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Drug-Induced Sleep Endoscopy and Surgical Outcomes: A Multicenter Cohort Study

Katherine K. Green, MD, MS; David T. Kent, MD; Mark A. D'Agostino, MD; Paul T. Hoff, MS, MD; Ho-Sheng Lin, MD; Ryan J. Soose, MD; M. Boyd Gillespie, MD, MSc; Kathleen L. Yaremchuk, MD; Marina Carrasco-Llatas, Md PhD; B. Tucker Woodson, MD; Ofer Jacobowitz, MD, PhD; Erica R. Thaler, MD; José E. Barrera, MD; Robson Capasso, MD; Stanley Yung Liu, MD, DDS; Jennifer Hsia, MD; Daljit Mann, MD; Taha S. Meraj, MD; Jonathan A. Waxman, MD, PhD; Eric J. Kezirian, MD, MPH

Objective: To evaluate the association between findings of blinded reviews of preoperative drug-induced sleep endoscopy (DISE) examinations using the VOTE Classification and obstructive sleep apnea (OSA) surgical outcomes in a large multicenter, international cohort.

Methods: Retrospective, multi-center cohort study of adults without tonsillar hypertrophy who underwent pharyngeal surgery for OSA. The study included only participants without enlarged tonsils. Four independent reviewers performed blinded review of preoperative DISE videos using the VOTE Classification system and scoring of a primary structure contributing to airway obstruction. DISE findings were examined for an association with surgical outcomes with univariate analyses and multiple regression.

Results: Two hundred seventy-five study participants were included from 14 centers. Mean age was 51.4 ± 11.8 years, and body mass index was 30.1 ± 5.2 kg/m^2. There was moderate interrater reliability (kappa = 0.40–0.60) for DISE findings. Oropharyngeal lateral wall-related obstruction was associated with poorer surgical outcomes (adjusted odds ratio (AOR) 0.51; 95% CI 0.27, 0.93). Complete tongue-related obstruction was associated with a lower odds of surgical response in moderate to severe OSA (AOR 0.52; 95% CI 0.28, 0.98), with findings that were similar but not statistically significant in other analyses. Surgical outcomes were not clearly associated with the degree and configuration of velum-related obstruction or the degree of epiglottis-related obstruction. Surgical response was associated with tonsil size and body mass index (inversely).

Conclusion: DISE findings concerning the oropharyngeal lateral walls and tongue may be the most important findings of this evaluation technique.

Key Words: Surgery, sleep apnea, obstructive, endoscopy, drug-induced sleep endoscopy.

Level of Evidence: 2b

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From the Department of Otolaryngology, University of Colorado School of Medicine (K.K.G.), Denver, Colorado, U.S.A.; the Department of Otolaryngology–Head and Neck Surgery, Vanderbilt University Medical Center (D.T.K), Nashville, Tennessee, U.S.A.; the Southern New England Ear, Nose and Throat Group, Middlesex, Connecticut, USA; Department of Surgery, Yale University School of Medicine (M.A.D.), New Haven, Connecticut, U.S.A.; the University of Michigan, Department of Otolaryngology–Head and Neck Surgery (P.T.H.), Ann Arbor, Michigan, U.S.A.; the Department of Otolaryngology–Head and Neck Surgery, Wayne State University School of Medicine (H.-S.L.), Detroit, Michigan, U.S.A.; the UPMC Department of Otolaryngology Head and Neck Surgery, University of Pittsburgh School of Medicine (R.J.S.), Pittsburgh, Pennsylvania, U.S.A.; the Department of Otolaryngology–Head and Neck Surgery, University of Tennessee Memphis (M.B.G.), Memphis, Tennessee, U.S.A.; the Department of Otolaryngology–Head and Neck Surgery, Henry Ford Health System (K.L.Y.), Detroit, Michigan, U.S.A.; the ENT department, Hospital Universitario Dr. Peset (M.C.-L.), Valencia, Spainc; the Department of Otolaryngology and Communication Sciences, Medical College of Wisconsi (B.T.W.), Milwaukee, Wisconsin, U.S.A.; the ENT and Allergy Associates, New York, New York, U.S.A.; and Department of Otolaryngology, The Mount Sinai Hospital (O.J.), New York, New York, U.S.A.; the Department of Otorhinolaryngology: Head and Neck Surgery, Perelman School of Medicine of the University of Pennsylvania (E.R.T.), Philadelphia, Pennsylvania, U.S.A.; the Department of Otolaryngology Head and Neck Surgery, Uniformed Services University, Washington, D.C., U.S.A.; and Endormir Sleep and Sinus Institute (J.E.B.), San Antonio, Texas, U.S.A.; the Department of Otolaryngology–Head and Neck Surgery, Stanford University School of Medicine (R.C., S.Y.L), Stanford, California, U.S.A.; the Department of Otolaryngology, Head and Neck Surgery, University of Minnesota Medical School (J.H.), Minneapolis, Minnesota, U.S.A.; the University of Oklahoma Health Sciences Center, Department of Otolaryngology–Head & Neck Surgery (D.M.), Oklahoma City, Oklahoma, U.S.A.; the Department of Otolaryngology Head and Neck Surgery, Wayne State University School of Medicine (T.S.M., J.A.W.), Detroit, Michigan, U.S.A.; and the the USC Caruso Department of Otolaryngology–Head & Neck Surgery, Keck School of Medicine of the University of Southern California (E.J.K.), Los Angeles, California, U.S.A.

Institution where work was performed: the Keck School of Medicine of the University of Southern California, Los Angeles, California, U.S.A.

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Send correspondence to Eric J. Kezirian, MD, MPH, USC Caruso Department of Otolaryngology–Head & Neck Surgery, Keck School of Medicine of the University of Southern California, 1450 San Pablo Street, Suite 5100, Los Angeles, CA 90033. E-mail: Eric.Kezirian@med.usc.edu

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INTRODUCTION

Obstructive sleep apnea (OSA) surgical evaluation techniques attempt to characterize the pattern of upper airway obstruction to improve procedure selection and surgical outcomes. Drug-induced sleep endoscopy (DISE) involves endoscopic upper airway examination during unconscious sedation, identifying structures that contribute to airway obstruction.[1] DISE technique is based on research indicating that upper airway physiology at the transition from consciousness to unconscious sedation has some similarities to physiology during natural sleep.[2] Previous relatively small, single-center studies have demonstrated that DISE may be associated with surgical outcomes,[3–7] although others have had conflicting findings.[8,9] These studies have been limited by their performance in single centers with small sample size.

The objective of this study was to evaluate the association between blinded reviews of preoperative DISE examinations using the VOTE Classification and surgical outcomes in a larger, multicenter cohort.

MATERIALS AND METHODS

This was a retrospective cohort study of adults undergoing pharyngeal surgery for treatment of obstructive sleep apnea. Inclusion criteria included the following: age ≥ 21 years; preoperative sleep study showing OSA (apnea-hypopnea index [AHI] ≥ 5 events/hour); absence of enlarged tonsils (3+/4 + on Brodsky[10] or Friedman[11] classifications, depending on standard practice at each center); pharyngeal surgery (with or without nasal surgery) to treat OSA; no previous pharyngeal surgery other than tonsillectomy and/or adenoidectomy; recorded video of preoperative DISE examination; and postoperative sleep study. Individuals with enlarged tonsils were not included for two reasons: DISE interpretation can be difficult (obscuring the possible contribution of other structures), and clinical experience suggested that DISE may not be as necessary (tonsillectomy is performed, regardless of DISE findings). Individuals treated with hypoglossal nerve stimulation, maxillomandibular advancement, or maxillary or mandibular expansion were not included.

As a retrospective study, there were no uniform protocols for physical examination, DISE, or sleep studies. All were performed according to standard practice at each center. All data, including recorded DISE videos, were sent to the Keck School of Medicine of the University of Southern California (Los Angeles, CA), where the database was compiled. The study was approved by each center's institutional review board or similar committee.

DISE videos were reviewed in a blinded fashion independently by four authors (K.K.G., D.T.K., M.A.D'A, E.J.K.). DISE recordings were scored according to the VOTE Classification,[12] which incorporates the degree (0: none, 1: partial, and 2: complete) and configuration (anteroposterior, lateral, and concentric) of the most common structures contributing to obstruction (velum, or palate; oropharyngeal lateral walls; tongue; and epiglottis). Epiglottis-related obstruction was defined as present if occurring independently of any mechanical effect of collapse of other structures (oropharyngeal lateral walls or tongue). In addition, an assessment was made of the primary structure (of the four VOTE structures) contributing to airway obstruction. If at least two reviewers felt they were unable to review the DISE video due to poor technical quality, the study participant was excluded.

A priori criteria for reconciling DISE scoring disagreements to obtain consensus scores were established. For each VOTE structure degree and configuration, agreement of at least three of four reviews was considered the consensus score. In cases without such agreement, the mean score was used for degree, and no configuration was assigned for configuration. Similarly, primary structure was assigned only if there was agreement among at least three of four reviews; otherwise, there was no consensus primary structure.

Palate surgery was defined as any palate procedure, including various techniques: uvulopalatopharyngoplasty, expansion sphincter pharyngoplasty, lateral pharyngoplasty, Z-palatoplasty, palatal advancement, or palate stiffening. No analysis of specific palate surgery technique was performed because the technique was often unreported or unclear. Tongue surgery included partial tongue resection (lingual tonsillectomy or partial glossectomy, regardless of technique), tongue radiofrequency, genioglossus advancement, and tongue stabilization/suspension. Hyoid suspension and partial epiglottis resection were characterized as epiglottis-directed procedures. Nasal surgery was not considered separately and was often performed in conjunction with pharyngeal surgery.

Because the DISE findings most closely associated with surgical outcomes have not been clearly established, multiple statistical analyses were performed. DISE findings were examined for each VOTE structure, related to both the degree and configuration of structure-related obstruction (as applicable). For each VOTE structure, the consensus degree score was treated in separate analyses as a raw variable (0, 1, or 2) or the dichotomous variables of complete (2) versus none/partial (0–1) or any (1–2) versus none (0). The specific finding of complete concentric collapse related to the velum were also considered. Different patterns of epiglottis-related obstruction configuration (anteroposterior vs. lateral) were not examined separately due to insufficient sample size. Cohen's kappa statistic (unweighted due to presence of more than two reviewers) assessed interrater agreement for the degree of obstruction related to each VOTE structure.

Surgical outcomes were defined by the change in the AHI after surgery and the primary outcome: surgery "response," defined by AHI decrease ≥ 50% to a level below 15 events per hour, which is more stringent than the Sher criteria of AHI decrease ≥ 50% to < 20 events per hour.[13]

Statistical analyses examined the association between individual DISE findings and both definitions of surgical outcomes (surgical response and change in AHI). Univariate analyses (*t* tests for change in AHI and chi-squared tests for surgical response) were performed in the entire cohort; in only those with moderate to severe OSA prior to surgery; and in surgical treatment subgroups: isolated palate surgery, combined palate, tongue surgery, and combined palate and tongue resection surgery. For DISE findings concerning epiglottis-related obstruction, additional analyses were performed for epiglottis surgery (generally performed with palate surgery) without and with tongue surgery.

For the primary structure contributing to airway obstruction, analyses were performed for the surgical response outcome measure in the entire cohort and the subgroups outlined above, comparing outcomes across the different primary structures. Due to inadequate sample size, analyses were not performed within subgroups defined by the primary structures.

Logistic regression examined the association between DISE findings and surgical response, without and with adjustment for potential confounders: age, gender, body mass index, and OSA severity group. For each DISE structure, the finding most clearly associated with outcomes in the univariate analyses was used, with a default of including each structure as a dichotomous variable of complete versus partial or no obstruction.

Logistic regression then examined the association between surgical response and key DISE findings that were not treated surgically, without and with adjustment for the potential confounders. For example, untreated velum-related obstruction was defined as the presence of the key velum-related DISE finding

(identified in the univariate analyses) without undergoing palate surgery. A similar methodology was used for defining untreated tongue- and epiglottis-related obstruction. For the oropharyngeal lateral walls, the key DISE finding was included in this model because it was assumed that no procedure specifically addressed this structure.

Sample size estimation was based on examination of the outcomes associated with a specific DISE finding. To provide conservative estimates, it was assumed that 30% of the sample would demonstrate the presence (or absence) of a specific DISE finding. For the outcome measure of surgical response, previous research suggested a 40% response rate for isolated palate surgery[13] versus 60% response rates for combined palate and hypopharyngeal surgery.[14] With $\alpha = 0.05$ (two-sided) and 80% power, detecting this difference of 20% in response rate required a minimum sample size of 230 study participants. P values < 0.05 were considered statistically significant.

RESULTS

Two hundred seventy-five study participants were included in the cohort from 14 centers (Table I). Age at time of surgery was 51.4 ± 11.8 years (range 21–81 years), and 53 (19%) were female. Body mass index was 30.1 ± 5.2 kg/m^2. The distribution of tonsil size was 37% (102) 0/absent, 38% (104) 1+, and 25% (69) 2+. The distributions among commonly used categories of OSA severity were 11% mild (AHI > 5–15 events/hour), 30% moderate (AHI > 15–30 events/hour), and 59% severe (AHI > 30 events/hour).

In this selected cohort, AHI decreased from 41.2 ± 24.4 to 20.9 ± 19.5 events/hour ($P < 0.0001$). AHI did not change for those with mild OSA (10.9 ± 3.4 preoperative to 10.7 ± 11.8 postoperative; $P = 0.92$). AHI decreased in the moderate and severe OSA subgroups (22.1 ± 4.4 to 15.8 ± 12.6 and 56.3 ± 20.3 to 25.3 ± 22.1, respectively; both $P < 0.0001$). The decrease in AHI was greater in severe than moderate OSA ($P < 0.001$). AHI decreased for all tonsil size subgroups (decrease in AHI of 16.8 ± 23.5 for 0 tonsils, 20.2 ± 22.7 for 1 + tonsils, and 25.7 ± 25.4 for 2 + tonsils; all $P < 0.001$). There was a greater decrease in AHI with 2 + versus 0 tonsils ($P = 0.02$), but no differences for other comparisons across tonsil size subgroups (all $P > 0.14$).

Overall, 41% (113 of 275) of study participants achieved a surgical response (49%, or 135 of 275, according to Sher criteria). Univariate analyses showed that there was an increase in the odds of surgical response ($P = 0.008$) with increasing tonsil size: 31% (32 of 102) with 0 tonsils, 41% (43 of 104) with 1 + tonsils, and 55% (38 of 69) with 2 + tonsils. There was no difference in surgical response according to OSA severity subgroup ($P = 0.78$) or center ($P = 0.50$).

Most (93%, 256 of 275) underwent palate surgery, and isolated palate surgery was performed in 35% (97). Tongue surgery was performed in 60% (166), including tongue resection (48%, 131), genioglossus advancement or tongue stabilization (9%, 25), and tongue radiofrequency (4%, 12). Hyoid suspension (11%, 31) and partial epiglottis resection (15%, 42) were also performed. Epiglottis surgery was generally performed with other procedures. Only 4% (12) underwent hyoid suspension (7) or partial epiglottis resection (5) without concurrent tongue surgery, and only 7% underwent hyoid suspension (1) or partial epiglottis resection (18) without concurrent palate surgery.

Individual DISE consensus findings are presented in Table II. There was a substantial range of scores for the degree and configuration of obstruction related to specific VOTE structures, with the large majority having velum-related obstruction and relatively few having epiglottis-related obstruction. The distribution of primary structure was 35% (90 of 257) velum, 24% (62 of 257) oropharyngeal lateral walls, 39% (100 of 257) tongue, and 2% (5 of 257) epiglottis. Cohen's kappa (unweighted) statistics for the reviewer ratings of the degree of obstruction were 0.40 (velum), 0.42 (oropharyngeal lateral walls), 0.60 (tongue), and 0.55 (epiglottis), indicating moderate interrater agreement.[15]

Univariate analyses for the association between individual DISE findings and change in AHI and surgical response are presented in Tables III and IV, respectively. In isolation, most DISE findings were not associated with outcomes. There was a *greater* AHI decrease with

TABLE I.
Distribution of Study Participants Across Centers.

Center	Study Participants	Percent of Total Cohort
ENT and Allergy Associates	12	4.4
Henry Ford Health System	17	6.2
Hospital Universitario Doctor Peset	15	5.5
Medical College of Wisconsin	12	4.4
Medical University of South Carolina	21	7.6
Southern New England Ear, Nose and Throat Group	7	2.6
Stanford University	8	2.9
Uniformed Services University	5	1.8
University of Michigan	65	23.6
University of Minnesota	3	1.1
University of Pennsylvania	5	1.8
University of Pittsburgh	29	10.6
University of Southern California	43	15.6
Wayne State University	33	12

ENT = ear, nose, and throat.

TABLE II.
VOTE Classification Findings.

Structure	Configuration A–P	Configuration Lateral	Configuration Concentric	Degree of Obstruction (0/1/2)*
Velum	0/35/113	0/1/4	0/9/98	7/47/221
Oropharynx lateral walls				122/83/70
Tongue Base				83/82/110
Epiglottis				225/26/24

*Numbers in cells reflect number of study participants with degrees of obstruction 0/1/2 for each structure. Shaded cells reflect combinations of structure and configuration that are not possible in the VOTE Classification. For the velum, the numbers are also presented for each configuration, with 8 patients having obstruction (degree of 1 or 2) but no consensus on configuration.

TABLE III.
Change in AHI associated with DISE findings in overall cohort and subgroups defined by surgical procedure(s).

	Overall (n=275)	Moderate to Severe OSA (n=245)	Isolated palate (n=97)	Palate + Tongue (n=148)	Palate + Tongue Resection (n=115)
V—complete vs. partial*	−21.2 ± 24.7 vs. −15.5 ± 20.3 (p = 0.14)	−23.5 ± 24.4 vs. −19.4 ± 20.9 (p = 0.29)	−17.1 ± 22.6 vs. −16.8 ± 16.2 (p = 0.97)	−24.2 ± 26.7 vs. −13.8 ± 21.9 (p = 0.07)	**−26.4 ± 24.1 vs. −14.1 ± 21.8 (p = 0.03)**
V—complete concentric collapse presence vs. absence	−22.4 ± 27.8 vs. −19.1 ± 21.2 (p = 0.27)	−25.3 ± 26.8 vs. −21.2 ± 21.7 (p = 0.20)	−19.6 ± 24.9 .vs −15.0 ± 18.9 (p = 0.30)	−24.5 ± 30.9 vs. −21.0 ±22.6 (p = 0.43)	−29.1 ± 25.7 vs. −21.0 ± 22.4 (p = 0.08)
O—none vs. partial vs. complete	−18.5 ± 21.2 vs. −21.5 ± 24.8 vs. −22.0 ± 26.9 (all p > 0.13)	−20.7 ± 21.9 vs. −23.2 ± 25.0 vs. −25.6 ± 25.4 (all p > 0.18)	−16.0 ± 21.1 vs. −12.8 ± 21.2 vs. −22.4 ± 22.4 (all p > 0.09)	−18.8 ± 21.7 vs. −27.6 ± 26.7 vs. −22.1 ± 31.5 (all p > 0.60)	−19.3 ± 22.1 vs. −30.6 ± 25.2 vs. −22.8 ± 23.6 (p = 0.03 for none vs. partial but >0.22 for others)
O—complete vs. partial/none	−22.0 ± 26.9 vs. −19.7 ± 22.7 (p = 0.27)	−25.6 ± 25.4 vs. −21.8 ± 23.3 (p = 0.27)	−22.4 ± 22.4 vs. −14.5 ± 21.0 (p = 0.10)	−22.1 ± 31.5 vs. −22.3 ± 24.1 (p = 0.96)	−22.8 ± 23.6 vs. −24.1 ± 24.0 (p = 0.81)
O—any vs. none	−21.7 ± 25.7 vs. −18.5 ± 21.2 (p = 0.27)	−24.3 ± 25.1 vs. −20.7 ± 21.9 (p = 0.25)	−17.6 ± 22.1 vs. −16.0 ± 21.1 (p = 0.73)	−25.2 ± 28.9 vs. −18.8 ± 21.7 (p = 0.13)	−27.5 ± 24.7 vs. −19.3 ± 22.1 (p = 0.07)
T—none vs. partial vs. complete	−20.0 ± 25.2 vs. −22.3 ± 24.7 vs. −19.1 ± 22.2 (all p > 0.35)	−22.7 ± 24.7 vs. −24.3 ± 24.3 vs. −21.6 ± 22.8 (all p > 0.45)	−19.4 ± 22.1 vs. −11.5 ± 22.1 vs. −16.8 ± 19.5 (all p > 0.15)	−21.1 ± 33.0 vs. −26.6 ± 25.4 vs. −19.9 ± 23.6 (all p > 0.09)	−23.4 ± 30.3 vs. −25.8 ± 21.6 vs. −22.4 ± 23.6 (all p > 0.46)
T—complete vs. partial/none	−219.1 ± 22.2 vs. −21.1 ± 24.9 (p = 0.49)	−21.6 ± 22.8 vs. −23.5 ± 24.5 (p = 0.54)	−16.8 ± 19.5 vs. −17.1 ± 22.3 (p = 0.95)	−19.2 ± 23.6 vs. −25.0 ± 27.8 (p = 0.17)	−22.4 ± 23.6 vs. −25.1 ± 24.1 (p = 0.54)
T—any vs. none	−20.4 ± 23.3 vs. −20.0 ± 25.2 (p = 0.89)	−22.8 ± 23.5 vs. −22.7 ± 24.7 (p = 0.98)	−13.9 ± 20.9 vs. −19.4 ± 22.1 (p = 0.21)	−22.5 ± 24.6 vs. −21.1 ± 33.0 (p = 0.83)	−23.9 ± 22.7 vs. −23.4 ± 30.3 (p = 0.94)
E—none vs. partial vs. complete	−20.1 ± 24.6 vs. −22.5 ± 21.6 vs. −19.4 ± 19.2 (all p > 0.59)	−22.9 ± 24.5 vs. −23.1 ± 21.9 vs. −21.5 ± 19.5 (all p > 0.79)	−17.4 ± 22.4 vs. −14.0 ± 12.9 vs. −12.6 ± 11.4 (all p > 0.68)	−21.7 ± 26.8 vs. −24.4 ± 24.2 vs. −23.7 ± 22.2 (all p > 0.68)	−23.7 ± 24.6 vs. −21.0 ± 21.3 vs. −28.8 ± 21.2 (all p > 0.68)
E—complete vs. partial/none	−19.4 ± 19.2 vs. −20.4 ± 24.3 (p = 0.84)	−21.5 ± 19.5 vs. −22.9 ± 24.2 (p = 0.80)	−12.6 ± 11.4 vs. −17.2 ± 22.0 (p = 0.68)	−23.7 ± 22.2 vs. −22.1 ± 26.3 (p = 0.82)	−28.8 ± 21.2 vs. −23.3 ± 24.1 (p = 0.82)
E—any vs. none	−21.0 ± 20.3 vs. −20.1 ± 24.6 (p = 0.81)	−22.4 ± 20.6 vs. −22.9 ± 24.5 (p = 0.90)	−13.3 ± 11.3 vs. −17.4 ± 22.4 (p = 0.62)	−24.1 ± 23.0 vs. −21.7 ± 26.8 (p = 0.64)	−24.2 ± 21.2 vs. −23.7 ± 24.6 (p = 0.93)

Statistically-significant findings are shown in bold.
*Sample size reduced because of exclusion of total n=7 with DISE findings of no velum-related obstruction.

TABLE IV.
Odds ratios and proportions of surgical response associated with DISE findings in overall cohort and subgroups defined by surgical procedure(s).

	Overall (n=275)	Moderate to Severe OSA (n=245)	Isolated palate (n=97)	Palate + Tongue (n=148)	Palate + Tongue Resection (n=115)
V—complete vs. partial*	0.98 (0.67, 1.44) 40% vs. 40%	1.02 (0.66, 1.57) 39% vs. 38%	2.06 (0.58, 7.30) 41% vs. 20%	0.85 (0.51, 1.42) 36% vs. 42%	0.87 (0.49, 1.54) 36% vs. 41%
V—complete concentric collapse presence vs. absence	0.97 (0.72, 1.30) 40% vs. 42%	1.04 (0.77, 1.42) 41% vs. 40%	1.52 (0.94, 2.48) 50% vs. 33%	0.76 (0.48, 1.20) 31% vs. 41%	0.82 (0.48, 1.37) 33% vs. 40%
O—none vs. partial vs. complete**	**50% vs. 33% vs. 36% (p=0.02)**	49% vs. 32% vs. 37% (p=0.07)	46% vs. 32% vs. 42% (p=0.52)	46% vs. 31% vs. 31% (p=0.20)	46% vs. 32% vs. 28% (p=0.20)
O—complete vs. partial/none	0.83 (0.59, 1.18) 36% vs. 43%	0.87 (0.61, 1.26) 37% vs. 42%	1.06 (0.64, 1.77) 42% vs. 39%	0.79 (0.46, 1.35) 31% vs. 40%	0.70 (0.36, 1.38) 28% vs. 40%
O—any vs. none	**0.68 (0.51, 0.90)** **34% vs. 50%**	**0.71 (0.52, 0.95)** **34% vs. 49%**	0.81 (0.50, 1.32) 37% vs. 46%	0.69 (0.45, 1.04) 31% vs. 46%	0.65 (0.41, 1.05) 30% vs. 46%
T—none vs. partial vs. complete**	40% vs. 44% vs. 40% (p=0.83)	41% vs. 45% vs. 36% (p=0.52)	42% vs. 43% vs. 32% (p=0.71)	31% vs. 41% vs. 38% (p=0.69)	24% vs. 40% vs. 40% (p=0.44)
T—complete vs. partial/none	0.96 (0.71, 1.28) 40% vs. 42%	0.84 (0.61, 1.16) 36% vs. 43%	0.75 (0.37, 1.52) 32% vs. 42%	1.01 (0.67, 1.53) 38% vs. 38%	1.14 (0.71, 1.83) 40% vs. 35%
T—any vs. none	1.05 (0.77, 1.43) 42% vs. 40%	0.97 (0.70, 1.34) 40% vs. 41%	0.91 (0.55, 1.50) 38% vs. 42%	1.29 (0.67, 2.48) 39% vs. 30%	1.69 (0.69, 4.12) 40% vs. 24%
E—none vs. partial vs. complete**	40% vs. 50% vs. 46% (p=0.52)	39% vs. 48% vs. 43% (p=-.68)	39% vs. 50% vs. 50% (p=0.84)	36% vs. 47% vs. 43% (p=0.67)	35% vs. 44% vs. 46% (p=0.36)
E—complete vs. partial/none	1.13 (0.71, 1.79) 46% vs. 41%	1.07 (0.63, 1.79) 43% vs. 40%	1.26 (0.46, 3.46) 50% vs. 40%	1.15 (0.60, 2.19) 43% vs. 37%	1.24 (0.62, 2.49) 45% vs. 37%
E—any vs. none	1.21 (0.87, 1.69) 48% vs. 40%	1.16 (0.81, 1.67) 46% vs. 39%	1.27 (0.61, 2.66) 50% vs. 39%	1.27 (0.82, 1.99) 46% vs. 36%	1.26 (0.76, 2.10) 44% vs. 35%

Statistically-significant findings are shown in bold.
*Sample size reduced because of exclusion of total n=7 with DISE findings of no velum-related obstruction.
**p-values are for chi-squared test of association between surgical response and degree of structure-related obstruction. Individual odds ratios for comparisons between different degrees are not presented.

TABLE V.
Association Between Primary DISE Structure and Surgical Response for Overall Cohort and Subgroups Defined by Surgical Procedure(s).

	Velum	Oropharyngeal Lateral Walls	Tongue	Epiglottis	*P* Value
Overall (n = 257)	37% (33/90)	40% (25/62)	44% (44/100)	0% (0/5)	0.22
Moderate to severe OSA (n = 229)	37% (29/79)	42% (25/59)	40% (35/87)	0% (0/4)	0.38
Isolated palate (n = 93)	37% (18/49)	50% (14/28)	27% (4/15)	0% (0/1)	0.38
Tongue ± palate ± epiglottis (n = 153)	32% (12/37)	32% (11/34)	46% (36/79)	0% (0/3)	0.23
Tongue resection ± palate ± Epiglottis (n = 122)	31% (9/29)	32% (8/25)	46% (30/65)	0% (0/3)	0.24
Epiglottis ± other (n = 69)	36% (5/14)	36% (4/11)	40% (17/42)	0% (0/2)	0.71

DISE = drug-induced sleep endoscopy; OSA = obstructive sleep apnea.

complete versus partial velum-related obstruction in those undergoing palate and tongue resection procedures; the preoperative AHI was greater in those with complete versus partial/none velum-related obstruction (50.6 ± 26.3 vs. 35.8 ± 16.5, $P = 0.02$), but there was no difference in the postoperative AHI (22.0 ± 17.4 vs. 18.6 ± 17.0, $P = 0.44$). There was also a lower odds of surgical response associated with greater degrees of oropharyngeal lateral wall-related

TABLE VI.
Logistic Regression Analyses for Odds Ratios Reflecting Association Between Surgical Response and Specific DISE Findings in Overall Cohort and Subgroups Defined by Surgical Procedure(s).

	Unadjusted			Adjusted		
Subgroups	N	Odds Ratio	95% CI	N	Odds Ratio	95% CI
Overall						
Velum	275	0.93	(0.50, 1.75)	258	0.97	(0.49, 1.93)
Oropharynx lateral walls	275	0.47	(0.28, 0.80)	258	0.51	(0.27, 0.93)
Tongue base	275	0.72	(0.42, 1.23)	258	0.68	(0.38, 1.21)
Epiglottis	275	1.19	(0.50, 2.82)	258	1.63	(0.62, 4.24)
Moderate to severe OSA						
Velum	245	0.91	(0.46, 1.81)	229	1.01	(0.48, 2.10)
Oropharynx lateral walls	245	0.47	(0.26, 0.83)	229	0.49	(0.26, 0.93)
Tongue base	245	0.58	(0.32, 1.03)	229	0.52	(0.28, 0.99)
Epiglottis	245	1.00	(0.39, 2.54)	229	1.24	(0.45, 3.47)
Isolated palate						
Velum	97	1.42	(0.38, 5.27)	84	2.44	(0.54, 11.13)
Oropharynx lateral walls	97	0.59	(0.24, 1.44)	84	0.31	(0.10, 0.99)
Tongue base	97	0.56	(0.18, 1.73)	84	0.46	(0.21, 1.76)
Epiglottis	97	1.51	(0.20, 11.47)	84	2.14	(0.24, 19.33)
Palate + tongue						
Velum	148	0.84	(0.36, 1.99)	146	1.30	(0.45, 3.75)
Oropharynx lateral walls	148	0.52	(0.25, 1.10)	146	0.78	(0.32, 1.92)
Tongue base	148	0.81	(0.40, 1.68)	146	0.65	(0.28, 1.53)
Epiglottis	148	1.30	(0.42, 4.02)	146	1.77	(0.48, 6.45)
Palate + tongue resection						
Velum	115	0.84	(0.33, 2.14)	113	1.22	(0.40, 3.75)
Oropharynx lateral walls	115	0.52	(0.22, 1.19)	113	0.77	(0.29, 2.06)
Tongue base	115	1.02	(0.45, 2.30)	113	0.77	(0.31, 1.95)
Epiglottis	115	1.58	(0.44, 5.67)	113	1.61	(0.38, 6.86)
Epiglottis ± other						
Velum	73	1.26	(0.37, 4.32)	71	0.42	(0.07, 2.62)
Oropharynx lateral walls	73	0.43	(0.15, 1.22)	71	0.68	(0.15, 3.04)
Tongue base	73	0.75	(0.28, 2.03)	71	0.80	(0.20, 3.23)
Epiglottis	73	1.21	(0.35, 4.22)	71	2.01	(0.28, 14.30)

Velum, tongue base, and epiglottis were categorized as complete versus partial/none. Oropharynx lateral walls was categorized as complete/partial versus none. Variables in the adjusted model include: age, gender, BMI, and OSA severity group.

BMI = body mass index; CI = confidence interval; DISE = drug-induced sleep endoscopy; OSA = obstructive sleep apnea.

TABLE VII.
Logistic Regression Analyses for Odds Ratios Reflecting Association Between Surgical Response and Untreated Specific DISE Findings in Overall Cohort.

	Unadjusted (n = 275)		Adjusted (n = 258)	
Tongue Surgery Type*	Odds Ratio	95% CI	Odds Ratio	95% CI
Any tongue surgery				
Velum	1.35	(0.35, 5.25)	1.26	(0.27, 5.91)
Oropharynx lateral walls	0.50	(0.30, 0.82)	0.52	(0.29, 0.94)
Tongue base	0.78	(0.33, 1.86)	0.61	(0.24, 1.57)
Epiglottis	1.27	(0.37, 4.36)	1.71	(0.45, 6.49)
Age (years)	–	–	0.99	(0.97, 1.01)
Male gender	–	–	0.81	(0.39, 1.68)
BMI (kg/m^2)	–	–	0.92	(0.87, 0.97)
Tonsil Size	–	–	1.69	(1.18, 2.42)
OSA Severity Group				
Mild	–	–	Ref	Ref
Moderate	–	–	0.82	(0.32, 2.12)
Severe	–	–	1.10	(0.45, 2.69)
Tongue resection surgery				
Velum	1.29	(0.33, 5.05)	1.16	(0.24, 5.52)
Oropharynx lateral walls	0.47	(0.30, 0.83)	0.49	(0.27, 0.90)
Tongue base	0.62	(0.30, 1.27)	0.51	(0.23, 1.13)
Epiglottis	1.21	(0.35, 4.17)	1.60	(0.42, 6.10)
Age (years)	–	–	0.99	(0.96, 1.01)
Male gender	–	–	0.87	(0.41, 1.85)
BMI (kg/m^2)	–	–	0.92	(0.86, 0.97)
Tonsil size	–	–	1.66	(1.16, 2.38)
OSA Severity Group				
Mild	–	–	Ref	Ref
Moderate	–	–	0.79	(0.30, 2.07)
Severe	–	–	1.05	(0.42, 2.59)

Untreated velum, tongue base, and epiglottis were categorized as complete versus partial/none. Untreated oropharynx lateral walls were categorized as complete/partial versus none. Variables in the adjusted model include: age, gender, BMI, and OSA severity group.

*Untreated tongue base is referring to patients that did not receive any tongue surgery or tongue resection surgery, as indicated in the table header.

BMI = body mass index; CI = confidence interval; DISE = drug-induced sleep endoscopy; OSA = obstructive sleep apnea.

obstruction in the entire cohort and a lower odds of surgical response associated with partial or complete (vs. none) oropharyngeal lateral-wall related obstruction in the entire cohort and in the moderate to severe OSA subgroup.

For epiglottis-related obstruction, there was no association between epiglottis surgery and change in AHI or surgical response, without or with tongue surgery (all $P > 0.40$).

Table V presents results for the primary site of obstruction and surgical response. Primary structure was not statistically associated with surgical response. However, there are some notable findings. First, no study participants with the epiglottis as the primary structure achieved a surgical response, albeit in a small sample size. Second, examination of coefficient estimates in surgical treatment subgroups (with decreased statistical power) suggested two other possible associations that were not statistically significant: 1) in isolated palate surgery, participants with the tongue as primary structure had a lower likelihood of surgical response than those with the velum ($P = 0.47$) or oropharyngeal lateral walls ($P = 0.20$) as primary structure; 2) with the tongue as a primary structure, the response rate was lower for isolated palate surgery than for other surgical treatments ($P = 0.17$); and 3) with the combination of palate and tongue (and palate and tongue resection) surgery, participants with the tongue as primary structure had a greater likelihood of surgical response than those with velum or oropharyngeal lateral walls (or epiglottis) as primary structure (all $P > 0.30$).

Any oropharyngeal lateral wall-related obstruction was associated with gender, body mass index, and preoperative AHI but not with age or tonsil size (data not shown). Complete velum- and tongue-related obstruction were associated with body mass index but not with age, gender, tonsil size, or preoperative AHI (data not shown).

Table VI presents unadjusted and adjusted logistic regression results for the association between specific DISE findings and surgical response. The odds of surgical response was approximately 50% lower with any oropharyngeal lateral wall-related obstruction among all study participants and in those with moderate to severe OSA and in isolated palate surgery (adjusted analyses); the coefficient estimates in other subgroups were similar but not statistically significant. Complete tongue-related obstruction was also associated with lower odds of surgical response in moderate to severe OSA in adjusted analyses; the coefficient estimates in other subgroups were similar (although not statistically significant) but closer to 1 in subgroups with tongue surgery (suggesting that tongue surgery may address tongue-related obstruction). Coefficient estimates also suggested that complete versus partial/none velum-related obstruction may have a *greater* likelihood of surgical response with isolated palate surgery, although this was not statistically significant. There were no substantial differences in the estimates if complete concentric collapse was included as the key DISE finding related to the velum instead of complete (vs. partial/none) velum-related obstruction (data not shown).

Table VII presents logistic regression results for surgical response and untreated key DISE findings. The odds of surgical response was similarly 50% lower with any oropharyngeal lateral wall-related obstruction, with body mass index and tonsil size also associated with surgical response in the adjusted models. Untreated complete tongue-related obstruction occurred in 25 or 42 study participants (of 110 with complete tongue-related obstruction), depending on whether treatment was defined as any tongue surgery or tongue resection surgery, respectively. Coefficient estimates (not statistically significant) for untreated complete tongue-related obstruction indicated that there may be an association with a lower odds of surgical response, with a greater decrease for the definition based on tongue resection (suggesting that tongue resection might have greater effectiveness than other tongue surgeries with complete tongue-related obstruction). For untreated complete velum-related obstruction (n = 6)

and untreated epiglottis-related obstruction (n = 11), there were wide confidence intervals for all estimates. There were no qualitative differences if complete concentric collapse was included as the key velum finding instead of complete (vs. partial/none) velum-related obstruction (data not shown).

DISCUSSION

This is the largest study examining the association between DISE findings and surgical outcomes. It is the only multicenter study and just the second to incorporate blinded DISE reviews.[9] The multicenter nature of this study is a major strength because it supports the generalizability of the findings.

Outcomes in the study cohort do not reflect sleep surgery outcomes more broadly because the study cohort was designed to include the most challenging surgical patients (absence of enlarged tonsils and preoperative DISE performed for clinical care, likely done with unclear or more complex obstruction). This study also utilized a stricter definition of surgical response than the Sher criteria[13] widely used in the literature.

Oropharyngeal Lateral Walls

Any oropharyngeal lateral wall-related obstruction was associated with a 50% decrease in the odds of surgical response. This generally agrees with our clinical experience and with previous studies, whether for a mix of procedures,[6] transoral robotic surgery-assisted tongue resection with other procedures,[7] or possibly the combination of H-UPPP and palatal advancement pharyngoplasty.[16]

Poorer outcomes may occur because the oropharyngeal lateral walls are not as directly amenable to surgery. However, there are viable treatment options. Palate surgery techniques (other than traditional uvulopalatopharyngoplasty) such as lateral pharyngoplasty,[17] expansion sphincter pharyngoplasty,[18] relocation pharyngoplasty,[19] or palatal advancement pharyngoplasty[20] may treat oropharyngeal lateral wall-related obstruction;[9] the present study could not examine specific palate surgery techniques. Hypoglossal nerve stimulation[21] and maxillomandibular advancement[22] also may address oropharyngeal lateral wall-related obstruction. Finally, when considering treatment, there may be differences in whether the oropharyngeal lateral wall-related obstruction may be due to tonsil tissue (easily resectable), increased muscle mass (potentially addressed with procedures that reposition muscle or muscle attachments), or fat deposition (likely less amenable to existing procedures).

Tongue

Complete tongue-related obstruction and untreated complete tongue-related obstruction were broadly associated with poorer surgical outcomes, although individual point estimates were generally not statistically significant. The odds of surgical response after isolated palate surgery was estimated as lower when the tongue was the primary structure, although this was not statistically significant. We believe that the magnitude of coefficient estimates and the consistent pattern suggest real associations between both complete tongue-related obstruction and untreated complete tongue-related obstruction and poorer outcomes; the lack of statistical significance is likely related to sample size.

The importance of tongue-related obstruction has been demonstrated in previous smaller studies, whether for uvulopalatopharyngoplasty alone,[3] palate surgery and tongue radiofrequency (performed in 86%) with or without hyoid suspension (performed in 49%),[5] palatine tonsillectomy with or without soft palate surgery,[8] or possibly H-UPPP and palatal advancement pharyngoplasty.[16] In contrast, another relatively small study questioned the importance of tongue-related obstruction, showing similar findings with newer palate surgery techniques, regardless of whether there was complete tongue- and/or epiglottis-related obstruction.[9]

Velum

Surgical outcomes were not associated with velum-related obstruction, whether for the degree of obstruction or complete concentric collapse. Interestingly, coefficient estimates (none statistically significant) suggested possible *positive* associations for isolated palate surgery and possible negative association for combined palate and tongue-directed surgery between surgical response and complete velum-related obstruction and complete concentric collapse.

These findings differ from a previous study of uvulopalatopharyngoplasty that showed greater AHI decreases with complete anteroposterior velum-related obstruction or with enlarged tonsils, compared to complete concentric collapse or with tongue-related obstruction.[4] Potential explanations include different study populations (including the present study's exclusion of enlarged tonsils), different DISE technique/medication (previous study used 10 mg diazepam rather than primarily propofol), and the present study's greater diversity of DISE findings and procedures.

The present study did not evaluate specific palate surgery techniques because this information was not available; however, one study showed that complete concentric collapse related to the velum was associated with lower odds of surgical response after newer palate surgery techniques in the presence of oropharyngeal lateral wall-related obstruction.[9]

Epiglottis

The degree of epiglottis-related obstruction was not associated with surgical outcomes. This differs from one previous study,[6] which may be explained by differences in the definition of epiglottis-related obstruction (not clear in previous study). The present study defined epiglottis-related obstruction as occurring only if independent of mechanical effects from oropharyngeal lateral wall- or tongue-related obstruction, but some studies (and surgeons) consider epiglottis-related obstruction as present if the epiglottis obstructs the airway for any reason. Epiglottis-related obstruction has been considered one of the unique attributes of DISE in that other evaluation

techniques do not visualize airway obstruction specifically related to the epiglottis. The value of epiglottis assessment is ultimately dependent on whether this finding, and possible surgical treatment, are associated with outcomes. Future research is needed.

Other Factors

Body mass index was independently inversely associated with surgical response; this agrees with earlier investigations showing an association between increased body mass index and poorer outcomes after combined palate and hypopharyngeal surgery.[14] Tonsil size (0–2 + tonsils) was associated with surgical response. The importance of tonsil size to surgical outcomes has been clearly demonstrated for enlarged (3+/4+) tonsils,[23–27] but few studies have examined the association with smaller/absent tonsils.

Limitations

Although this study is the largest study of its kind, it has limited statistical power, particularly with subgroup analyses and with adjustment for confounders. The present study also examined a selected cohort of study participants without enlarged tonsils. This may reflect the population where DISE may provide the greatest utility, but the findings are limited to this subgroup.

DISE is only one part of surgical evaluation. The present study has included other key characteristics in the analyses, but a retrospective study is limited by preoperative findings documented at all centers. For example, lingual tonsil size (not documented) may be associated with outcomes of tongue resection surgery[28] because this tissue is more easily removed.

The inclusion of study participants from multiple centers enhances generalizability, although there were differences in DISE technique across centers. Most centers (approximately 90% of study participants) utilized propofol as the sole sedative agent, but variations in technique were not examined.

The present study focused on outcomes defined by AHI changes; however, differences in sleep study interpretation were not examined. AHI is overly simplistic (as is the threshold definition of surgical response) and is not associated with other clinically relevant outcomes.[29]

Finally, DISE interpretation is subjective. Interrater reliability was moderate in this study (kappa = 0.40–0.60), despite the fact that all reviewers have substantial DISE experience. The performing surgeon or other blinded reviewers could have had different interpretation. These differences could be systematic (differences in visual assessment) or related to other physical examination findings or factors affecting interpretation (e.g., patient positioning or sedation depth) not available to blinded reviewers.

CONCLUSION

Any oropharyngeal lateral wall-related obstruction and complete tongue-related obstruction were associated with poorer surgical outcomes. Tongue-directed surgery may improve outcomes in the presence of complete tongue-related obstruction. DISE findings concerning the velum or epiglottis were not clearly associated with surgical outcomes. There was moderate interrater reliability (kappa = 0.40–0.60) for DISE findings.

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