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ORIGINAL ARTICLE

Tongue size matters: revisiting the Mallampati classification system in patients with obstructive sleep apnea

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ABSTRACT

Objective: The Mallampati classification system has been used to predict obstructive sleep apnea (OSA). Upper airway soft tissue structures are prone to fat deposition, and the tongue is the largest of these structures. Given that a higher Mallampati score is associated with a crowded oropharynx, we hypothesized that the Mallampati score is associated with tongue volume and an imbalance between tongue and mandible volumes. **Methods:** Adult males underwent clinical evaluation, polysomnography, and upper airway CT scans. Tongue and mandible volumes were calculated and compared by Mallampati class. **Results:** Eighty patients were included (mean age, 46.8 years). On average, the study participants were overweight (BMI, 29.3 ± 4.0 kg/m^2) and had moderate OSA (an apnea-hypopnea index of 26.2 ± 26.7 events/h). Mallampati class IV patients were older than Mallampati class II patients (53 ± 9 years vs. 40 ± 12 years; $p < 0.01$), had a larger neck circumference (43 ± 3 cm vs. 40 ± 3 cm; $p < 0.05$), had more severe OSA (51 ± 27 events/h vs. 24 ± 23 events/h; $p < 0.01$), and had a larger tongue volume (152 ± 19 cm^3 vs. 135 ± 18 cm^3; $p < 0.01$). Mallampati class IV patients also had a larger tongue volume than did Mallampati class III patients (152 ± 19 cm^3 vs. 135 ± 13 cm^3; $p < 0.05$), as well as having a higher tongue to mandible volume ratio (2.5 ± 0.5 cm^3 vs. 2.1 ± 0.4 cm^3; $p < 0.05$). The Mallampati score was associated with the apnea-hypopnea index ($r = 0.431$, $p < 0.001$), BMI ($r = 0.405$, $p < 0.001$), neck and waist circumference ($r = 0.393$, $p < 0.001$), tongue volume ($r = 0.283$, $p < 0.001$), and tongue/mandible volume ($r = 0.280$, $p = 0.012$). **Conclusions:** The Mallampati score appears to be influenced by obesity, tongue enlargement, and upper airway crowding.

Keywords: Sleep apnea, obstructive; Tongue; Obesity; Diagnostic imaging.

INTRODUCTION

Obstructive sleep apnea (OSA) is characterized by repeated upper airway obstruction during sleep. OSA is highly prevalent and is associated with impaired quality of life and increased cardiovascular risk.[1-5] Obesity, advanced age, and being male are the major risk factors for OSA.[6,7] Each one of these factors is associated with soft tissue enlargement and higher upper airway collapsibility.[6] The tongue is the largest anatomical structure of the pharynx and is particularly prone to enlargement caused by fat deposition.[8] The imbalance between upper airway bone structure and soft tissue volume is thought to play a major role in the increased upper airway collapsibility of OSA patients.[9]

The Mallampati scoring system was developed to predict the risk of difficult endotracheal intubation on the basis of direct examination of the upper airway when the tongue is maximally protruded in a seated patient.[10] If the base of the tongue is disproportionately large, it overshadows the oropharynx. The Mallampati score ranges from I to IV, a higher score translating to a narrower upper airway.[10] The Mallampati score has recently been used in order to assess the risk of OSA.[11-15] However, the anatomical structures that lead to a higher Mallampati score have yet to be fully described. Given that a higher Mallampati score is associated with a crowded oropharynx, we hypothesized that the Mallampati score is associated with tongue volume and an imbalance between tongue and mandible volumes.

METHODS

The present study is part of a larger study addressing anatomical risk factors for OSA.[9] The study protocol consisted of a clinical evaluation, baseline polysomnography (PSG), and upper airway CT scans.[9] All procedures were performed within 14 days; however, in most of the study participants, CT scans were performed in the afternoon before baseline PSG.[9]

We recruited male Brazilians (either White or of Japanese descent) who were in the 18- to 70-year

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age bracket and who had been referred to the University of São Paulo *Hospital das Clínicas* sleep clinic, located in the city of São Paulo, Brazil.[9] The exclusion criteria were as follows: being female; having craniofacial abnormalities; having comorbidities such as COPD, heart failure, chronic kidney disease, and neuromuscular disease; and currently using sedatives.[9] All patients underwent clinical evaluation and physical examination, including measurements of height, weight, waist circumference, and neck circumference, as well as assessment of the Mallampati score.[9]

Patients were evaluated by PSG during natural sleep. Monitoring and evaluation included electroencephalography, electrooculography, chin and leg electromyography, electrocardiography, oximetry, measurements of airflow (with a nasal pressure cannula and an oronasal thermistor), and measurements of thoracic and abdominal movements during breathing (Alice 5; Philips Respironics, Murrysville, PA, USA), in accordance with the American Academy of Sleep Medicine guidelines.[9,16]

All patients underwent a CT scan of the upper airway (Discovery CT 750 HD; GE HealthCare Technologies Inc., Chicago, IL, USA). Image acquisition was performed during quiet tidal breathing, with patients lying supine and a neutral head position. This neutral position was defined by aligning the Frankfurt plane, a plane from the inferior margin of the orbit to the superior portion of the tragus, perpendicular to the scanner table.[17] The scans were acquired at a 2.5-mm collimation/interval and were reconstructed at a 0.625/0.625-mm thickness/interval, with 120 kV, 100 mA, and a rotation time of 0.8 s. Axial and sagittal image reconstructions were performed on an Advantage Workstation, version 4.5 (GE HealthCare Technologies Inc.) for linear and volumetric measurements.[18] Mandible volume was determined by a technique based on HU values for bone (i.e., 160-3,000 HU). To determine tongue volume, the tongue outline was identified and manually traced on each axial image.[19,20] Volumetric reconstructions were performed to determine mandible and tongue volumes. All measurements were performed by the same investigator.[9]

All patients underwent upper airway examination and assessment of the Mallampati score.[9] Patients were asked to breathe through their nose after a single swallowing and open their mouths wide with voluntary protrusion of the tongue without phonation. All evaluations were performed by the same investigator. Oropharyngeal crowding was graded in accordance with the Mallampati classification system, as follows: grade I—tonsils, pillars, and soft palate were clearly visible; grade II—the uvula, pillars, and upper pole were visible; grade III—only part of the soft palate was visible, whereas the tonsils, pillars, and base of the uvula could not be seen; and grade IV—only the hard palate was visible. At the same visit, the BMI was calculated.[9]

Clinical, polysomnographic, and anatomical variables were compared between Mallampati classes (I-IV). The Kolmogorov-Smirnov test was used in order to test whether variables had a normal distribution. One-way ANOVA with Bonferroni post-hoc analysis was used for between-group comparisons. Spearman's rank correlation was used in order to test the associations among the Mallampati score, the apnea-hypopnea index (AHI), BMI, neck circumference, waist circumference, tongue volume, and tongue/mandible volume ratio. The accuracy of the study variables in predicting moderate to severe OSA was also tested. ROC curve analysis was applied, and the AUC was used in order to test the accuracy of the study variables in detecting an AHI > 15 events/h, a cutoff showing the best balance between sensitivity and specificity being determined. Univariate and multivariate logistic regression models were built to test predictors of moderate to severe OSA (an AHI > 15 events/h). A value of $p < 0.05$ was considered significant. Variables were described as mean ± SD or median [IQR]. All statistical analyses were performed with the SPSS Statistics software package, version 17.0 (SPSS Inc., Chicago, IL, USA).

The present study was approved by the University of São Paulo School of Medicine *Hospital das Clínicas* Research Ethics Committee (Protocol no. 0230/09; SDC 3235/08/151).[9] All participating patients gave written informed consent.[9]

RESULTS

Eighty male patients were included in the study (Table 1) and divided into four groups on the basis of the Mallampati score (Table 2). In comparison with the study participants who were classified as being Mallampati class IV patients, those who were classified as being Mallampati class I patients had a lower BMI (26.7 ± 2.4 kg/m^2 vs. 30.8 ± 3.6 kg/m^2; $p < 0.01$), a smaller neck circumference (39.7 ± 2.3 cm vs. 42.7 ± 2.7 cm; $p < 0.01$), a smaller waist circumference (94.2 ± 9.1 cm vs. 106.5 ± 11.0 cm; $p < 0.01$), and less severe OSA (22.3 ± 17.8 events/h vs. 51.3 ± 27.2 events/h; $p < 0.01$). The study participants who were classified as being Mallampati class II patients were younger (40.1 ± 11.7 years of age vs. 53.3 ± 9.3 years of age; $p < 0.01$), had a smaller neck circumference (40.4 ± 3.0 cm vs. 42.7 ± 2.7 cm; $p < 0.05$), had less severe OSA (23.6 ± 22.7 events/h vs. 51.3 ± 27.2 events/h; $p < 0.01$), and had smaller tongue volume (134.8 ± 17.7 cm^3 vs. 152.3 ± 19.1 cm^3; $p < 0.01$) than did those who were classified as being Mallampati class IV patients (Figure 1). The study participants who were classified as being Mallampati class III patients had smaller tongue volume (134.5 ± 12.7 cm^3 vs. 152.3 ± 19.1 cm^3; $p < 0.05$) and lower tongue-to-mandible volume ratio (2.1 ± 0.4 cm^3 vs. 2.5 ± 0.5 cm^3; $p < 0.05$) than did those who were classified as being Mallampati class IV patients. The Mallampati score was associated with the AHI (r = 0.431, p < 0.001), BMI (r = 0.405, p < 0.001), neck circumference (r = 0.393, p < 0.001), waist circumference (r = 0.393, p < 0.001), tongue volume (r = 0.283, p < 0.001), and tongue/mandible volume ratio (r = 0.280, p = 0.012).

Table 3 shows the accuracy of the study variables in predicting OSA, as well as the results of the univariate logistic regression analysis in which OSA (an AHI > 15 events/h) was used as the dependent variable. Table 4 presents the results of the multivariate logistic regression analysis in which OSA (an AHI > 15 events/h) was used as the dependent variable. Mallampati class III or IV (OR = 3.075; 95% CI, 1.003-9.428; p = 0.049) and being over 45 years of age (OR = 5.300; 95% CI, 1.768-15.873; p = 0.003) were independently associated with an increased risk of OSA, regardless of ethnicity.

Table 1. Demographic and anthropometric characteristics of the study participants (N = 80), as well as polysomnographic parameters.[a]

Parameter	Result
Males	80 (100%)
Brazilians of Japanese descent	40 (50%)
Age, years	46.8 ± 13.0
BMI, kg/m^2	29.3 ± 3.9
Waist circumference, cm	101 ± 10
Neck circumference, cm	41 ± 3
Comorbidities	49 (60%)
Hypertension	30 (37%)
Diabetes	13 (16%)
Dyslipidemia	16 (19%)
Epworth Sleepiness Scale score	11 ± 6
AHI, events/h	26.2 ± 26.7
Total sleep time, min	360.3 ± 64.6
Sleep efficiency, %	80 ± 9
Sleep latency, min	11 ± 12
REM sleep, %	11.5 ± 8.1
Lowest SpO_2, %	79 ± 9
Tongue volume, cm^3	141.3 ± 18.3
Tongue/mandible volume ratio	2.3 ± 0.4

AHI: apnea-hypopnea index; and REM: rapid eye movement. [a]Data expressed as n (%) or mean ± SD.

DISCUSSION

The major finding of the present study is that the Mallampati score was associated with obesity-related variables, OSA severity, tongue volume, and an imbalance between tongue and mandible volumes. Mallampati class IV patients tended to be older and more obese (having either a higher BMI or larger neck and waist circumferences) than Mallampati class I or II patients, had as well as having more severe OSA and greater tongue volume. Mallampati class IV patients also had a greater imbalance between tongue and mandible volumes than did Mallampati class III patients. These findings suggest that the Mallampati score is influenced by obesity and tongue volume.

Obesity is a major risk factor for OSA and can lead to enlargement of upper airway soft tissue structures, particularly the tongue.[8,21] Animal studies have shown that obesity leads to an increase in tongue volume through fat infiltration.[22] In an autopsy study, Nashi et al.[8] showed that tongue weight and tongue fat percentage were strongly correlated with BMI. Studies using CT and magnetic resonance imaging have shown that tongue fat infiltration and upper airway soft tissue volume are associated with obesity.[6] Schwab et al.[23] analyzed digital photographs of 318 controls and 542 patients with

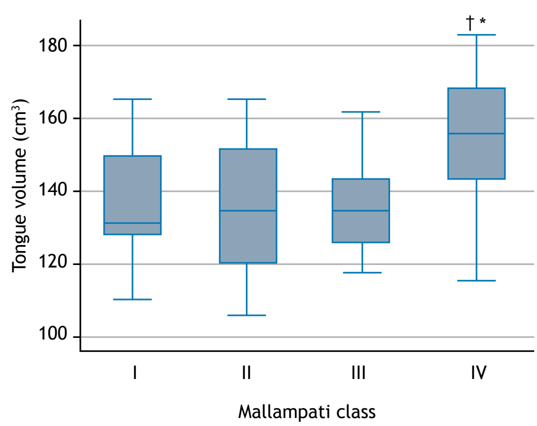

Figure 1. Tongue volume, by Mallampati class. *p < 0.01 vs. Mallampati class II. †p < 0.05 vs. Mallampati class III.

Table 2. Anthropometric variables and tongue volume, by Mallampati class.[a]

Variable	Mallampati class I	Mallampati class II	Mallampati class III	Mallampati class IV
Participants, n	17	19	18	26
Age, years	44.4 ± 14.0	40.1 ± 11.7*	46.3 ± 14.4	53.3 ± 9.3
BMI, kg/m^2	26.7 ± 2.4*	28.9 ± 4.6	29.5 ± 4.3	30.8 ± 3.6
AHI, events/h	22.3 ± 17.8*	23.6 ± 22.7*	39.8 ± 25.1	51.3 ± 27.2
Neck circumference, cm	39.7 ± 2.3*	40.4 ± 3.0†	41.6 ± 2.3	42.7 ± 2.7
Waist circumference, cm	94.2 ± 9.07*	100.1 ± 11.56	101 ± 9.61	106.5 ± 10.99
Tongue volume, cm^3	138.1 ± 17.2	134.8 ± 17.7*	134.5 ± 12.7†	152.3 ± 19.1
Tongue/mandible volume ratio, cm^3	2.2 ± 0.4	2.2 ± 0.4	2.1 ± 0.4†	2.5 ± 0.5

AHI: apnea-hypopnea index. [a]Data expressed as mean ± SD, except where otherwise indicated. *p < 0.01. †p < 0.05 vs. Mallampati class IV.

Table 3. Univariate logistic regression between obstructive sleep apnea (an apnea-hypopnea index > 15 events/h) and clinical/anthropometric variables and their accuracy in predicting obstructive sleep apnea (an apnea-hypopnea index > 15 events/h).

Variable	OR [95% CI]	p	AUC	Cutoff	Sensitivity, %	Specificity, %
BMI	1.26 [1.08-1.48]	0.003	0.729	27.86	70.37	69.23
BMI > 27.86 kg/m²	5.34 [1.93-14.78]	< 0.001				
Mallampati classes I and II	1.75 [1.13-2.71]	0.013	0.671	3	66.67	69.23
Mallampati classes III and IV	4.5 [1.64-12.31]	0.003				
Age	1.07 [1.03-1.12]	< 0.001	0.751	45	72.2	73.1
Age > 45 years	7.06 [2.47 - 20.20]	< 0.001				
ESS score	1.12 [1.02-1.22]	0.015	0.664	10	68.5	53.9
Berlin questionnaire	4.99 [0.59-41.78]	0.137				
Neck circumference	1.74 [1.32-2.29]	0.000	0.831	40.2	77.78	76.92
Neck circumference > 40.2 cm	11.67 [3.82-35.59]	< 0.001				
Waist circumference	1.10 [1.04-1.16]	< 0.001	0.739	100	64.81	69.23
Waist circumference > 100 cm	4.14 [1.52-11.30]	0.005				

ESS: Epworth Sleepiness Scale.

Table 4. Multivariate logistic regression analysis of predictors of obstructive sleep apnea (an apnea-hypopnea index > 15 events/h).

Predictor	OR	SE	Z	p > lzl	95% CI	
Mallampati class III or IV	3.075	1.757	1.97	0.049	1.003	9.428
Age > 45 years	5.300	2.966	2.98	0.003	1.768	15.873
White	1.135	0.635	0.23	0.821	0.379	3.398
_cons	0.495	0.255	-1.36	0.173	0.180	1.360

OSA. Tongue size was larger in the patients with OSA than in the controls in unadjusted models controlled for age, sex, and race, but the difference was not significant when the models were controlled for BMI.[23,24] Weight loss leads to a reduction in tongue fat content and pharyngeal length, reinforcing the association between obesity and increased tongue volume through fat infiltration.[7]

Ahn et al. reported that the Mallampati score was associated with a higher tongue volume and a higher tongue volume/intramandibular area ratio.[25] In another study, a higher Mallampati score was associated with a larger tongue area in surgical patients ($p < 0.05$).[26] The Mallampati score has been associated with the BMI.[11,23] In the present study, the Mallampati score was associated with tongue volume and an imbalance between tongue and mandible volumes. Amra et al. evaluated anthropometric data and the Mallampati score in patients with confirmed OSA and found that those with severe OSA were more obese and had a higher Mallampati score than those with mild to moderate OSA.[11] These findings are consistent with ours, which show that the Mallampati score is associated with obesity-related variables (BMI, neck circumference, and waist circumference). Together, obesity and enlargement of upper airway soft tissue structures can lead to a higher Mallampati score.

In the present study, Mallampati classes III and IV were accurate predictors of moderate to severe OSA (i.e., an AHI > 15 events/h). In a meta-analysis, Friedman et al. showed that a higher Mallampati score was significantly associated with OSA severity.[12] Previous studies assessing predictors of OSA severity showed that the Mallampati score was the most important variable associated with OSA severity, Mallampati class IV patients having a five-fold increased risk of mild to severe OSA.[27,28] Nuckton et al.[13] found that for every 1-point increase in the Mallampati score, the odds of having OSA increased by 2.5 (95% CI, 1.2-5.0; $p = 0.01$) and the AHI increased by 5.2 events/h (95% CI, 0.2-10; $p = 0.04$), independently of variables related to airway anatomy, body habitus, symptoms, and medical history. In another study, a higher Mallampati score was associated with a higher AHI, both unadjusted and controlling for age, sex, race, and BMI.[23] Therefore, a higher Mallampati score is a risk factor for OSA.

Our study has several limitations. Because of the cross-sectional design, we cannot establish a causal relationship among the Mallampati score, tongue volume, and obesity. We included male patients only, our findings therefore being limited to men. By including male patients only, we intended to reduce the variability of the study variables. Our study population consisted of male Brazilians who were either White or of Japanese descent, our conclusions therefore being limited to these ethnicities. Future studies should address these limitations by investigating larger samples, including other ethnicities, and exploring differential tongue and mandibular measurements in males and females. The Mallampati classification is susceptible to interobserver disagreement. In order to minimize this potential bias, the same investigator performed all of the examinations in the present study. Future studies assessing the effects of weight loss on tongue volume and the Mallampati score are warranted.

The Mallampati score was found to be associated with obesity-related variables, a larger tongue, and a greater tongue/mandible volume imbalance. The Mallampati score might be affected by the impact of obesity on tongue size and upper airway crowding.

AUTHOR CONTRIBUTIONS

RABA: data/statistical analysis and drafting of the manuscript. LLIC: data/statistical analysis. FS: data collection and data/statistical analysis. EMMSG and GLF: critical revision of the manuscript for important intellectual content. PRG: study conception/design, data/statistical analysis, and critical revision of the manuscript for important intellectual content. All authors read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

None declared.

REFERENCES

1. Heatley EM, Harris M, Battersby M, McEvoy RD, Chai-Coetzer CL, Antic NA. Obstructive sleep apnoea in adults: a common chronic condition in need of a comprehensive chronic condition management approach. Sleep Med Rev. 2013;17(5):349-355. https://doi.org/10.1016/j.smrv.2012.09.004
2. Benjafield AV, Ayas NT, Eastwood PR, Heinzer R, Ip MSM, Morrell MJ, et al. Estimation of the global prevalence and burden of obstructive sleep apnoea: a literature-based analysis. Lancet Respir Med. 2019;7(8):687-698. https://doi.org/10.1016/S2213-2600(19)30198-5
3. Peppard PE, Young T, Barnet JH, Palta M, Hagen EW, Hla KM. Increased prevalence of sleep-disordered breathing in adults. Am J Epidemiol. 2013;177(9):1006-1014. https://doi.org/10.1093/aje/kws342
4. Heinzer R, Vat S, Marques-Vidal P, Marti-Soler H, Andries D, Tobback N, et al. Prevalence of sleep-disordered breathing in the general population: the HypnoLaus study. Lancet Respir Med. 2015;3(4):310-318. https://doi.org/10.1016/S2213-2600(15)00043-0
5. Tufik S, Santos-Silva R, Taddei JA, Bittencourt LR. Obstructive sleep apnea syndrome in the Sao Paulo Epidemiologic Sleep Study. Sleep Med. 2010;11(5):441-446. https://doi.org/10.1016/j.sleep.2009.10.005
6. Godoy IR, Martinez-Salazar EL, Eajazi A, Genta PR, Bredella MA, Torriani M. Fat accumulation in the tongue is associated with male gender, abnormal upper airway patency and whole-body adiposity. Metabolism. 2016;65(11):1657-1663. https://doi.org/10.1016/j.metabol.2016.08.008
7. Wang SH, Keenan BT, Wiemken A, Zang Y, Staley B, Sarwer DB, et al. Effect of Weight Loss on Upper Airway Anatomy and the Apnea-Hypopnea Index. The Importance of Tongue Fat. Am J Respir Crit Care Med. 2020;201(6):718-727. https://doi.org/10.1164/rccm.201903-0692OC
8. Nashi N, Kang S, Barkdull GC, Lucas J, Davidson TM. Lingual fat at autopsy. Laryngoscope. 2007;117(8):1467-1473. https://doi.org/10.1097/MLG.0b013e318068b566
9. Schorr F, Kayamori F, Hirata RP, Danzi-Soares NJ, Gebrim EM, Moriya HT, et al. Different Craniofacial Characteristics Predict Upper Airway Collapsibility in Japanese-Brazilian and White Men. Chest. 2016;149(3):737-746. https://doi.org/10.1378/chest.15-0638
10. Mallampati SR, Gatt SP, Gugino LD, Desai SP, Waraksa B, Freiberger D, et al. A clinical sign to predict difficult tracheal intubation: a prospective study. Can Anaesth Soc J. 1985;32(4):429-434. https://doi.org/10.1007/BF03011357
11. Amra B, Pirpiran M, Soltaninejad F, Penzel T, Fietze I, Schoebel C. The prediction of obstructive sleep apnea severity based on anthropometric and Mallampati indices. J Res Med Sci. 2019;24:66. https://doi.org/10.4103/jrms.JRMS_653_18
12. Friedman M, Hamilton C, Samuelson CG, Lundgren ME, Pott T. Diagnostic value of the Friedman tongue position and Mallampati classification for obstructive sleep apnea: a meta-analysis. Otolaryngol Head Neck Surg. 2013;148(4):540-547. https://doi.org/10.1177/0194599812473413
13. Nuckton TJ, Glidden DV, Browner WS, Claman DM. Physical examination: Mallampati score as an independent predictor of obstructive sleep apnea. Sleep. 2006;29(7):903-908. https://doi.org/10.1093/sleep/29.7.903
14. Liistro G, Rombaux P, Belge C, Dury M, Aubert G, Rodenstein DO. High Mallampati score and nasal obstruction are associated risk factors for obstructive sleep apnoea. Eur Respir J. 2003;21(2):248-252. https://doi.org/10.1183/09031936.03.00292403
15. Yu JL, Rosen I. Utility of the modified Mallampati grade and Friedman tongue position in the assessment of obstructive sleep apnea. J Clin Sleep Med. 2020;16(2):303-308. https://doi.org/10.5664/jcsm.8188
16. Kapur VK, Auckley DH, Chowdhuri S, Kuhlmann DC, Mehra R, Ramar K, et al. Clinical Practice Guideline for Diagnostic Testing for Adult Obstructive Sleep Apnea: An American Academy of Sleep Medicine Clinical Practice Guideline. J Clin Sleep Med. 2017;13(3):479-504. https://doi.org/10.5664/jcsm.6506
17. Schwab RJ, Gupta KB, Gefter WB, Metzger LJ, Hoffman EA, Pack AI. Upper airway and soft tissue anatomy in normal subjects and patients with sleep-disordered breathing. Significance of the lateral pharyngeal walls. Am J Respir Crit Care Med. 1995;152(5 Pt 1):1673-1689. https://doi.org/10.1164/ajrccm.152.5.7582313
18. Genta PR, Schorr F, Eckert DJ, Gebrim E, Kayamori F, Moriya HT, et al. Upper airway collapsibility is associated with obesity and hyoid position. Sleep. 2014;37(10):1673-1678. https://doi.org/10.5665/sleep.4078
19. Abramson Z, Susarla S, August M, Troulis M, Kaban L. Three-dimensional computed tomographic analysis of airway anatomy in patients with obstructive sleep apnea. J Oral Maxillofac Surg. 2010;68(2):354-362. https://doi.org/10.1016/j.joms.2009.09.087
20. Welch KC, Foster GD, Ritter CT, Wadden TA, Arens R, Maislin G, et al. A novel volumetric magnetic resonance imaging paradigm to study upper airway anatomy. Sleep. 2002;25(5):532-542. https://doi.org/10.1093/sleep/25.5.530
21. Shigeta Y, Ogawa T, Ando E, Clark GT, Enciso R. Influence of tongue/mandible volume ratio on oropharyngeal airway in Japanese male patients with obstructive sleep apnea. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;111(2):239-243. https://doi.org/10.1016/j.tripleo.2010.10.013
22. Brennick MJ, Delikatny J, Pack AI, Pickup S, Shinde S, Zhu JX, et al. Tongue fat infiltration in obese versus lean Zucker rats. Sleep. 2014;37(6):1095-1102C. https://doi.org/10.5665/sleep.3768
23. Schwab RJ, Leinwand SE, Bearn CB, Maislin G, Rao RB, Nagaraja A, et al. Digital Morphometrics: A New Upper Airway Phenotyping Paradigm in OSA. Chest. 2017;152(2):330-342. https://doi.org/10.1016/j.chest.2017.05.005
24. Schwab RJ, Pasirstein M, Pierson R, Mackley A, Hachadoorian R, Arens R, et al. Identification of upper airway anatomic risk factors for obstructive sleep apnea with volumetric magnetic resonance imaging. Am J Respir Crit Care Med. 2003;168(5):522-530. https://doi.org/10.1164/rccm.200208-866OC
25. Ahn SH, Kim J, Min HJ, Chung HJ, Hong JM, Lee JG, et al. Tongue Volume Influences Lowest Oxygen Saturation but Not

Apnea-Hypopnea Index in Obstructive Sleep Apnea. PLoS One. 2015;10(8):e0135796. https://doi.org/10.1371/journal.pone.0135796

26. Hiremath AS, Hillman DR, James AL, Noffsinger WJ, Platt PR, Singer SL. Relationship between difficult tracheal intubation and obstructive sleep apnoea. Br J Anaesth. 1998;80(5):606-611. https://doi.org/10.1093/bja/80.5.606
27. Ruangsri S, Jorns TP, Puasiri S, Luecha T, Chaithap C, Sawanyawisuth K. Which oropharyngeal factors are significant risk factors for obstructive sleep apnea? An age-matched study and dentist perspectives. Nat Sci Sleep. 2016;8:215-219. https://doi.org/10.2147/NSS.S96450
28. Friedman M, Tanyeri H, La Rosa M, Landsberg R, Vaidyanathan K, Pieri S, et al. Clinical predictors of obstructive sleep apnea. Laryngoscope. 1999;109(12):1901-1907. https://doi.org/10.1097/00005537-199912000-00002