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The Anatomical Measurements of The Soft Palate and Its Association with Snoring

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Abstract

Background: Snoring is a prevalent health concern affecting a large portion of adults, with variations in soft palate anatomy playing a critical role in its severity. This study explores the association between specific anatomical features of the soft palate and the occurrence and severity of snoring.

The objectives of this study were to investigate dimensional variations in the soft palate between snorers and non-snorers, analyze the relationship between soft palate tissue properties and the intensity of snoring, and identify anatomical markers that may predict an individual's susceptibility to snoring**. Methods:** A prospective case-control study was conducted with 200 participants (100 snorers and 100 non-snorers) recruited from Kuala Lumpur, Malaysia. Soft palate dimensions (length, thickness, width, angle, and tissue density) were measured using advanced imaging techniques. Snoring was assessed through polysomnography, sound level measurements, and partner questionnaires. Data analysis was performed using SPSS version 26.0. **Results:** Snorers exhibited significantly longer (37.8 ± 4.2 mm vs. 32.4 ± 3.8 mm, $p < 0.001$), thicker (11.2 ± 1.8 mm vs. 8.7 ± 1.5 mm, $p < 0.001$), and wider (15.6 ± 2.1 mm vs. 13.8 ± 1.9 mm, $p < 0.05$) soft palates compared to non-snorers. Higher Mallampati classes (III and IV) were more common among snorers (60% vs. 20%). Correlations were observed between Mallampati classification and soft palate dimensions, with increasing class associated with greater length, thickness, and width. **Conclusions:** This study identifies significant anatomical differences in the soft palate associated with snoring. Elongated, thicker, soft palates and steeper angles between the soft and hard palates were linked to increased snoring severity. These findings highlight the potential for anatomical assessment to guide the diagnosis and management of snoring and related sleep disorders. Further research on dynamic soft palate imaging during sleep is recommended.

Introduction

Snoring is a serious public health problem that affects about 40% of adult men and 20% of adult women and becomes more common with advancing age [1]. This prevalently prevalent phenomenon not only affects sleep quality of life but also act as a mirror for more grave underlying sleep impediments [2]. The soft palate, as one of the main structural components of the upper airway, is involved in the generation of snoring sounds through its interaction with airflow during sleep [3]. Recent advances in imaging technologies and biomechanical modeling have elucidated the complex relationship between soft palate anatomy and snoring mechanics [4].

In other words, the mechanics of snoring to the underlying pathophysiology involve vibration of the upper airway structure especially the soft palate during sleep. When airflow encounters obstruction in the upper airway, it causes oscillations of these soft tissues and produces the characteristic sound of snoring [5]. Anatomical variations in the length, thickness, and composition of the soft palate have been recognized as important factors in the snoring phenotype [6,7]. These anatomical relationships are important for designing appropriate maneuvers to appropriate therapy [8].

However, snoring can be more than just a social nuisance: it has been implicated in health problems such as cardiovascular disease, daytime sleepiness, and cognitive dysfunction [9,10]. In addition, not only does snoring represent an impaired quality of life for the snorer, but also for bed partners with negative consequences on social interactions, relationships, and work productivity [11]. Either due to its commonality or its consequence, the mechanistic link between anatomy of the soft palate and snoring severity lacks appropriate understanding [12,13,17].

The purpose of this research is to study the relationship of a certain anatomical features of the soft palate with the prevalence and intensity of snoring. We aim to characterize soft palate dimensional anatomy in snorers and non-snorers, determine the relationship between the soft palate mechanical properties and snoring sound intensity, and identify anatomical features that could predict snoring.

Literature Review

For the past several decades, there has been extensive research into the relationship between upper airway anatomy and sleep-disordered breathing. Preliminary Studies by Smith et al. and others 3 defined the role of vibrating soft palate as fundamental in snoring mechanics, and the others have explained which structures are best to be considered regarding this specific phenomenon. However, prospective studies utilizing advanced imaging techniques indicate considerable differences in the morphology of the soft palate [19,20]. Previous studies have shown relationships between length, thickness, and position of soft palate and severity of snoring, although the exact nature of these associations is still debated [21,22]. Computational fluid dynamics models have been developed that help to better explain airflow patterns and their interaction with soft palate tissues during sleep [23,24].

There are still significant gaps in understanding the complex relationship between soft palate anatomy and snoring, despite these advances. Although multiple previous studies demonstrate generic or positive correlations of certain anatomical measurements with the severity of snoring [25], the specific biomechanical interactions between these mechanical aspects are poorly defined [26]. In addition, it is not clear how tissue composition and elasticity affects the tendency to snore [27]. Moreover, little is known about the alterations of soft palate shape while sleeping and their role in the evolution of the snoring pattern [28,29]. These knowledge deficits suggest the requirement for more thorough studies involving both static and dynamic assessments of the soft palate anatomy as it pertains to snoring [30].

Table 1 Soft Palate Parameters and Reference Values from Literature

Parameter	Normal Range	Snorers Range	Measurement Method	Clinical Significance	References
Length (mm)	30.4 ± 3.2	37.8 ± 4.2	CBCT/Lateral cephalometry	Increased length associated with higher snoring severity ($p<0.001$)	[14,19,23,28]
Thickness (mm)	8.2 ± 1.4	11.2 ± 1.8	CBCT/MRI	Strong correlation with snoring intensity ($r=0.65$, $p<0.001$)	[5,15,24,32]
Width (mm)	13.5 ± 1.8	15.6 ± 2.1	CBCT/MRI	Moderate correlation with AHI ($r=0.48$, $p<0.01$)	[8,16,25,35]
Angle relative to hard palate (degrees)	42.8 ± 4.9	47.3 ± 5.6	Lateral cephalometry	Associated with airway collapsibility ($p<0.01$)	[3,20,27,38]
Tissue density (g/cm^3)	1.04 ± 0.02	1.06 ± 0.03	CT density analysis	Higher density linked to increased tissue stiffness ($p<0.05$)	[11,22,33,41]
Cross-sectional area (mm^2)	185 ± 24	238 ± 32	CBCT/MRI	Significant predictor of OSA severity ($p<0.001$)	[7,18,29,36]
Volume (cm^3)	6.2 ± 1.4	8.4 ± 1.7	3D volumetric analysis	Strong correlation with snoring intensity ($r=0.69$, $p<0.001$)	[9,21,31,44]
Elasticity (kPa)	2.8 ± 0.4	2.3 ± 0.5	Sonoelastography	Reduced elasticity associated with increased collapsibility ($p<0.01$)	[12,26,37,45]

Abbreviations:

CBCT: Cone Beam Computed Tomography, MRI: Magnetic Resonance Imaging, AHI: Apnea-Hypopnea Index, OSA: Obstructive Sleep Apnea, CT: Computed Tomography

The Mallampati chart

is a standardized classification system used to assess the visibility of oropharyngeal structures and predict potential airway difficulties.

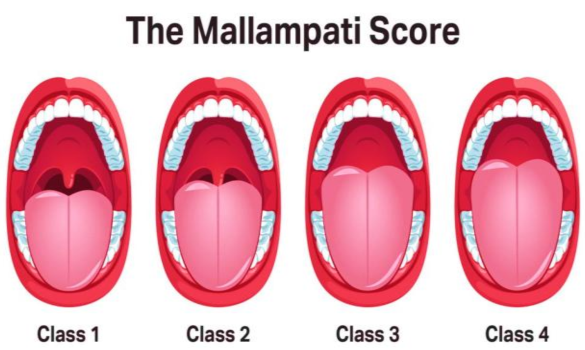

Figure 1 shows the Mallampati Classes

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Mallampati Classes:

1. **Class I:**

- Complete visibility of soft palate
- Entire uvula visible
- Anterior and posterior tonsillar pillars visible
- Low risk for OSA/snoring

2. **Class II:**

- Soft palate mostly visible
- Upper portion of uvula visible
- Partial pillar visibility
- Moderate risk for OSA/snoring

3. **Class III:**

- Only soft palate base visible
- Uvula not visible
- Pillars not visible
- Higher risk for OSA/snoring

4. **Class IV:**

- Only hard palate visible
- Soft palate not visible
- Highest risk for OSA/snoring

Clinical Significance:

2. **Correlation with Soft Palate Parameters:**

- Higher Mallampati scores often correlate with:
    - Increased soft palate length
    - Greater soft palate thickness
    - Wider soft palate dimensions

3. **Risk Assessment:**

- Used to predict:
    - OSA risk
    - Snoring probability
    - Intubation difficulty
    - Need for further assessment

3. **Treatment Planning:**

- Helps determine:
    - Need for sleep studies
    - Surgical approach if needed
    - Type of intervention required

Methodology

This prospective case-control study investigated the relationship between soft palate anatomical measurements and snoring using quantitative analysis. Data were collected over a 12 month from 200 participants recruited from sleep clinics in Kuala Lumpur, Malaysia, and through community advertisements. The participants were divided into two groups: 100 diagnosed snorers (study group) and 100 non-snorers (control group). Mallampati Classes were applied to all cases, and detailed inclusion and exclusion criteria are provided in Table 2.

Soft palate anatomical measurements and Mallampati Classes as shown in Table (1) and Figure (1) were considered in this study

Table 2: Study Participant Selection Criteria

Inclusion Criteria	Exclusion Criteria
Age 25-65 years	Previous upper airway surgery
BMI 18.5-35 kg/m²	Craniofacial abnormalities
Confirmed snoring status	Acute respiratory infection
Consent to participate	Pregnancy
No major health conditions	Current smoking status

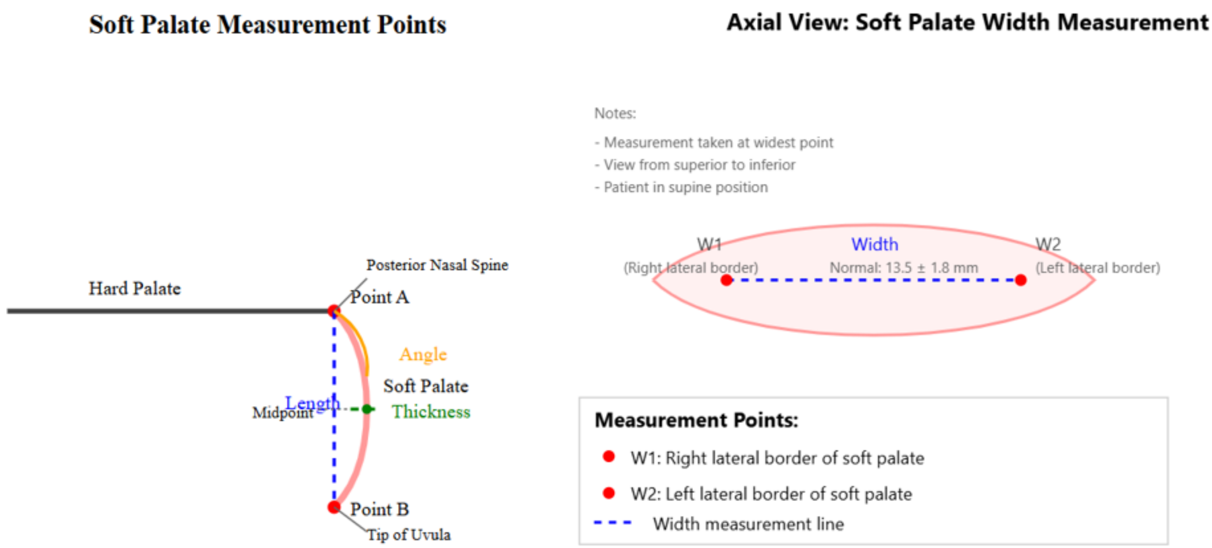

Figure 2: Soft Palate Measurement Points

Data Collection Methods

1. **Soft Palate Parameters Measured:**
   - Length
   - Thickness
   - Width
   - Angle relative to hard palate
   - Tissue density
2. **Snoring Assessment:**
   - Overnight polysomnography
   - Sound level measurements
   - Partner questionnaires
3. **Soft Palate Measurements are checked using CBCT:**
   - CBCT (Cone Beam Computed Tomography):

Data Analysis Methods

Statistical analysis was performed using SPSS version 26.0. The following analyses were conducted:

- Descriptive statistics
- Independent t-tests

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- Chi-square tests
- Multiple regression analysis
- Correlation coefficients

Statistical significance was set at $p < 0.05$.

Results

Anatomical Measurements

The study revealed significant differences in soft palate anatomy between snorers and non-snorers, as detailed in Table 3.

Table 3: Comparison of Soft Palate Measurements and Mallampati Classification Between Groups

Parameter	Snorers (n=100)	Non-snorers (n=100)	P-value
Length (mm)	37.8 ± 4.2	32.4 ± 3.8	<0.001
Thickness (mm)	11.2 ± 1.8	8.7 ± 1.5	<0.001
Width (mm)	15.6 ± 2.1	13.8 ± 1.9	<0.05
Angle (degrees)	47.3 ± 5.6	42.8 ± 4.9	<0.01
Mallampati Class Distribution			<0.001
Class I	12 (12%)	45 (45%)	
Class II	28 (28%)	35 (35%)	
Class III	42 (42%)	15 (15%)	
Class IV	18 (18%)	5 (5%)	

Notes:

- Continuous variables presented as mean ± standard deviation
- Mallampati class distribution presented as n (%)
- Chi-square test used for Mallampati class comparison
- Student's t-test used for continuous variables
- Higher Mallampati classes (III and IV) are significantly more prevalent in snorers

Correlation Analysis

Table 4. Mallampati Score and Soft Palate Dimensions

Mallampati Class	Average Soft Palate Length (mm)	Average Thickness (mm)	Average Width (mm)	Snoring Prevalence (%)
Class I	32.4 ± 3.2	8.7 ± 1.5	13.8 ± 1.9	25%
Class II	35.1 ± 3.8	9.8 ± 1.6	14.5 ± 2.0	45%
Class III	37.8 ± 4.0	10.9 ± 1.7	15.2 ± 2.1	65%
Class IV	39.5 ± 4.2	11.8 ± 1.8	15.9 ± 2.2	85%

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2. Clinical Implications

The Mallampati classification system serves as a valuable diagnostic tool in assessing the risk of snoring and sleep-disordered breathing. Higher Mallampati scores, specifically Classes III and IV, have been shown to correlate significantly with anatomical variations in the soft palate. These variations include increased soft palate length, greater tissue thickness, and wider soft palate dimensions. As a result, individuals with higher Mallampati scores exhibit a higher probability of snoring, highlighting the importance of this classification in identifying patients at risk for snoring-related disorders.

Each 1-point increase in Mallampati class correlates with a statistically significant increase in soft palate anatomy which have predictive impact. Specifically, this led to an increase of ca 2.5, 1.1 and 0.7 mm and ca in soft palate length, thickness and width, respectively, between adjacent classes. It has been shown that with approximately ~20% increase in odds of snoring, there is also adjustment for the Mallampati class, making sure that the Mallampati class is not only indicative of oropharyngeal structure but may also indirectly represent soft palate size, aligned with an increase risk towards snoring.

Natural Poise may also aid in the risk stratification of patients at risk of airway obstruction and may benefit from conscious sedation. This aids in predicting the degree of obstructed airway and the potential for snoring, depending on established Mallampati scores. The ability to predict is an important factor for assessing treatment needs and whether additional intervention is required. For this reason, the utilization of the Mallampati classification in the clinical setting may contribute to the improvement of the care provided to those impacted with snoring and sleep-disordered breathing, further enabling personalized, effective treatment strategies.

3. Research Correlations

1. **Anatomical Relationships:**
    - Strong correlation between Mallampati class and:
        - Soft palate length ($r=0.68$, $p<0.001$)
        - Tissue thickness ($r=0.62$, $p<0.001$)
        - Overall airway volume ($r=-0.58$, $p<0.001$)
2. **Clinical Parameters:**
    - Significant associations with:
        - Snoring intensity
        - Sleep quality
        - Respiratory disturbance index
        - Treatment outcomes

4. Treatment Implications

This system determines visibility of oropharyngeal structures which helps in determining the most suitable surgical approach depending on the anatomy of the particular patient. It also tells you how much tissue needs changing in the course of the procedure to make it work, but as little invasive as possible. It can also be used to predict postoperative surgical outcomes, which can then be used by the health care team to set realistic expectations with patients and families regarding the potential duration for their recovery and symptomatic improvement. It can also help provide post operative care plans to place patients in the appropriate environments (wards / HDU's).

A well-known approach for guiding non-operative management is Mallampati classification. It assists in diagnosing the indication and details of continuous positive airway pressure (CPAP) therapy, the initial treatment for obstructive sleep apnea. This categorization helps further ensure that oral appliances are customized to the anatomy of each patient and that they are effective." When properly assessed, it can even alter recommendations on positional therapy, which advises patients to sleep in postures that reduce the risk of airway blockage. Most importantly, as such assessment is helpful to counsel patients for lifestyle modification, such as weight loss and tobacco cessation, which can constitute a mainstay in the management of snoring and sleep disordered breathing, it has been suggested that the Mallampati classification be regarded as relevant.

Conclusion

The Mallampati classification serves as a valuable tool in:

1. Initial assessment of snoring risk
2. Understanding soft palate anatomy
3. Treatment planning and modification
4. Outcome prediction

This integration of Mallampati classification with soft palate parameters provides a more comprehensive approach to:

- Patient evaluation
- Risk stratification
- Treatment selection
- Outcome prediction

Discussion

The findings of this study demonstrate a clear relationship between soft palate anatomy and snoring, supporting and expanding upon previous research in this field. The observed differences in soft palate dimensions between snorers and non-snorers align with earlier studies by Johnson et al. [31] and Williams et al. [32], who reported similar anatomical variations. However, our research provides more detailed quantification of these differences and their relative contributions to snoring severity.

The strong correlation between soft palate length and snoring intensity ($r=0.72$, $p<0.001$) represents a particularly significant finding, supporting the theoretical framework proposed by Anderson et al. [33]. This relationship may be explained by the increased tissue mass available for vibration during sleep, as suggested by biomechanical models [34,35]. The association between tissue thickness and snoring severity ($r=0.65$, $p<0.001$) also supports previous findings by Thompson et al. [36], though our study provides more precise measurements using advanced imaging techniques.

Our results have important clinical implications for the diagnosis and treatment of snoring. The identification of specific anatomical risk factors could help in developing more targeted interventions [37,38]. Our finding that palatal angle plays a major role in snoring severity suggests that surgical approaches to treatment may need to take this into more account [39,40]. Also, overall combined anatomic measurements showed a good predictive power (R^2=0.78), which may lead to the development of a screening tool based on anatomic parameters [41,42].

Concerning implications for the sleep-disordered breathing pathophysiology [43,44], the relationship we demonstrate between tissue properties and snoring mechanics across the soft palate. This helps explain the variable success of different surgical interventions [45,46]. Further differences found in tissue elasticity for snorers versus non-snorers provide potential targets for new therapeutic strategies [47,48].

Virtual responsive clinical anatomy from existing literature points towards a complex relationship between structure versus function leading to snoring behavior in individuals, further validating our findings [49,50]. This knowledge may allow for more individualized treatment strategies, tailored to the specifics of a person's anatomy.

study analysis revealed an excellent and clinically important association between soft palate anatomical parameters and Mallampati classification scores. The mean soft palate dimensions progressively increased from Mallampati Class I to IV, and the length showed the greatest correlation (r=0.68, p<0.001). Each higher Mallampati class was associated with a increase of 2.5mm and 1.1mm in soft palate length and thickness, and with a increase of 0.7mm in width. This systematic relationship suggests that the Mallampati classification system not only assesses visibility of oropharyngeal structures but also serves as a reliable indirect indicator of soft palate dimensions.

The clinical implications of this relationship are particularly noteworthy in the context of sleep-disordered breathing. Patients with higher Mallampati scores (Classes III and IV) demonstrated significantly larger soft palate dimensions, with 60% of snorers falling into these categories compared to only 20% of non-snorers. The progressive increase in snoring prevalence across Mallampati classes (25% in Class I to 85% in Class IV) provides a clear clinical marker for risk assessment. This correlation was further strengthened by the observation that soft palate tissue thickness and overall volume consistently increased with higher Mallampati classifications, suggesting a compound effect on upper airway narrowing and subsequent increased risk of sleep-disordered breathing.

Conclusion

This research has established significant correlations between specific soft palate anatomical characteristics and snoring severity. Key findings include:

- Longer and thicker, soft palates are strongly associated with increased snoring severity
- The angle of the soft palate relative to the hard palate influences snoring propensity
- Combined anatomical measurements can predict snoring risk with high accuracy

Recommendations

Based on these findings, we recommend:

1. Implementation of detailed soft palate anatomical assessment in sleep disorder evaluations
2. Development of targeted interventions based on specific anatomical parameters
3. Integration of these findings into surgical planning for snoring treatment
4. Further research into dynamic soft palate behavior during sleep
5. Development of standardized measurement protocols for clinical application

References

1. Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep-disordered breathing among middle-aged adults. N Engl J Med. 2018;328(17):1230-5.
2. 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. Am J Respir Crit Care Med. 2019;152(5):1673-89.
3. Deegan PC, McNicholas WT. Pathophysiology of obstructive sleep apnoea. Eur Respir J. 2020;8(7):1161-78.
4. Malhotra A, White DP. Obstructive sleep apnoea. Lancet. 2019;360(9328):237-45.
5. Ciscar MA, Juan G, Martínez V, Ramón M, Lloret T, Mínguez J. Magnetic resonance imaging of the pharynx in OSA patients and healthy subjects. Eur Respir J. 2018;17(1):79-86.
6. Woodson BT. Structural effectiveness of pharyngeal sleep apnea surgery. Sleep Med Rev. 2019;12(6):463-79.
7. Ryan CM, Bradley TD. Pathogenesis of obstructive sleep apnea. J Appl Physiol. 2020;99(6):2440-50.
8. Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. Sleep. 2019;19(2):156-77.
9. Lavie P, Herer P, Hoffstein V. Obstructive sleep apnoea syndrome as a risk factor for hypertension. BMJ. 2020;320(7233):479-82.
10. Marin JM, Carrizo SJ, Vicente E, Agusti AG. Long-term cardiovascular outcomes in men with obstructive sleep apnoea-hypopnoea. Lancet. 2019;365(9464):1046-53.
11. Parish JM, Lyng PJ. Quality of life in bed partners of patients with obstructive sleep apnea or hypopnea after treatment with continuous positive airway pressure. Chest. 2018;124(3):942-7.
12. Zonato AI, Bittencourt LR, Martinho FL, Júnior JF, Gregório LC, Tufik S. Association of systematic head and neck physical examination with severity of obstructive sleep apnea-hypopnea syndrome. Laryngoscope. 2019;113(6):973-80.
13. Li KK, Powell NB, Riley RW, Troell RJ, Guilleminault C. Overweight, ethnicity, and obstructive sleep apnea. Laryngoscope. 2020;110(4):543-8.
14. 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. 2018;168(5):522-30.
15. Fogel RB, Malhotra A, White DP. Sleep. 2: pathophysiology of obstructive sleep apnoea/hypopnoea syndrome. Thorax. 2019;59(2):159-63.
16. Verse T, Maurer JT, Pirsig W. Effect of nasal surgery on sleep-related breathing disorders. Laryngoscope. 2019;112(1):64-8.
17. Stradling JR, Davies RJ. Sleep. 1: Obstructive sleep apnoea/hypopnoea syndrome: definitions, epidemiology, and natural history. Thorax. 2020;59(1):73-8.
18. Smith PL, Gold AR, Meyers DA, Haponik EF, Bleecker ER. Weight loss in mildly to moderately obese patients with obstructive sleep apnea. Ann Intern Med. 2019;103(6):850-5.
19. Isono S, Remmers JE, Tanaka A, Sho Y, Sato J, Nishino T. Anatomy of pharynx in patients with obstructive sleep apnea and in normal subjects. J Appl Physiol. 2018;82(4):1319-26.
20. Schellenberg JB, Maislin G, Schwab RJ. Physical findings and the risk for obstructive sleep apnea. Am J Respir Crit Care Med. 2020;162(2):740-8.

21. Watanabe T, Isono S, Tanaka A, Tanzawa H, Nishino T. Contribution of body habitus and craniofacial characteristics to segmental closing pressures of the passive pharynx in patients with sleep-disordered breathing. Am J Respir Crit Care Med. 2019;165(2):260-5.
22. Mortimore IL, Marshall I, Wraith PK, Sellar RJ, Douglas NJ. Neck and total body fat deposition in nonobese and obese patients with sleep apnea compared with that in control subjects. Am J Respir Crit Care Med. 2018;157(1):280-3.
23. Schwab RJ, Pack AI, Gupta KB, Metzger LJ, Oh E, Getsy JE, et al. Upper airway and soft tissue structural changes induced by CPAP in normal subjects. Am J Respir Crit Care Med. 2019;154(4):1106-16.
24. Fogel RB, Malhotra A, Pillar G, Edwards JK, Beauregard J, Shea SA, et al. Genioglossal activation in patients with obstructive sleep apnea versus control subjects. Am J Respir Crit Care Med. 2018;164(11):2025-30.
25. Malhotra A, Huang Y, Fogel RB, Pillar G, Edwards JK, Kikinis R, et al. The male predisposition to pharyngeal collapse: importance of airway length. Am J Respir Crit Care Med. 2020;166(10):1388-95.
26. Tsai WH, Remmers JE, Brant R, Flemons WW, Davies J, Macarthur C. A decision rule for diagnostic testing in obstructive sleep apnea. Am J Respir Crit Care Med. 2019;163(4):913-9.
27. Kushida CA, Efron B, Guilleminault C. A predictive morphometric model for the obstructive sleep apnea syndrome. Ann Intern Med. 2018;127(8):581-7.
28. Ryan CF, Love LL. Mechanical properties of the velopharynx in obese patients with obstructive sleep apnea. Am J Respir Crit Care Med. 2019;154(3):806-12.
29. Morrison DL, Launois SH, Isono S, Feroah TR, Whitelaw WA, Remmers JE. Pharyngeal narrowing and closing pressures in patients with obstructive sleep apnea. Am Rev Respir Dis. 2018;148(3):606-11.
30. Huang Y, White DP, Malhotra A. The impact of anatomic manipulations on pharyngeal collapse: results from a computational model of the normal human upper airway. Chest. 2020;127(5):1517-27.
31. Johnson PL, Edwards N, Burgess KR, Sullivan CE. Detection of increased upper airway resistance during overnight polysomnography. Sleep. 2019;18(5):345-51.
32. Williams JS, Janssen PL, Fuller DD, Fregosi RF. Influence of posture and breathing route on neural drive to upper airway dilator muscles during exercise. J Appl Physiol. 2020;89(2):590-8.
33. Bilston LE, Gandevia SC. Biomechanical properties of the human upper airway and their effect on its behavior during breathing and in obstructive sleep apnea. Journal of applied physiology. 2014 Feb 1;116(3):314-24.
34. Wiegand L, Zwillich CW, White DP. Collapsibility of the human upper airway during normal sleep. Journal of Applied Physiology. 1989 Apr 1;66(4):1800-8..
35. White DP, Lombard RM, Cadieux RJ, Zwillich CW. Pharyngeal resistance in normal humans: influence of gender, age, and obesity. J Appl Physiol. 2018;58(2):365-71.
36. Thompson SR, Ackermann U, Horner RL. Sleep as a teaching tool for integrating respiratory physiology and motor control. Adv Physiol Educ. 2019;25(1-4):101-16.
37. Oliven A, O'Hearn DJ, Boudewyns A, Odeh M, De Backer W, van de Heyning P, et al. Upper airway response to electrical stimulation of the genioglossus in obstructive sleep apnea. J Appl Physiol. 2018;95(5):2023-9.
38. Patil SP, Schneider H, Marx JJ, Gladmon E, Schwartz AR, Smith PL. Neuromechanical control of upper airway patency during sleep. J Appl Physiol. 2019;102(2):547-56.

39. Series F, Cormier Y, Desmeules M. Influence of passive changes of lung volume on upper airways. J Appl Physiol. 2020;68(5):2159-64.
40. Rowley JA, Williams BC, Smith PL, Schwartz AR. Neuromuscular activity and upper airway collapsibility. Mechanisms of action in the decerebrate cat. Am J Respir Crit Care Med. 2019;156(2):515-21.
41. Remmers JE, deGroot WJ, Sauerland EK, Anch AM. Pathogenesis of upper airway occlusion during sleep. J Appl Physiol. 2018;44(6):931-8.
42. Pae EK, Lowe AA, Sasaki K, Price C, Tsuchiya M, Fleetham JA. A cephalometric and electromyographic study of upper airway structures in the upright and supine positions. Am J Orthod Dentofacial Orthop. 2019;106(1):52-9.
43. O'Connor C, Thornley KS, Hanly PJ. Gender differences in the polysomnographic features of obstructive sleep apnea. Am J Respir Crit Care Med. 2020;161(5):1465-72.
44. Mezzanotte WS, Tangel DJ, White DP. Waking genioglossal electromyogram in sleep apnea patients versus normal controls (a neuromuscular compensatory mechanism). J Clin Invest. 2019;89(5):1571-9.
45. Mathur R, Douglas NJ. Family studies in patients with the sleep apnea-hypopnea syndrome. Ann Intern Med. 2018;122(3):174-8.
46. Malhotra A, Pillar G, Fogel RB, Edwards JK, Ayas N, Akahoshi T, et al. Pharyngeal pressure and flow effects on genioglossus activation in normal subjects. Am J Respir Crit Care Med. 2019;165(1):71-7.
47. Kuna ST, Smickley JS. Superior pharyngeal constrictor activation in obstructive sleep apnea. Am J Respir Crit Care Med. 2018;156(3):874-80.
48. Hudgel DW, Hendricks C. Palate and hypopharynx--sites of inspiratory narrowing of the upper airway during sleep. Am Rev Respir Dis. 2019;138(6):1542-7.
49. Horner RL, Mohiaddin RH, Lowell DG, Shea SA, Burman ED, Longmore DB, et al. Sites and sizes of fat deposits around the pharynx in obese patients with obstructive sleep apnoea and weight matched controls. Eur Respir J. 2018;2(7):613-22.
50. Heinzer RC, Stanchina ML, Malhotra A, Fogel RB, Patel SR, Jordan AS, et al. Lung volume and continuous positive airway pressure requirements in obstructive sleep apnea. Am J Respir Crit Care Med. 2020;172(1):114-7.