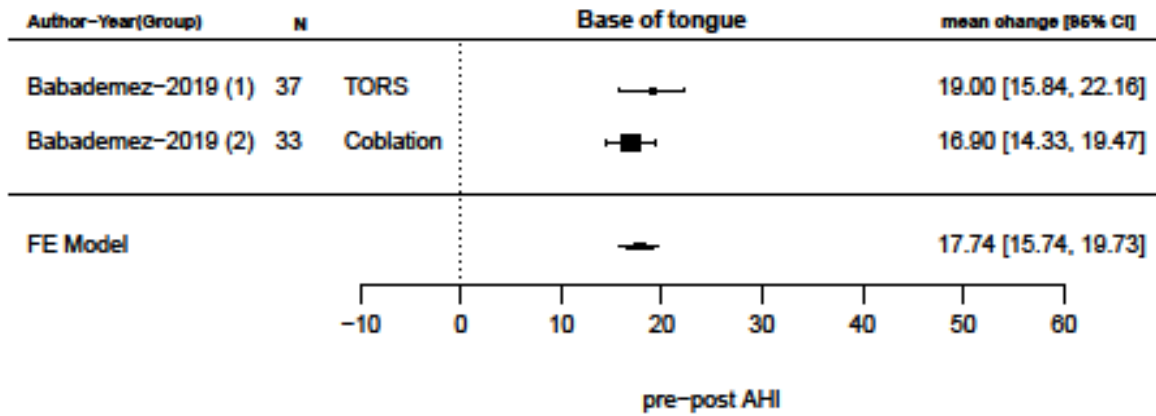


Figure 4: Reduction i AHI after surgery directed at base of tongue

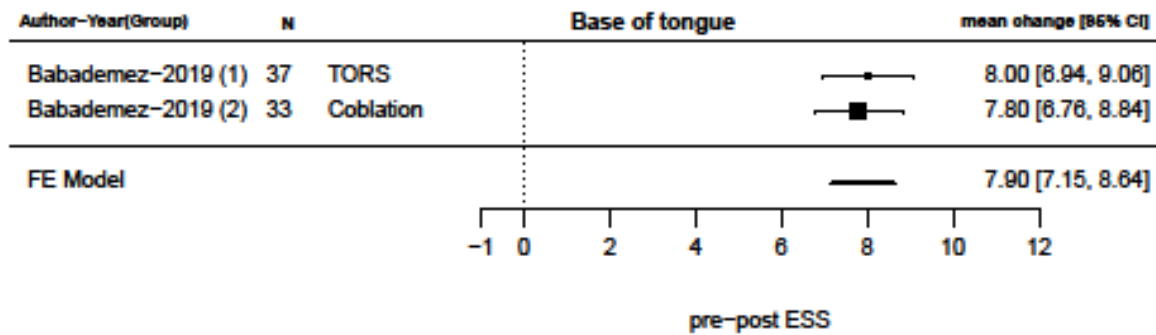


Figure 5: Reduction i ESS after surgery directed at base of tongue

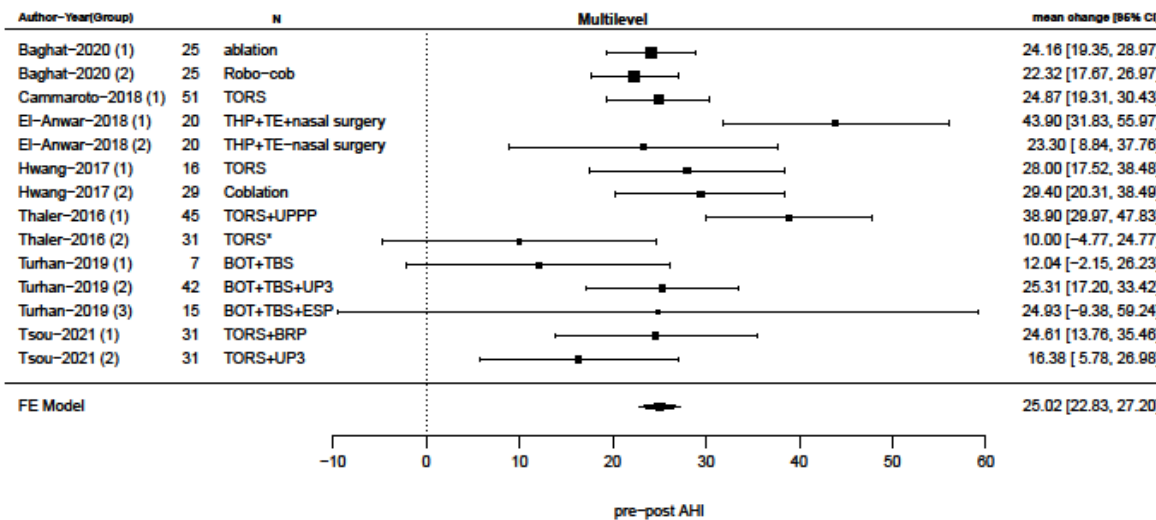


Figure 6: Reduction i AHI after multilevel surgery

each patient’s pre-operative and postoperative data were tested and if possible, reported individually. All studies except El-Anwar et al. and Thaler et al. reported true statistical analysis (paired-t-tests). The use of the arbitrary Sher’s criteria defined as reduction of AHI > 50% and to a value of less than 20 events per hour is the most used measurement of individual response of any sleep surgery regarding AHI. Plaza et al. [31]

reported 90% surgical success when using Sher’s criteria, however only 33.3% were cured (AHI<5 events per hour) and patients with an AHI>5 were included. Furthermore, the authors found that seven patients failed surgical response and in two of these patients, AHI increased. In contrary, Thaler et al. [42] reported merely 45% surgical success using Sher’s criteria. Due to their study setup, patients with higher AHI

values were included, hence mean preoperative AHI was high. A 50% reduction of AHI in patients with relatively low AHI (22.1 events per hour, Plaza et al.) compared to 50% reduction in AHI in patients with relatively high AHI (57.5 events per hour, Thaler et al.) is difficult to compare. However, the combination of PSG data, patient reported outcome, and use of Sher's criteria can illustrate the influence of sleep surgery. Unfortunately, individual changes are not reported in these publications. We advocate that further research report individual changes regarding both PSG data and in data on patient reported outcome.

Although many surgical approaches exist, only a few therapeutic interventions were included in this review. For soft palate surgery BRP, ESP, UPPP and MRFTA is reviewed and show promising results. MRFTA is suggested to treat mild OSA, while BRP, ESP and UPPP is suggested in patients with isolated lateral wall collapse of the oropharynx

regardless of maximum AHI. Moffa et. al found five different approaches to address retropalatal airway collapse in a recently published systematic review [53]. Although primary outcomes were improved after surgery, heterogeneity was high and therefore the level of evidence for these procedures are low and further randomized studies are needed. For BOT, primarily two approaches were addressed. Either the reduction and removal of lingual tissue with the use of coblation or TORS. Although resection of BOT is widely investigated, most studies are biased with either small sample sizes or short follow-up. We found that the studies of Hwang et al. [41], Bahgat et al. [38] and Babademez et al. [37] showed large reduction in AHI without significant difference between TORS, coblation, and so-called Robot ablation respectively. This concurs with Tsou et al. [54] whom recently published a systematic review and found no differences in operation time, success rate or complication rate between TORS, coblation and UAS. Decline in AHI and ESS were also comparable.

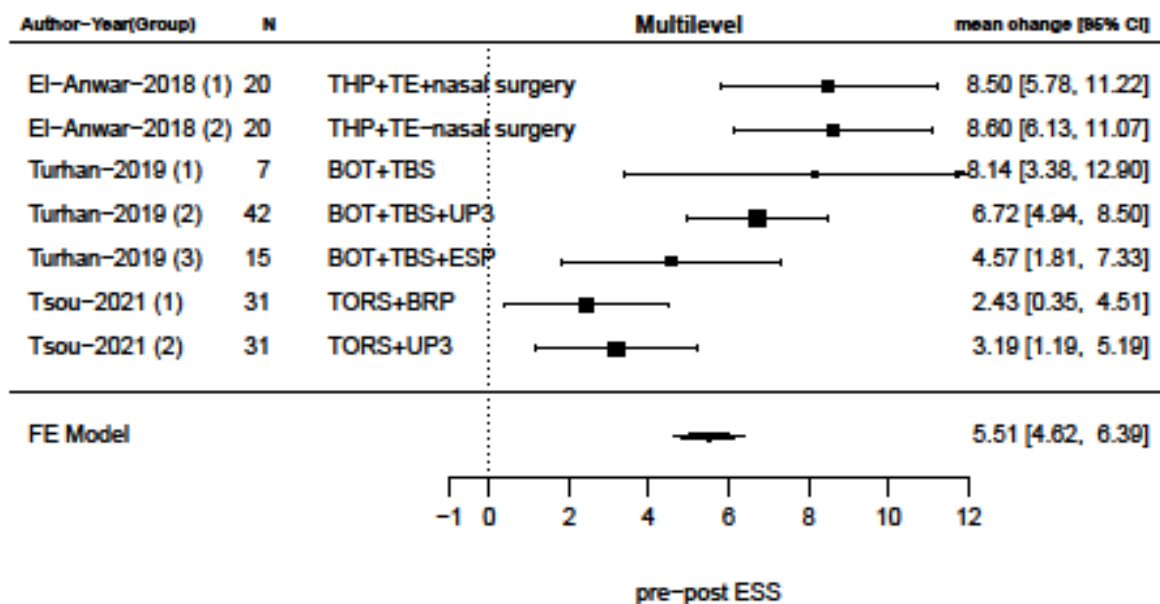


Figure 7: Reduction i ESS after multilevel surgery

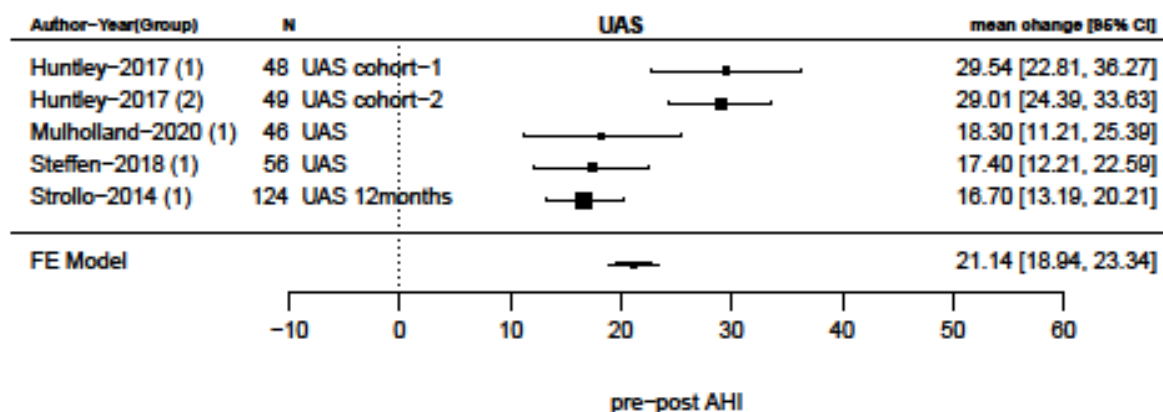


Figure 8: Reduction i AHI after upper airway stimulation

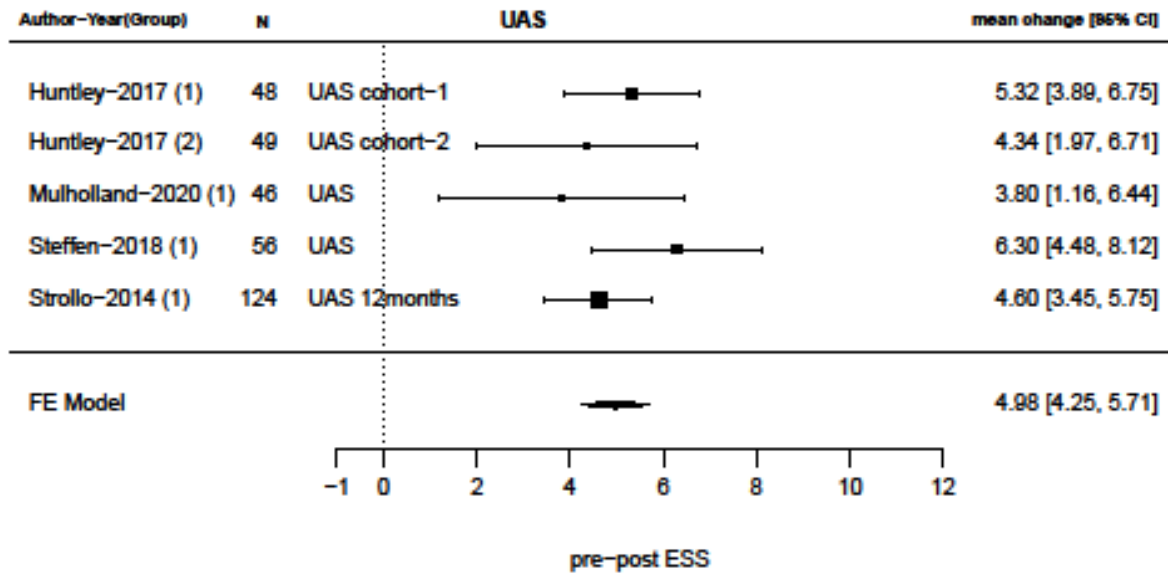


Figure 9: Reduction in ESS after upper airway stimulation

We found that more studies of higher level of evidence exists when it comes to UAS, especially with a longer follow-up time, and although Babademez et. al. show promising results as a single-step BOT intervention, it was the only single-step BOT study included in this review. Furthermore, Costantino et al. published a systematic review including twelve studies with 350 patients regarding UAS and found AHI and ESS improvements similar to this review [9].

The use of UAS and thereby protrusion of the entire tongue synchronous with expiration during sleep can be considered to affect the BOT but it also affects the velum. UAS show compelling results, not only because of the reported effects on AHI and ESS, but also based upon three different studies with long follow-up. Furthermore, the benefits of UAS are that the implant can be removed if compliance is not achievable, and that the implant is tailored to each patient individually and controlled by the patient.

Single step multilevel upper airway surgery is a heterogeneous entity and hence difficult to compare. Vroegop et al found in a cohort study of 1249 patients that single level collapse appeared in 31.8% of patients and multilevel collapse appeared in 68.2% of patients during DISE [55]. The discussion of single step vs. multi-step approach is beyond the scope of this review, however, the studies included in this review were single step multilevel approaches except for Thaler et al [42]. This review found seven multilevel studies suitable for review, although they vary greatly in study design and the surgical interventions used. Cammaroto et. al used tonsillectomy, ESP, TORS BOT surgery, and septo-turbinoplasty [39], El-Anwar et al. included hyoid suspension and a specific pharyngeal suture technique introduced by the first author [40], whereas Thaler et al. combined TORS

with traditional UPPP [42]. All studies showed statistically significant reduction in AHI and in ESS, if ESS was reported. Secondary outcomes were also improved. Although the studies all included DISE, the specific findings were not reported. It is therefore critical not to compare the studies regarding the surgical approaches, but to consider the fact, that clinical screening and evaluation of the patient with the use of DISE is of utmost importance before surgical approach is selected. This results in a personal and individual approach to each patient, where single step multilevel surgery should be one of these modalities. In the multilevel group, mean preoperative AHI was among the highest compared to all the studies in this review. This illustrates, that severe OSA usually is comprised by several anatomical collapses, and a multilevel approach as either single or two-step procedure seems beneficial. In the SAMs trial by Mackay et al. 101 patients with moderate to severe OSA was randomized to either modified UPPP + RFA tongue base in a single step procedure or to ongoing medical treatment. They found a statistically significant greater reduction in AHI after surgery [56]. The SAMS trial study was excluded from this review because DISE was not performed.

### Limitations

Our inclusion criteria with preliminary DISE excluded many interesting studies. Especially the criteria of minimum 40 patients excluded many interesting, but smaller studies. Studies regarding maxillomandibular advancement (MMA) surgery were excluded due to small sample size (<40 patients) or due to no preliminary DISE, although MMA surgery in minor studies have shown a great and sustained reduction in AHI in a selected group of patients with OSA and maxillary or mandibular hypoplasia [57].



&RVWDSQ W5LQFD OGL 9 0RuD \$ HW D9L FL-QS R J-ORQV DZO ( &DPSDQLQL \$  
 QHUYH VWLPXODWLRQ ORQJ WHURJH S R V Q M L R Q R S K M D I R Q H R S O D V W \ %  
 V\ VWHPDWLF UHYLHZ DQG PHWD D Q D D X V E V O L V D H H S D P H U M D M K F D F \ D Q G  
 3:H DUH RQ WKH JLDQW \ V V K R X O G H  
 -XVW\$ Q &KDQJ (7 &DPDFKR 0 HW /DU\ Q J R O R J )  
 5RERWLF 6XUJHU\ IRU 2EVWUXFWL R Z H O H H S O H S O S H D 7 \$ R H O O 5) H V  
 6\ VWHPDWLF 5HYLHZ DQG 0HWD \$ Q D D X V V M L J D W L R O D U \ G D R Q L R I U H T X H Q F  
 1HFN 6XUJ 5HGXFWLRQ RI WKH 3DODWH LQ 6XEM  
 0L00&HU1JX\HQ 6\$ 2QJ \$\$ HW DO 7U D Q V R U D O J U R E R W L F  
 EDVH RI WRQJXH UHGXFWRQ IRU R E V W U X F W L Y H V O H H S D S Q R H D \$ 0 /  
 V\ VWHPDWLF UHYLHZ DQG PHWD D Q D X O R S D O D W R S D O F R A H / \$ 8 3 F R P S  
 H u H F W V \$ V \ V W H P D W L F U H Y L H Z > , C  
 6XQGDUDIPP - /DVVHUVRQ 7- 6XUJHU D Q R O F R E Q W L X F W L Y H H S ' R Y H 0 H G L I  
 VOHHS DSQRHD LQ DGXOWV &RFKUDQH 'DWDEDVH 6\ VW 5HY  
 (2005) &KDQJ .ZRQ <' -XQJ - HW DO \*H  
 :HU 60 3IHLÅH 0 6FKUDGHU ) HW position and oxygenation advancement in obstructive  
 REVWUXFWLYH VOHHS DSQRHD LQ D Q D X V V D S Q R H D \$ 0 H W W I D E V P H Q W  
 6\ VW 5HY 0D[L00RIDF 3ODVW 5HFRQVWU 6XUJ  
 6KHSU 6FKHFKWPDQ .% 3LFFLUL00R 3R Z H O H H V F \* X L O O H P L Q D X O W &  
 RI VXUJLFDO PRGL¿FDWLRQV RI W K R Q S S H U E D V H Z H N H Q X F W L R Q V V O H H  
 ZLWK REVWUXFWLYH VOHHS DSQHD S L Q R W R P W X G O H Z V R O D U \ Q J R O + H D G  
 \$URPDWDULV%, 0DQXDO IRU (YLGHEPAGG00MPPDQW ( \*ROGEHUJ \$1 0  
 (2020) 7RQJXH VVSHQVLRQ /DU\QJRVFRSH  
 /RFNZRGRUULW . 0XQQ = HW D O 9 L F % Q D D Q D O , I R & D Q J L 3 HW DO 7U  
 (YLGHQFH 6\QWKHVLV EDVH UHVHFWLRQ LQ REVWUXFWLY  
 2X]]DQ+DPPDG\ + )HGRURZLF] = HW DO 5 D \ D Q D  
 ZHE DQG PRELOH DSS IRU V\ VWHPDWLF UHYLHZV 6\ VW 5HY  
 (LVH:06PLWK 3/ \$ODP '6 HW DO 'LU  
 0XQ= \$URPDWDULV ( 7XIDQDUX & HW Q H Y H V W L P X O D W L R Q L Q R E V W U X  
 RI VRIWZDUH WR VXSSRUW PXOWLSOH V \ V W H P D W L F H D G 1 H F N 6 X U J  
 WKH -RDQQD %ULJJV ,QVWLWXWH 30 D M D S M R L V W K H 2 Q & 8 Q R U 5 H L Q  
 0DQDJHPHQW \$VVHVPHQW DQG 5 P X O M Z R H Q W I R U P D W G R Q Q H \ S D Q V L R  
 -%, 680\$5, -%, (YLG ,PSOHPHQW \$FWD 2WRODU\QJRO  
 +XWWRGDODQWL \* &DOGZHOO '0 H W Q D 7 P H + 3 5 , 6 D D 6 < HW DO , Q G I  
 H\WHQVLRQ VWDWHPHQW IRU UHSRUW R P R I V V W H P D W L R Q H S L H Z F W H  
 LQFRUSRUDWLQJ QHWZRUN PHWD D Q D D X V D O S K D U \ Q J R O F R O D S V H I  
 LQWHUYHQWLRQV &KHFNOLVW D Q Q H I S D S Q M D R Q \$ 0 \$ 2 W R O D U \ Q J R O  
 0HG  
 )XM6WB333 IRU VOHHS DSQHD DQG 6 V Q S L Q D W D U 2 1 R W H N O L d 6 X S L Q F  
 7KURDW - DSQHD ZKLFK FDQ EH WUHDWHG  
 %URZD00K LQJ - )ULEHUJ ' 6.83 D Q G F R W H U S K D U \ Q J R S O D V W \ \$ X U L  
 follow-up of changes in respiration and sleepiness after  
 PRGL¿HG 8333 /DU\QJRVFRSH \$ P D \$ L 0 R W L H H / D Q J U R X G L 0 6 D H G  
 3DQ3 :RRGVRQ %7 :RRGVRQ % (I S D F R P S D U L V R Q F W H Y X O R S D O D W R S K D U  
 SKDU\QJRSODVW\ D Q H Z W H F K Q L T X P G I R U U W K X H W E H D W V W Q W R E O D W L I  
 REVWUXFWLYH VOHHS DSQHD 2WRODU\QJRO W H Y H G Y A H N S X U S Q H D \$ U D  
 &OLQ 6OHHS 0HG



35. Elzayat S, El-Sobki A, El-Deeb ME, et al. Managing obstructive sleep apnea patients with CPAP failure with a novel Lateral Pharyngoplasty as a stand-alone procedure. *Am J Otolaryngol - Head Neck Med Surg* 41 (2020): 3698.
36. Babademez MA, Gul F, Teleke YC. Barbed palatoplasty vs. expansion sphincter pharyngoplasty with anterior palatoplasty. *Laryngoscope* 130 (2020): 9568.
37. Babademez MA, Gul F, Sancak M, et al. Prospective randomized comparison of tongue base resection techniques: Robotic vs coblation. *Clin Otolaryngol* 44 (2019): 989-996.
38. Bahgat A, Bahgat Y, Alzahrani R, et al. Transoral Endoscopic Coblation Tongue Base Surgery in Obstructive Sleep Apnea: Resection versus Ablation. *ORL* 82 (2020): 201-208.
39. Giovanni C, Giuseppe M, Matteo C, et al. Trans-Oral Robotic Tongue Reduction for OSA: Does Lingual Anatomy Influence the Surgical Outcome? *J Clin Sleep Med* 14 (2022): 1347-1351.
40. El-Anwar MW, Amer HS, Askar SM, et al. Could Nasal Surgery Affect Multilevel Surgery Results for Obstructive Sleep Apnea? *J Craniofac Surg* 29 (2018): 1897-1899.
41. Hwang CS, Kim JW, Kim JW, et al. Comparison of robotic and coblation tongue base resection for obstructive sleep apnoea. *Clin Otolaryngol* 43 (2018).
42. Thaler ER, Rassekh CH, Lee JM, et al. Outcomes for multilevel surgery for sleep apnea: Obstructive sleep apnea, transoral robotic surgery, and uvulopalatopharyngoplasty. *Laryngoscope* 126 (2016): 266-269.
43. Tsou YA, Hsu CC, Shih LC, et al. Combined transoral robotic tongue base surgery and palate surgery in obstructive sleep apnea syndrome: Modified uvulopalatopharyngoplasty versus barbed reposition pharyngoplasty. *J Clin Med* 10 (2021).
44. Turhan M, Bostanci A. Robotic Tongue-Base Resection Combined With Tongue-Base Suspension for Obstructive Sleep Apnea. *Laryngoscope* 130 (2020).
45. Huntley C, Kaffenberger T, Doghramji K, et al. Upper Airway Stimulation for Treatment of Obstructive Sleep Apnea: An Evaluation and Comparison of Outcomes at Two Academic Centers. *J Clin Sleep Med* 13 (2022): 1075-1079.
46. Mulholland GB, Dedhia RC. Success of Hypoglossal Nerve Stimulation Using Mandibular Advancement During Sleep Endoscopy. *Laryngoscope* 130 (2020).
47. Steffen A, Sommer JU, Hofauer B, et al. Outcome after one year of upper airway stimulation for obstructive sleep apnea in a multicenter German post-market study. *Laryngoscope* 128 (2018): 509-515.
48. Strollo PJ, Soose RJ, Maurer JT, et al. Upper-Airway Stimulation for Obstructive Sleep Apnea. *N Engl J Med* 370 (2014):139-149.
49. Friedman M, Salapatas AM, Bonzelaar LB. Updated Friedman Staging System for Obstructive Sleep Apnea. *Adv Otorhinolaryngol* 80 (2017): 41-48.
50. Weaver EM, Woodson BT, Steward DL. Polysomnography indexes are discordant with quality of life, symptoms, and reaction times in sleep apnea patients. *Otolaryngol Neck Surg Off J Am Acad Otolaryngol Neck Surg* 132 (2005): 255-262.
51. Lee JL, Chung Y, Waters E, et al. The Epworth sleepiness scale: Reliably unreliable in a sleep clinic population. *J Sleep Res* 29 (2020): e13019.
52. Kendzerska TB, Smith PM, Brignardello-Petersen R, et al. Evaluation of the measurement properties of the Epworth sleepiness scale: a systematic review. *Sleep Med Rev* 18 (2014): 321-331.
53. Moffa A, Rinaldi V, Mantovani M, et al. Different barbed pharyngoplasty techniques for retropalatal collapse in obstructive sleep apnea patients: a systematic review. *Sleep Breath* 24 (2020): 1115-1127.
54. Tsou YA, Chang WD. Comparison of transoral robotic surgery with other surgeries for obstructive sleep apnea. *Sci Reports* 10 (2020): 18163.
55. Vroegop AV, Vanderveken OM, Boudewyns AN, et al. Drug-induced sleep endoscopy in sleep-disordered breathing: Report on 1,249 cases. *Laryngoscope* (2014).
56. Carney AS, Antic NA, Catcheside PG, et al. Sleep Apnea Multilevel Surgery (SAMS) trial protocol: A multicenter randomized clinical trial of upper airway surgery for patients with obstructive sleep apnea who have failed continuous positive airway pressure. *Sleep* 42 (2019).
57. Boyd SB, Walters AS, Waite P, et al. Long-Term Effectiveness and Safety of Maxillomandibular Advancement for Treatment of Obstructive Sleep Apnea. *J Clin Sleep Med JCSM Off Publ Am Acad Sleep Med* 11 (2015): 699-708.
58. Gouveia CJ, Zaghi S, Awad M, et al. Publication trends and levels of evidence in obstructive sleep apnea literature. *Laryngoscope* 128 (2018): 2193-2199.