

RESEARCH ARTICLE

Effect of pharyngeal wall compliance on passive collapsibility of retropalatal airway in patients with obstructive sleep apnea

Hongyi Tian^{1,2} | Yanru Li^{1,2} | Na Lin³ | Jianhong Liao^{1,2} | Yunhan Shi^{1,2} | Dan Kang^{1,2} | Xiu Ding^{1,2} | Hongguang Li^{1,2} | Demin Han^{1,2}

¹Department of Otolaryngology Head and Neck Surgery, Beijing Tongren Hospital, Capital Medical University, Beijing, China

²Key Laboratory of Otolaryngology Head and Neck Surgery, Ministry of Education, Capital Medical University, Beijing, China

³Department of Anesthesiology, Beijing Tongren Hospital, Capital Medical University, Beijing, China

Correspondence

Yanru Li, Department of Otolaryngology Head and Neck Surgery, Beijing Tongren Hospital, Capital Medical University, 1 Dongjiaominxiang Street, Dongcheng District, Beijing, 100730, China.
Email: liyanruru@mail.ccmu.edu.cn

Funding information

National Natural Science Foundation of China, Grant/Award Number: 81970866; Qualified Personnel Project, Dongcheng District, Beijing, Grant/Award Number: 2023-dchrcpyzz-10

Abstract

Objective: To evaluate the pharyngeal compliance of patients with obstructive sleep apnea with complete muscle relaxation. And to study the relationship between the pharyngeal wall compliance and the mechanical load of the retropalatal airway.

Methods: The static mechanical load of the retropalatal pharynx was determined by critical closing pressure (P_{crit}) of the segment during general anesthesia in 30 patients. The size/dimensions of the pharynx were measured while intraluminal pressure was controlled at 3–20 cmH₂O.

Results: A total of 30 participants (age: 37.6 ± 7.6 years, 27 males) were studied. The mean apnea-hypopnea index was 51.6 ± 23.9 events/h. The retropalatal mean P_{crit} was 12.68 ± 4.13 cmH₂O. There was a significant difference in the length of the obstruction segment ($F = 26.028$, $p < 0.001$) among groups with different pharyngeal collapsibility. The correlation between the mechanical load of retropalatal airway and pharyngeal compliance in the level of the hard palate ($r = -0.448$, $p = 0.015$) and the uvula level ($r = -0.462$, $p = 0.026$) were significant.

Conclusions: Increased retropalatal mechanical loads were related to abnormal passive compliance of the pharyngeal wall. The contribution of each pharyngeal wall to airway collapse was varied.

KEYWORDS

obstructive sleep apnea, P_{crit} , pharyngeal compliance, upper airway

INTRODUCTION

Compared to healthy individuals, patients with obstructive sleep apnea (OSA) have a higher upper airway (UA) mechanical load that manifests by a lack of resistance to negative airway pressure and

is collapsible even under positive pharyngeal pressure [1, 2]. Abnormal airway compliance is an important contributor to airway collapsibility and may be related to airway dilator dysfunction [3, 4]. Studies have shown that the proportion of fat around the airway in OSA patients was significantly higher than that of

Hongyi Tian and Yanru Li contributed equally to this article.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2024 The Authors. *Eye & ENT Research* published by John Wiley & Sons Australia, Ltd on behalf of Higher Education Press.

healthy individuals [5]. It is speculated that the fat tissue proportion affects airway rigidity (passive compliance), resulting in an increased airway mechanical load in OSA patients, though this remains unconfirmed.

We hypothesized that in addition to the difference in airway basal area and diameter, the abnormal passive compliance of the airway wall also affects the airway mechanical load in OSA patients. Furthermore, different pharyngeal walls might have varied decisive effects on the mechanical load [5].

The active effect of the UA dilator is excluded by complete muscle relaxation under general anesthesia in this study. The correlation between pharyngeal wall compliance and the retropalatal airway mechanical load is analyzed and the key factors affecting the retropalatal airway load are explored.

MATERIALS AND METHODS

Participants

Thirty adults with untreated OSA were included. All were diagnosed by overnight polysomnography, with an apnea-hypopnea index (AHI) ≥ 5 events per hour of sleep, and complaints of sleep snoring, apnea, daytime sleepiness, or other symptoms. Sleep stages and respiratory events were scored based on the AASM manual. All subjects were enrolled in the study after a written informed consent.

Exclusion criteria include (1) sleep apnea caused by hypothyroidism, acromegaly, or vocal cord paralysis; (2) patients with severe mental conditions, such as severe cardiac-pulmonary dysfunction, and chronic obstructive pulmonary disease, myasthenia gravis or other known myopathy, long-term alcohol abuse, and drug abuse history; (3) patients with central sleep apnea.

Measurement of pharyngeal mechanical load

Measurements in this study were performed using the method outlined by Isano et al. [6, 7]. Each subject was positioned in a supine posture, with the neck in a neutral position. The passive airway was evaluated under general anesthesia to induce complete muscle paralysis. Nasal delivery of intraluminal pressure (P_{AW}) was controlled using a pressure control system, ranging from 3 to 20 cmH₂O in increments of 1 cmH₂O. A modified continuous positive airway pressure (CPAP) machine (Knight Star 330, Puritan Bennett, USA) was utilized for this purpose. The critical pressure (P_{crit}) was defined as the minimal P_{AW} required to compensate for the mechanical load acting on a specific pharyngeal segment. A higher P_{crit} value indicated increased collapsibility of the passive pharynx.

To increase the precision of measuring P_{crit} , a pressure-measuring catheter with two solid-state pressure sensors (SSD1057, Millar

Instrument Co, the external diameter of the catheter was 1.8 mm) was used to monitor the input pressure at the nasopharynx (equivalent to P_{AW}) and the pressure below the collapsed segment. The pressure signals were recorded using additional channels of a polysomnography recorder (Sandman SD32+(MP100), Tyco Healthcare). When the collapsed pharyngeal segment was patented, the pressure below the collapsed segment equaled the intraluminal pressure at the nasopharynx.

Subjects were divided into three groups according to their retropalatal P_{crit} values: the low mechanical load group ($P_{crit} \leq 10$ cmH₂O, referred to as the “low load group”), the median mechanical load group (10 cmH₂O $< P_{crit} \leq 15$ cmH₂O, referred to as the “median load group”), and the high mechanical load group ($P_{crit} > 15$ cmH₂O, referred to as the “high load group”).

Evaluation of size and compliance in the retropalatal UA

Firstly, pharyngeal images at the level of the hard palate and uvula were captured and analyzed during wakefulness in the supine position using computer-assisted fiberoptic pharyngoscopy (Olympus, TYPE P4). The calibration and measurement methods used for the endoscope were described in our previous publications [8]. Various anatomical parameters were measured, including (1) anterior-posterior diameter, (2) minimal lateral diameter of the pharyngeal, and (3) thickness of lateral pharyngeal bands at atmospheric pressure (P_0) at the hard palate level.

Subsequently, the characteristics of the airway following complete muscular paralysis were obtained at P_0 and various pressure levels. In addition to the aforementioned parameters used to describe the baseline size of the airway, measurements were taken for anterior-posterior pharyngeal wall compliance (C_{AP}) and lateral pharyngeal wall compliance (C_L), which represent the average increase in diameter when P_{AW} rises by 1 cmH₂O. Furthermore, the obstructing height, defined as the length of the collapsed segment of the retropalatal pharynx, was also determined. This distance was read from the scale on the pressure-measuring catheter.

Statistical analysis

For statistical analysis, the SPSS software was used to establish the database and perform the necessary calculations. The normal distribution of data was assessed using the Kolmogorov-Smirnov test. Descriptive analysis was described as mean \pm standard deviation for normally distributed data. *T*-tests were used to compare differences between groups, and Pearson's correlation analysis was used to evaluate correlations and calculate correlation coefficients. A significance level of $p < 0.05$ was considered statistically significant.

RESULTS

Characteristics of subjects

Thirty participants (age: 37.6 ± 7.6 years, 27 males) with a body mass index of 28.3 ± 3.9 kg/m² were included in this study. The average AHI was 51.6 ± 23.9 events/h. Among the participants, 5 were diagnosed with mild sleep apnea, 3 with moderate sleep apnea, and 22 with severe sleep apnea.

Passive collapsibility of the pharynx at different sites

For a pharyngeal segment at P_0 , a closed pharynx indicated $P_{crit} > 0$ cmH₂O, while an open pharynx indicated $P_{crit} < 0$ cmH₂O. During muscle paralysis at P_0 , the collapse of the pharyngeal cavity at the hard palate level was observed in only one patient (3.3%). At the level of the tongue base, 23 subjects (76.7%) had $P_{crit} > 0$ cmH₂O. However, at the uvula level of the pharynx, collapses were observed in all 30 subjects (100%). The one subject who exhibited a positive closing pressure at the hard palate level had noticeable adenoid hypertrophy. The average P_{crit} value for the entire cohort was 12.68 ± 4.13 cmH₂O, ranging from 3 to 19 cmH₂O (Table 1).

Among the participants, 12 patients (40%) were classified into the low mechanical load group, with $P_{crit} \leq 10$ cmH₂O. In the median load group, 11 patients (36.7%) had P_{crit} values ranging from >10 cmH₂O to ≤ 15 cmH₂O. Lastly, 7 patients (23.3%) in the high mechanical load group had $P_{crit} > 15$ cmH₂O, suggesting relatively poor pharyngeal anatomy.

Pharyngeal size and compliance

The mean cross-sectional area of the pharynx at the hard palate level was 241.78 ± 33.92 mm² (95% CI 229.11–254.45) at P_{crit} , while the anterior–posterior diameter was 11.39 ± 2.59 mm (95% CI 10.42–12.35), and the lateral diameter was 20.64 ± 2.74 mm (95% CI 20.19–22.39). The baseline cross-sectional area at the uvula level was 79.70 ± 44.35 mm² in the active airway. The anterior–posterior diameter was 7.71 ± 2.94 mm, and the lateral diameter was 8.60 ± 2.93 mm. The mean cross-sectional area at the uvula level at P_{crit} was 18.14 ± 27.79 mm², ranging from 1.44 to 137.89.

In the passive retropalatal airway, as P_{AW} increased, the cross-sectional area also increased, and the highest collapse site moved downward. The mean C_{AP} at the hard palate level was

0.31 ± 0.17 mm/cmH₂O, and the C_L was 0.54 ± 0.34 mm/cmH₂O. The average increment in area when P_{AW} rose by 1 cmH₂O was 9.60 ± 4.36 mm².

The median value of C_{AP} at the uvula level was 0.64 mm/cmH₂O ($P_{25} = 0.22$, $P_{75} = 0.86$), and the median value of C_L was 1.12 mm/cmH₂O, ($P_{25} = 0.45$, $P_{75} = 1.80$). The following analyses were performed after logarithmic transformation. A negative relationship was found between lateral pharyngeal wall compliance at the uvula level and tonsil size ($r = -0.442$, $p = 0.031$).

The mean obstructing height in the retropalatal airway, excluding the patient who had collapsed at the hard palate level, was 1.6 ± 0.9 cm (95% CI 12.9–19.6). The length of the obstructing segment was correlated with the cross-sectional area ($r = -0.613$, $p = 0.000$) and lateral diameter ($r = -0.503$, $p = 0.005$) of the hard palate level. Furthermore, there was a positive correlation between obstructing height and BMI ($r = 0.421$, $p = 0.023$).

The correlation between the pharyngeal airway measurement and the mechanical load of the retropalatal airway

One subject was excluded because they exhibited pharynx collapse at both the hard palate level and the uvula level. The correlation between P_{crit} (mechanical load of the retropalatal airway) and passive pharyngeal measurements is summarized in Table 2. The findings indicate that as P_{crit} increased, the length of the collapsed airway also increased. Higher P_{crit} values were associated with a smaller baseline area at the hard palate level, thicker lateral pharyngeal bands, and smaller C_{AP} at the hard palate plane/ C_L at the uvula level. A multivariate linear regression model showed that the obstruction height, anterior pharyngeal wall compliance at the hard palate level, and thickness of the lateral pharyngeal bands could predict 85.2% of the variability in P_{crit} ($F = 47.927$, $p = 0.000$).

There was no consistent relationship between P_{crit} and BMI ($r = 0.325$, $p = 0.079$), age ($r = 0.085$, $p = 0.656$), or tonsils grade ($r = 0.309$, $p = 0.097$).

The difference in pharyngeal airway measurements among different groups

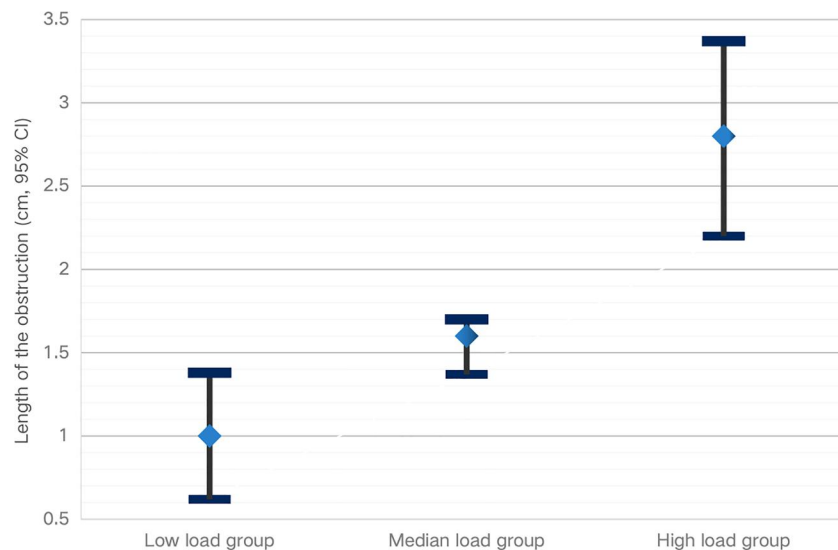
There was a significant difference in the length of the obstructing segment ($F = 26.028$, $p < 0.001$) among groups with different pharyngeal collapsibility (Figure 1). The average length of obstruction was 1.0 ± 0.6 cm (95% CI 0.62–1.38) in the lower load group (12 subjects). Among them, seven subjects had both relatively shorter obstructing height (<1.5 cm) and more compliant anterior–posterior pharyngeal wall at the hard palate level (≥ 0.3 mm/cmH₂O). Three subjects had relatively less compliant anterior–posterior pharyngeal walls at the hard palate level but a shorter obstructing height (≤ 1.0 cm). In contrast, the remaining two subjects had a relatively long obstructing height but a high

TABLE 1 Obstructive sites ($n = 30$).

Obstructive site	Number of subjects
Hard palate level	1
Soft palate level	30
Retroglossal area	23

TABLE 2 Correlation between the measurement of pharyngeal airway and the P_{crit} ($n = 29$).

	<i>r</i>	<i>p</i>
Cross-sectional area of the hard palate level (mm ²)	-0.662	0.000 ^b
Anteroposterior diameter of the hard palate level (mm)	-0.449	0.015 ^a
Minimum lateral diameter of the hard palate level (mm)	-0.539	0.003 ^b
The thickness of the lateral pharyngeal bands of the hard palate level (mm)	0.498	0.006 ^b
Length of airway collapse (cm)	0.898	0.000 ^b
Increment of sectional area/increment of intraluminal pressure (mm ² /H ₂ O)	-0.553	0.002 ^b
Compliance of the anteroposterior wall of the hard palate level (mm/H ₂ O)	-0.448	0.015 ^a
Compliance of the lateral wall of the hard palate level (mm/H ₂ O)	-0.216	0.261
Compliance of the anteroposterior wall of the uvula level (mm/H ₂ O)	-0.187	0.392
Compliance of the lateral wall of the uvula level (mm/H ₂ O)	-0.462	0.026 ^a

^a $p < 0.05$.^b $p < 0.01$.**FIGURE 1** The length of airway obstruction ($F = 26.028$, $p = 0.000$) among different mechanical load groups. Low mechanical load group: 1.0 ± 0.6 cm; median mechanical load group: 1.6 ± 0.3 cm; high mechanical load group: 2.8 ± 0.6 cm.

compliance pharyngeal wall (≥ 0.4 mm/cmH₂O). The average length of obstruction was 1.6 ± 0.3 cm (95% CI 1.37-1.7) in the median mechanical load group and 2.8 ± 0.6 cm (95% CI 2.20-3.37) in the higher load group.

The C_{AP} wall at the hard palate level was 0.42 ± 0.20 mm/cmH₂O (95% CI 0.29-0.54) in the lower load group, 0.21 ± 0.07 mm/cmH₂O (95% CI 0.17-0.26) in median load group, and 0.21 ± 0.06 mm/cmH₂O (95% CI 0.15-0.26) in higher load group. There were significant differences among groups ($F = 7.984$, $p = 0.002$), as shown in Figure 2.

DISCUSSION

The study investigated the differences in the pharyngeal structure and compliance in OSA patients with different mechanical loads under complete muscle relaxation. The baseline area, diameter of the airway, and compliance of the pharyngeal wall contributed to the mechanical load of the retropalatal airway. The compliance of the anteroposterior wall at the hard palate level and the lateral wall at the uvula level were negatively correlated with the posterior airway mechanical load of the soft palate in OSA patients.

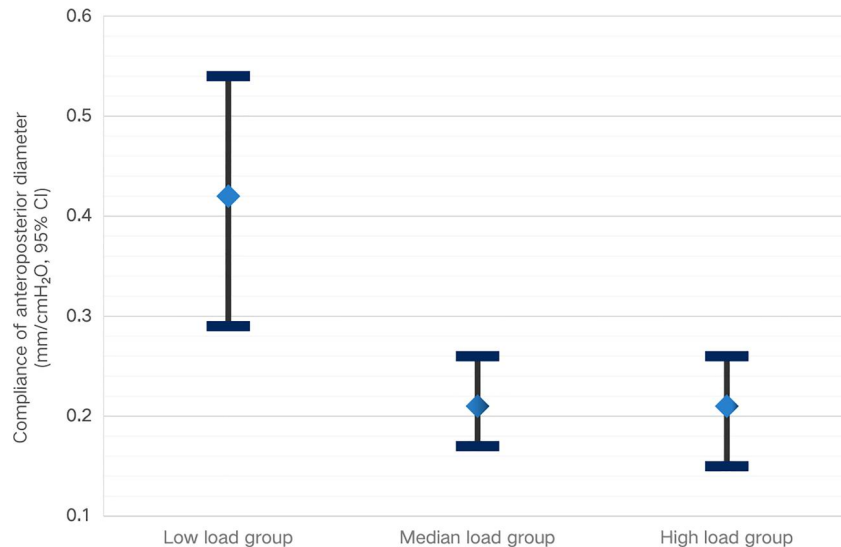


FIGURE 2 Comparison of the compliance of anteroposterior diameter in the level of the hard palate between groups. Low mechanical load group: 0.4 ± 0.2 mm/cmH₂O; median mechanical load group: 0.2 ± 0.1 mm/cmH₂O; high mechanical load group: 0.2 ± 0.1 mm/cmH₂O.

Mechanical loads of the retropalatal airway

Compensating for the mechanical loads in the UA through CPAP or reducing them through surgery are the main strategies for treating OSA [9]. Identifying the sources of increased mechanical loads in the passive airway will help us better understand the structural risk factors associated with OSA and decide whether a patient would benefit from structural changes [10]. Several previous studies have investigated the hypotonic or passive state of UA [11], but most only evaluated the mechanical loads of the entire UA rather than analyzing the specific mechanical loads generated by different anatomical regions of the UA.

Previous morphological studies have highlighted the significance of the uvula plane in UA collapse, as it is often the narrowest plane of the UA. Relatively, the hard palate plane tends to have less compliance and is less prone to collapse [11, 12]. Watanabe et al. [13] found that patients with small maxillas and mandibles had an increase in the closing pressure of the retroglossal pharynx. Our group [14] also found that the increased volumetric proportion of pharyngeal soft tissue to the bone enclosure may be an important contributor to increased retropalatal mechanical loads. However, the specific role of airway compliance in UA mechanical loads has not been investigated. This study is the first to evaluate the contributions of anatomy and compliance of each pharyngeal wall to the mechanical loads of the passive retropalatal airway.

The contributors to the retropalatal airway mechanical load

The contributors of P_{crit} include the length of the obstruction, the thickness of the lateral pharyngeal band at atmospheric pressure, as

well as the area and lateral diameter of the hard palate level. The results suggest that increased P_{crit} of the pharynx is caused by both a narrower pharyngeal cavity and abnormal passive compliance of the pharyngeal wall. The contributions of anatomy and compliance of each pharyngeal wall to the mechanical loads of the passive retropalatal airway differ. Specifically, an average increase of 2.36 mm in the thickness of the lateral pharyngeal bands will cause a rise of 1 cmH₂O in P_{crit} .

Obstructing height is identified as one of the most important determinants. This indicates that anatomical parameters for three-dimensional structures play a critical role in increasing mechanical loads. The cross-sectional area and lateral diameter of the hard palate level are correlated with a higher obstructing height. This suggests that individuals with relatively smaller airways at the hard palate level are more likely to have longer collapse lengths and larger mechanical loads, even with the same volume of the retropalatal airway. Previous studies have shown that OSA patients have smaller bony nasopharynx compared to those without OSA, emphasizing the role of pharyngeal morphology [15].

Contribution of passive pharyngeal wall compliance to the mechanical loads of the retropalatal airway

The compliance of the lateral wall at the uvula level and anteroposterior wall at the hard palate level are important contributors to P_{crit} . The variance of lateral wall compliance at the hard palate level is only 0.04, suggesting that there is little difference among subjects. The influence of each pharyngeal wall on P_{crit} varies. The compliance of the anteroposterior walls of the hard palate plane and the compliance of the lateral pharyngeal wall of the uvula plane has a greater influence on airway collapsibility.

Other studies have also demonstrated a strong correlation between pharyngeal compliance and P_{crit} [16]. One study speculated that patients with increased pharyngeal compliance as the main cause of airway obstruction may have better compliance with CPAP treatment [17].

The factors affecting the rigidity of the pharyngeal wall are still unclear. Schwab et al. [5] reported that the volume of the lateral pharyngeal walls and the fat pad was significantly larger in subjects with OSA compared to normal subjects. This may be the cause of the difference in lateral wall rigidity. However, this explanation is insufficient to account for the changes in the anterior-posterior wall and similar passive compliance of the lateral wall at the hard palate level. Thus, further research is needed to explore the effect of different constitutions of surrounding tissues of UA. Another potential factor altering pharyngeal compliance is the inflammatory response [18], which is manifested by angiogenesis, inflammatory edema, increased levels of Tumor Necrosis Factor- α , High-sensitivity C-reactive Protein, adhesion molecules, and Monocyte Chemotactic Protein-1 [19].

The proportion of soft tissue to the bony frame of the UA may provide another explanation. Isono et al. [7] deduced that the balance between the proportion of soft tissue and the size of the bony enclosure determines the airway size. Animal studies have also shown that tissue pressure may affect P_{crit} . [20] Even with the same airway size, the thicker the soft tissue inside the bone frame, the harder the soft tissue could be compressed, resulting in a higher mechanical load [21]. Additional research is needed to explore the specific mechanisms and variations in tissue properties that contribute to airway collapsibility at various segments of the UA.

Limitations

This study specifically examined the mechanical loads in the retro-palatal airway; however, it did not take into account the interaction between the soft palate and the tongue. To gain a comprehensive understanding of the mechanisms underlying UA collapse, it is essential to investigate the mechanical loads in the retroglottal region as well. Further studies will be needed to investigate the influence of special structures surrounding the UA on the mechanical properties of the pharynx.

Furthermore, it is important to note that the study was conducted on a clinical population consisting mostly of middle-aged males with moderate to severe OSA. It is necessary to conduct similar investigations involving younger and older individuals, as well as subjects with mild OSA to determine the contribution of anatomy and compliance of the pharyngeal wall to mechanical loads. Such investigations hold significant value in clarifying the pathophysiological mechanisms of airway obstruction, optimizing treatment approaches by reducing mechanical loads through surgery or CPAP, and tailoring treatment plans on an individual basis.

CONCLUSION

Both the anatomical characteristics and passive compliance of the pharynx at the hard palate level contribute to retro-palatal mechanical loads. Key determinants include the obstructing height, thickness of the lateral pharyngeal bands, as well as anterior-to-posterior pharyngeal wall compliance. It is important to note that the contribution of each pharyngeal wall to airway collapse differs. Pharyngeal measurements of the active airway in the supine position also have value in indicating retro-palatal mechanical loads.

AUTHOR CONTRIBUTIONS

Hongyi Tian: Writing – original draft (equal); writing – review & editing (equal). **Na Lin:** Conceptualization (equal); data curation (equal); methodology (equal). **Jianhong Liao:** Formal analysis (equal); writing – review & editing (equal). **Yunhan Shi:** Data curation (equal); software (equal); writing – review & editing (equal). **Dan Kang:** Data curation (equal); formal analysis (equal). **Xiu Ding:** Data curation (equal). **Hongguang Li:** Data curation (equal). **Demin Han:** Conceptualization (equal); resources (equal); supervision (equal). **Yanru Li:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (equal); investigation (lead); methodology (lead); resources (equal); writing – original draft (equal); writing – review & editing (equal).

ACKNOWLEDGMENTS

This study was funded by the National Natural Science Foundation of China (81970866) and the Beijing Dongcheng District Outstanding Talent Training Funding Project (2023-dchrcpyzz-10). The authors appreciate the contribution of the study participants, otolaryngologists, anesthetists, and technicians at the Department of Otolaryngology-Head and Neck Surgery, Beijing Tongren Hospital.

CONFLICT OF INTEREST STATEMENT

Work for this study was performed at Beijing Tongren Hospital, Beijing, China. All authors have seen and approved the manuscript. The authors declare that there is no conflict of interest except Demin Han, who is an Advisory Member of Editorial Board of *Eye & ENT Research*. He was excluded from the peer-review process and all editorial decisions related to the acceptance and publication of this article. Peer-review was handled independently by the other editors to minimize bias.

DATA AVAILABILITY STATEMENT

The data underlying this article cannot be shared publicly for the privacy of individuals who participated in the study. The data will be shared on reasonable request to the corresponding authors.

ETHICS STATEMENT

All procedures performed in studies involving human participants were following the ethical standards of the institutional and/or

national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

REFERENCES

- White DP. The pathogenesis of obstructive sleep apnea. *Am J Respir Cell Mol Biol*. 2006;34:1-6.
- Ayappa I, Rapoport DM. The upper airway in sleep: physiology of the pharynx. *Sleep Med Rev*. 2003;7(1):9-33.
- Horner RL. Review. Motor control of the pharyngeal musculature and implications for the pathogenesis of obstructive sleep apnea. *Sleep*. 1996;19(10):827-853.
- Horner RL, Innes JA, Murphy K, Guz A. Evidence for reflex upper airway dilator muscle activation by sudden negative pressure in man. *J Physiol*. 1991;436(1):15-29.
- Schwab RJ, Pasirstein M, Pierson 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.
- Isono S, Remmem 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*. 1997;82(4):1319-1326.
- Isono S, Tanaka A, Tagaito Y, et al. Influences of head positions and bite opening on collapsibility of the passive photo. *J Appl Physiol*. 2004;97:339-346.
- Ye J, Han D, Wang J, et al. Computer-assisted fiberoptic pharyngoscopy in obstructive sleep apnea syndrome. *J Otorhinolaryngol Relat Spec*. 2007;69(3):153-158.
- Hartfield PJ, Janczy J, Sharma A, et al. Anatomical determinants of upper airway collapsibility in obstructive sleep apnea: a systematic review and meta-analysis. *Sleep Med Rev*. 2023;68:101741. Epub 2022 Dec 30. PMID: 36634409.
- Malhotra A, Pillar G, Fogel R, Beauregard J, Edwards J, White DP. Upper-airway collapsibility, measurements and sleep effects. *Chest*. 2001;120(1):156-161.
- Chen NH, Li KK, Li SY, et al. Airway assessment by volumetric computed tomography in snorers and subjects with obstructive sleep apnea in a Far-East Asian population (Chinese). *Laryngoscope*. 2002;112(4):721-726.
- Hsu PP, Tan BY, Chan YH, Tay HN, Lu PKS, Blair RL. Clinical predictors in obstructive sleep apnea patients with computer-assisted quantitative videoendoscopic upper airway analysis. *Laryngoscope*. 2004;114(5):791-799.
- 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*. 2002;165(2):260-265.
- Li Y, Ye J, Li T, et al. Anatomic predictors of retropalatal mechanical loads in patients with obstructive sleep apnea. *Respiration*. 2011;82(3):246-253.
- Lan Z, Itoi A, Takashima M, Oda M, Tomoda K. Difference of pharyngeal morphology and mechanical property between OSAHS patients and normal subjects. *Auris Nasus Larynx*. 2006;33(4):433-439.
- Landry SA, Joosten SA, Eckert DJ, et al. Therapeutic CPAP level predicts upper airway collapsibility in patients with obstructive sleep apnea. *Sleep*. 2017;40(6). zsx056. PMID: 28419320; PMCID: PMC6410952.
- Zhang C, Chen M, Shen Y, Gong Y, Ma J, Wang G. Impact of upper airway characteristics on disease severity and CPAP therapy in Chinese patients with OSA: an observational retrospective study. *Front Neurol*. 2022;13:767336.
- Shrivastava D. Impact of sleep-disordered breathing treatment on upper airway anatomy and physiology. *Sleep Med*. 2014;15(7):733-741.
- Ryan S, Taylor CT, McNicholas WT. Systemic inflammation: a key factor in the pathogenesis of cardiovascular complications in obstructive sleep apnoea syndrome? *Thorax*. 2009;64(7):631-636.
- Kairatis K, Stavrinou R, Parikh R, Wheatley JR, Amis TC. Mandibular advancement decreases pressures in the tissues surrounding the upper airway in rabbits. *J Appl Physiol*. 2006;100(1):349-356.
- Schwartz AR, Kirkness J, Smith P. Extraluminal tissue pressure: what does it mean? *J Appl Physiol*. 2006;100(1):5-6.

How to cite this article: Tian H, Li Y, Lin N, et al. Effect of pharyngeal wall compliance on passive collapsibility of retropalatal airway in patients with obstructive sleep apnea. *Eye & ENT Res*. 2024;1(1):49-55. <https://doi.org/10.1002/eer3.6>