



# Can CPAP therapy alter nasolacrimal duct drainage in patients with obstructive sleep apnea??

Kamil Gokce Tulaci<sup>1</sup> · Nurhan Sarioglu<sup>2</sup> · Gözde Sahin Vural<sup>3</sup> · Erhan Arslan<sup>1</sup> · Hasan Canakci<sup>1</sup> · Tugba Tulaci<sup>1</sup> · Fuat Erel<sup>2</sup> · Hasmet Yazici<sup>4</sup>

Received: 14 February 2025 / Revised: 29 April 2025 / Accepted: 2 June 2025 / Published online: 6 June 2025  
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2025

## Abstract

**Purpose** To investigate whether the use of continuous positive airway pressure (CPAP) therapy due to obstructive sleep apnea (OSA) affects the nasolacrimal duct (NLD) drainage.

**Methods** In this prospective study, group 1 included 82 NLDs from 41 patients with OSA who were treated with CPAP at least 6 months to 2 years. Group 2 included 68 NLDs from 34 patients with OSA who received no CPAP therapy. Group 3 included 70 NLDs from 35 healthy volunteers, with no nasal/paranasal or nasolacrimal system problems. Nasolacrimal drainage times of participants in all groups were measured by observing the fluorescein-containing eye drops administered into the eye via endoscopic visualization of Hasner's valve area. The time of nasolacrimal drainage was compared between the three groups. The correlation of NLD drainage time with PAP pressure and CPAP usage was investigated.

**Results** The NLD drainage time of group 1 was significantly shorter compared both to the group 2 ( $p=0.001$ ) and group 3 ( $p<0.001$ ). Correlation analysis revealed a statistically significant negative correlation between NLD drainage time and CPAP pressure ( $p<0.01$ ,  $r=-0.305$ ) and no correlation between NLD drainage time and CPAP treatment duration ( $p=0.304$ ,  $r=0.115$ ).

**Conclusion** CPAP usage changes NLD drainage time in patients with OSA who regularly use CPAP.

**Keywords** Obstructive sleep apnea · Nasolacrimal canal · Side effect · CPAP

## Introduction

The incidence of obstructive sleep apnea (OSA), a chronic disease that causes serious morbidity and mortality, is continuously increasing [1–3]. Although various treatments such as nasal, palatal, tongue base, and mandibular

surgeries and the use of intraoral appliances are recommended in addition to lifestyle modifications such as weight control and sleep hygiene, continuous positive airway pressure (CPAP) remains the most effective and widely used method for symptomatic recovery in moderate and severe OSA [2, 4].

✉ Kamil Gokce Tulaci  
ktulaci@gmail.com

Nurhan Sarioglu  
nurhangencer@hotmail.com

Gözde Sahin Vural  
gozdejcgrl@hotmail.com

Erhan Arslan  
drarslanerhan@hotmail.com

Hasan Canakci  
hsn\_canakci@hotmail.com

Tugba Tulaci  
tugbatulaci@gmail.com

Fuat Erel  
fuatereldr@hotmail.com

Hasmet Yazici  
hsmtzyz@yahoo.com.tr

<sup>1</sup> Departments of Otorhinolaryngology Head and Neck Surgery, Faculty of Medicine, Balikesir University, Balikesir 10440, Turkey

<sup>2</sup> Departments of Pulmonary Diseases, Faculty of Medicine, Balikesir University, Balikesir, Turkey

<sup>3</sup> Department of Ophthalmology, Faculty of Medicine, Balikesir University, Balikesir, Turkey

<sup>4</sup> Private Clinic, Balikesir, Turkey

Owing to its splint-like effect, CPAP prevents the upper respiratory tract from collapsing and increases the speed and amount of airflow passing through the upper respiratory tract [5].

Despite its healing effects on OSA symptoms, skin irritation, dry mouth, dental issues, voice problems, pressure problems in the ears, aerophagia, nasal discharge, nasal infection, impaired mucociliary clearance, nasal resistance changes, and ophthalmological problems may be observed in patients using CPAP [6].

Moreover, several studies have demonstrated that CPAP therapy can alter the function of nearby anatomical structures such as the paranasal sinuses, nasal mucosa, middle ear, and Eustachian tube by modifying local airflow and pressure dynamics [5–10]. Given that the nasolacrimal duct (NLD) drains directly into the inferior nasal meatus—an area affected by CPAP-induced pressure—it is reasonable to hypothesize that this structure may also be physiologically influenced by CPAP use. Despite this reasonable connection, no prior study has specifically investigated whether CPAP therapy alters NLD drainage time.

Understanding whether CPAP therapy alters NLD drainage time may have important clinical implications, particularly in explaining the pathophysiology of dry eye symptoms frequently reported by OSA patients. Furthermore, if a relationship is established between CPAP use and changes in nasolacrimal function, this may provide new insights into the etiology of CPAP-associated ocular complications and potentially contribute to their prevention or management in clinical practice, ultimately improving ocular health in OSA patients using CPAP.

Therefore, this study aimed to explore the impact of CPAP treatment on nasolacrimal drainage, highlighting a previously unexamined consequence of CPAP therapy.

## Methods

### Study design

This prospective, comparative clinical study was conducted between September 2020 and 2022 and was approved by the institutional ethics committee (IEC approval number: 2020/120) of a tertiary reference center. The study was conducted in accordance with the basic principles of Helsinki Declaration. The study was conducted in the outpatient clinic conditions of a tertiary hospital, which is a regional reference center for the departments of ear, nose and throat, ophthalmology and chest diseases. All participants were given information about the study and written informed consent was obtained from all participants.

Group 1 included 82 NLDs from 41 patients aged between 18 and 65 years, diagnosed with OSA (moderate or severe) by polysomnography test, and treated with CPAP (in the form of a nasal mask) for OSA for at least 6 months to 2 years.

Group 2 included 68 NLDs from 34 patients aged between 18 and 65 years who were diagnosed with moderate to severe OSA based on PSG findings and were recommended CPAP therapy, but either declined treatment or had not yet initiated it at the time of the study. These patients did not receive any form of active intervention such as surgical procedures or oral appliance therapy. Instead, they were only provided with lifestyle modification counseling, including advice on weight management and sleep hygiene, which were also routinely recommended to all other patients diagnosed with moderate to severe OSA. Since no CPAP therapy or surgical intervention was applied to this group, they were included as an untreated control group in the study design to ensure that any potential outcomes could be attributed to CPAP therapy rather than to OSA itself.

The patients with any nasal or paranasal sinus problems such as nasal septum deviation, turbinate hypertrophy, or rhinosinusitis; those who had undergone nasal, paranasal, or ocular surgery; those who received any medical or surgical treatment for the nasolacrimal system or who had a history of facial surgery that may affect nasolacrimal drainage (medial maxillectomy, endoscopic sinus surgery, turbinate surgery, or maxillofacial surgery); those who had head and neck trauma; those who used alcohol or cigarettes; those with chronic diseases such as diabetes mellitus or hypertension (HT) were excluded.

Group 3 included 70 NLDs from 35 healthy volunteers between the age of 18 and 65 years; without any nasal or paranasal sinus problems such as nasal septum deviation, turbinate hypertrophy, and rhinosinusitis; no history of snoring, apnea, or nasal complaints; no systemic diseases, routine drug use, or alcohol consumption; who were not smokers; had not undergone any otorhinolaryngological, ophthalmological, or maxillofacial surgery; and had no complaints about the nasolacrimal system.

### Polysomnography (PSG)

The PSG procedure for all patients in the study group was performed as follows. All the patients underwent full-night polysomnography using a 62-channel Embla N7000 device (Medcare Flage, Iceland). Specific signals of interest for sleep scoring included EEG, EOG, chin EMG, ECG, bilateral anterior tibial muscle EMG, nasal airflow, respiratory effort (thoracic and abdominal movements), oxygen saturation, tracheal microphone, and body position. Sleep records were scored according to the standard criteria of

the American Academy of Sleep Medicine (AASM) [11]. Apnea was defined as a reduction of at least 90% in airflow amplitude for  $\geq 10$  s. Hypopnea was defined as a reduction of at least 30% airflow for  $\geq 10$  s with oxygen desaturation of  $\geq 3\%$  or accompanying arousal.

Patients were classified based on OSA severity as follows: AHI of  $< 5$  events/h was considered normal, AHI of 5–30 events/h was considered mild-to-moderate, and AHI of  $> 30$  events/h was considered severe [11].

## Study protocol

To measure the nasolacrimal duct drainage time, an experienced ophthalmologist (GSV) administered one drop of proparacaine 0.375% and 0.25% sodium fluorescein eye drops to the right eye of all participants. To calculate the NLD drainage time, following eye drop administration, an experienced otorhinolaryngologist (KGT) observed the area of Hasner's valve under the inferior turbinate with a rigid, 0°, 2.7-mm-diameter Hopkins pediatric endoscope (Karl Storz, Tuttlingen, Germany) and observed that the fluorescein drop reached the nasal cavity. The time between the instillation of the eye drop and its appearance in the inferior meatus was measured using a stopwatch by an otorhinolaryngologist (HC) who was unaware of which group the patient belonged to and recorded as the NLD drainage time in seconds. The same procedure and measurements were performed on the patient's left eye by the same researchers. No medications containing topical anesthetics or decongestants were administered before the examination. To standardize this measurement, these procedures were performed by the same experienced otolaryngologists and ophthalmologist, who did not know which group the patients belonged to, in the same outpatient clinic room and examination unit, using the same stopwatch, endoscope, and eye drops prepared in the same manner.

Nasolacrimal drainage times were compared between the three groups.

**Table 1** Demographics of patients and NLD drainage times

	Group 1 (n=41)	Group 2 (n=34)	Group 3 (n=35)	p-value
Age *	53.2±11.7	49±12.6	50.8±17.3	0.120 <sup>†</sup>
Gender (F/M)	14/27	9/25	15/20	0.128 <sup>‡</sup>
NLD drainage time (sec)*	185.2±154.7 <sup>a</sup>	288±195.7 <sup>b</sup>	335.8±191.7 <sup>c</sup>	$P < 0.001$ <sup>†</sup>

F, female; M, male; NLD, nasolacrimal duct; sec, seconds, n=number of patients. \*presented as mean±standard deviations, <sup>‡</sup> Chi-square test, <sup>†</sup>Kruskal-Wallis test, post hoc: a-b:  $P=0.001$  a-c:  $P < 0.001$  b-c:  $p=0.413$

In addition, demographic information and medical records of patients were examined, and PSG parameters (apnea–hypopnea index [AHI] and body mass index [BMI]) and titration pressures were recorded. In addition to comparing three groups based on the NLD drainage time, a correlation analysis was performed to evaluate the association of NLD drainage time with the CPAP use times and CPAP pressures of the Group 1.

## Statistical analysis

The data of the present study were evaluated using the Statistical Package for Social Sciences for Windows v.22.0 (SPSS Inc. Chicago, IL, USA) software. Descriptive statistics were expressed as mean ( $\pm$ ) standard deviation, frequency distribution, and percentage. Normally distributed variables were evaluated using the Kolmogorov–Smirnov test. Mann–Whitney U-test and Kruskal Wallis test were used for data analysis of continuous variables, whereas the chi-square test was used for categorical variables. The Yates continuity correction was utilized to improve the chi-square test and Fisher's exact test approximations. The relationships between variables were evaluated using Spearman's correlation analysis. A  $P$ -value of  $< 0.05$  was considered statistically significant.

## Results

A total of 136 participants were enrolled in this study. Seventeen patients were excluded from the study because they did not comply with CPAP and 9 refused eye drop administration into their eyes or measurements. Eventually, 110 participants aged between 18 and 65 years were enrolled in the present study. Among them, 72 (65.45%) were male and 38 (34.54%) were female.

Groups 1, 2 and 3 included 41, 34 and 35 participants, respectively. The three groups were similar and comparable in terms of age and gender (Table 1).

The average AHI was  $39.6 \pm 18.2$  in group 1,  $40.2 \pm 21.2$  in group 2 and no significant difference was evident between the AHIs of Group 1 and Group 2 ( $p=0.868$ ).

The CPAP pressure of the patients in Group 1 was between 4 and 14 cmH<sub>2</sub>O, with a mean of  $10.0 \pm 3.7$  cm H<sub>2</sub>O.

The average CPAP usage duration of patients in Group 1 was  $17.7 \pm 6.3$  months.

The NLD drainage time of Group 1 was significantly shorter compared both to the Group 2 ( $p=0.001$ ) and Group 3 ( $p < 0.001$ ) (Table 1).

No significant difference was observed between the NLD drainage times of the Group 2 and Group 3 ( $p=0.413$ ) (Table 1).

**Table 2** The correlation of NLD drainage time with CPAP pressure and CPAP usage time

N=41	NLD drainage time	CPAP pressure	CPAP usage time
	<i>r</i>	<i>r</i>	<i>r</i>
<b>NLD drainage time</b>	1		
<b>CPAP pressure</b>	-0,305**	1	
<b>CPAP usage time</b>	0,115	0,139	1

R, Spearman's correlation coefficient, \*\*= $p < 0.01$ , NLD, nasolacrimal duct; CPAP, continuous positive airway pressure; N, number of patients

A correlation analysis was performed to evaluate whether PAP pressure and CPAP usage time affected NLD drainage. A statistically significant negative correlation was found between the NLD drainage time and CPAP pressure ( $p < 0.01$ ,  $r = -0.305$ ), and it was concluded that as the CPAP pressure increased, the drainage time decreased (Table 2).

No correlation was detected between NLD drainage time and CPAP treatment duration ( $p = 0.304$ ,  $r = 0.115$ ) (Table 2).

## Discussion

To the best of our knowledge, this is the first study to investigate whether CPAP usage changes the NLD drainage time in patients with OSA. Our results found that NLD drainage time of patients using CPAP regularly for at least 6 months and at most 2 years (mean  $17.7 \pm 6.3$  months) was significantly shorter compared to both healthy volunteers and OSA patients not receiving CPAP therapy. In addition to this finding, whether the CPAP usage time and CPAP pressure were associated with the NLD drainage time was determined, and it was concluded that as the CPAP pressure increased, NLD drainage time shortened; however, no statistically significant relationship was observed between the CPAP usage duration and NLD drainage time.

OSA is a common health problem that can lead to serious morbidity and mortality. With increased disease occurrence and awareness, CPAP use, which is considered a basic treatment for OSA, has become more common [12–15]. CPAP therapy operates by delivering a constant stream of pressurized air to the upper airway via a nasal or oronasal mask, thereby preventing airway collapse during sleep. This pressurization alters not only airflow dynamics in the upper respiratory tract but also affects adjacent anatomical regions by modulating mucosal pressure gradients, airflow resistance, and tissue compliance [16, 17]. Studies have shown that CPAP can impact the function of the Eustachian tube, sinus ventilation, and mucociliary clearance by influencing local pressure and humidity levels [5–10]. These effects are not isolated to the upper respiratory tract; rather, they

can extend to anatomically contiguous systems such as the nasolacrimal duct (NLD), which drains tears from the ocular surface into the nasal cavity via Hasner's valve. The NLD shares a direct anatomical outlet into the inferior nasal meatus, making it susceptible to changes in intranasal airflow velocity and pressure gradients induced by CPAP.

Although CPAP therapy remains the most effective treatment for OSA, it is associated with various side effects. Dermatological complications include facial skin irritation and pressure-related lesions, often caused by prolonged mask use [6]. Respiratory and nasal issues such as nasal congestion, dryness, epistaxis, and impaired mucociliary clearance result from continuous airflow and reduced nasal humidity [6, 10]. Otologic symptoms like ear fullness may stem from pressure effects on the Eustachian tube [5, 7, 8]. Gastrointestinal symptoms, such as aerophagia, are attributed to inadvertent air swallowing. Ophthalmologic complications occur in 10–30% of patients treated with CPAP. Dry eyes and bacterial conjunctivitis have been reported as the most common ophthalmological complications in patients using CPAP [18–20].

Although eye complications resulting from PAP treatment have been predicted to be associated with three mechanisms, including air leakage from the mask, venous drainage disruption in the eyes due to the pressure exerted by the mask, or retrograde air and mucus escape via the nasolacrimal system, the main cause of eye complications remains unclear [21].

According to our literature research regarding the effects of PAP treatment on the paranasal region, the functions of almost all anatomical structures related to the paranasal sinuses, nasopharynx, and nasal cavity have been investigated, from affecting the eustachian tube function to changing the volume and function of the paranasal sinuses and nasal mucociliary clearance. However, no study has investigated the function of the NLD, a structure that is directly connected to the nasal cavity and may be related to dry eyes and other tear-related problems [5].

Hasner's valve is a mucosal fold located at the distal end of the nasolacrimal duct (NLD), opening into the inferior meatus of the nasal cavity. Tears collected in the lacrimal sac drain into the nasal cavity through Hasner's valve in an ejaculation manner, when sufficient pressure is generated. Hasner's valve is not a true valve or sphincter but a mucosal fold with function affected by pressure changes.

Tear drainage occurs in two ways: passive and active. While gravity is responsible for passive drainage, pressure changes in the lacrimal system and tear movement are responsible for active drainage from the Hasner's valve. In addition to the passive effect of gravity, as a result of pressure changes in the lacrimal apparatus, a pressure difference occurs between the nasal cavity and lacrimal system; thus,

the Hasner's valve opens and the tear is discharged into the nasal cavity [22].

Considering the NLD and Hasner's valve, which is in a fold formation unlike a normal valve, changes in the pressure, flow, and anatomical factors both in the lacrimal apparatus on the side of the eye and in the nasal cavity can affect drainage from the NLD. In PAP treatment, air pressure affects all respiratory tract surfaces and related structures, causing pressure and flow changes in the aforementioned areas.

Based on our study results, the NLD drainage time changed in patients treated with CPAP. This is thought to be caused by the following two possible mechanisms:

First, it may be due to the positional change that may occur in Hasner's valve due to CPAP pressure or the anatomical expansion of the nasolacrimal apparatus mentioned in previous studies [23].

Second, in accordance with Bernoulli's principle (which states that an increased velocity during a flow in fluid dynamics causes a simultaneous decrease in pressure), the airflow velocity and pressure changes occurring in the nasal cavity due to the use of CPAP may have increased the drainage from the valve by creating a pressure difference between the two sides of the Hasner's valve [24].

Although reasons such as air leakage from the mask or air regurgitation from the NLD are emphasized as the causes of eye complications observed in patients with OSA using CPAP, no definitive cause has been reported in the literature. So, it should be kept in mind that decreased NLD drainage time may be considered in the etiology of dry eye complaints in patients without retrograde air or mask leakage, which is a common side effect in patients using CPAP.

In our study, considering the correlation of NLD drainage time with CPAP pressure and CPAP usage duration, it was found that there was a negative correlation between increased CPAP pressure and NLD drainage time, regardless of the duration of CPAP usage. We believe that this finding may be meaningful in that it supports the mechanisms that we think may be responsible for the change in the NLD drainage time. Although the correlation between CPAP pressure and NLD drainage time was statistically significant, the strength of the association was weak ( $r = -0.305$ ). Therefore, while the findings suggest a possible link, they should be interpreted with caution and may warrant further investigation in larger cohorts to confirm the clinical relevance of this relationship.

We believe that our study may inspire new studies to clarify whether there is a relationship between the change in the NLD drainage time and eye complications, especially in patients receiving PAP therapy.

The fact that the study was single-center and had a small sample size can be considered a limitation.

## Conclusion

According to our literature review, this is the first study to investigate whether the use of CPAP therapy for OSA affects the NLD drainage time, and as a result of our study, the NLD drainage time of patients using CPAP regularly for at least 6 months was shorter compared to healthy volunteers and patients with OSA receiving no CPAP therapy.

We believe that our study may inspire future studies to elucidate whether changes in NLD drainage time are related to eye complications, especially in patients receiving CPAP treatment.

**Author contributions** All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Kamil Gokce TULACI, Gözde SAHIN VURAL, Erhan ARSLAN, Tugba TULACI. The first draft of the manuscript was written by Kamil Gokce TULACI and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Funding** No funds, grants, or other support was received.

**Data, material and/or code availability** The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request."

## Declarations

**Competing Interests** The authors declare that they have no known financial or non-financial competing interests.

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethics approval** This prospective study was approved by the Balikesir University Faculty of Medicine Clinical Research Ethics Committee (approval no 2020/120). The study was conducted in accordance with the basic principles of Helsinki Declaration.

**Informed consent** All participants were given information about the study and written informed consent was obtained from all individual participants included in the study.

## References

1. Giles TL, Lasserson TJ, Smith BJ, White J, Wright J, Cates CJ (2006) Continuous positive airways pressure for obstructive sleep Apnoea in adults. *Cochrane Database Syst Rev* CD001106. <https://doi.org/10.1002/14651858.CD001106.pub2>
2. Ruhl DS, Tolisano AM, Kesser BW, Hashisaki GT, Camacho M (2017) Use of positive airway pressure following middle ear surgery: A practice survey of otologists. *Otol Neurotol* 38:e134–e7. <https://doi.org/10.1097/mao.0000000000001455>
3. Hayirci E, Yagci A, Palamar M, Basoglu OK, Veral A (2012) The effect of continuous positive airway pressure treatment for obstructive sleep apnea syndrome on the ocular surface. *Cornea* 31:604–608. <https://doi.org/10.1097/ICO.0b013e31824a2040>

4. Sullivan CE, Issa FG, Berthon-Jones M, Eves L (1981) Reversal of obstructive sleep Apnoea by continuous positive airway pressure applied through the Nares. *Lancet* 1:862–865. [https://doi.org/10.1016/s0140-6736\(81\)92140-1](https://doi.org/10.1016/s0140-6736(81)92140-1)
5. Sivri B, Sezen OS, Akbulut S, Coskuner T (2013) The effect of continuous positive airway pressure on middle ear pressure. *Laryngoscope* 123:1300–1304. <https://doi.org/10.1002/lary.23896>
6. Ghadiri M, Grunstein RR (2020) Clinical side effects of continuous positive airway pressure in patients with obstructive sleep Apnoea. *Respirology* 25:593–602. <https://doi.org/10.1111/resp.13808>
7. Li J, Li K (2016) Effects of continuous positive airway pressure on middle ear pressure and acoustic stapedial reflex. *Otolaryngol Head Neck Surg* 155:307–311. <https://doi.org/10.1177/0194599816643706>
8. Lin FY, Gurgel RK, Popelka GR, Capasso R (2012) The effect of continuous positive airway pressure on middle ear pressure. *Laryngoscope* 122:688–690. <https://doi.org/10.1002/lary.22442>
9. McCormick JP, Hildrew DM, Lawlor CM, Guittard JA, Worley NK (2016) Otic barotrauma resulting from continuous positive airway pressure: case report and literature review. *Ochsner J* 16:146–149
10. Pitts KD, Arteaga AA, Hardy ET, Stevens BP, Spankovich CS, Lewis AF (2018) The effect of continuous positive airway pressure therapy on nasal patency. *Int Forum Allergy Rhinol* 8:1136–1144. <https://doi.org/10.1002/alr.22157>
11. Berry RBBR, Gamaldo CE, Harding SM, Lloyd RM, Marcus CL and, BV V (2016) The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, version 2.3. Darien. American Academy of Sleep Medicine, Illinois
12. Ali MJ, Psaltis AJ, Murphy J, Wormald PJ (2015) Endoscopic dacryocystorhinostomy and obstructive sleep apnoea: the effects and outcomes of continuous positive airway pressure therapy. *Clin Exp Ophthalmol* 43:405–408. <https://doi.org/10.1111/ceo.12483>
13. Kapur VK (2010) Obstructive sleep apnea: diagnosis, epidemiology, and economics. *Respir Care* 55:1155–1167
14. McDauid C, Griffin S, Weatherly H, Duree K, van der Burgt M, van Hout S, Akers J, Davies RJ, Sculpher M, Westwood M (2009) Continuous positive airway pressure devices for the treatment of obstructive sleep apnoea-hypopnoea syndrome: a systematic review and economic analysis. *Health Technol Assess* 13(iii–iv, xi–xiv, 1–119, 43–274). <https://doi.org/10.3310/hta13040>
15. Moyer CA, Sonnad SS, Garetz SL, Helman JI, Chervin RD (2001) Quality of life in obstructive sleep apnea: a systematic review of the literature. *Sleep Med* 2:477–491. [https://doi.org/10.1016/s1389-9457\(01\)00072-7](https://doi.org/10.1016/s1389-9457(01)00072-7)
16. Grau-Bartual S, Al-Jumaily AM, Young PM, Traini D, Ghadiri M (2020) Effect of continuous positive airway pressure treatment on permeability, inflammation and mucus production of human epithelial cells. *ERJ Open Res* 6. <https://doi.org/10.1183/23120541.00327-2019>
17. Schwab RJ, Pack AI, Gupta KB, Metzger LJ, Oh E, Getsy JE, Hoffman EA, Geftter WB (1996) Upper airway and soft tissue structural changes induced by CPAP in normal subjects. *Am J Respir Crit Care Med* 154:1106–1116. <https://doi.org/10.1164/ajrccm.154.4.8887615>
18. Guilleminault C, Nino-Murcia G, Heldt G, Baldwin R, Hutchinson D (1986) Alternative treatment to tracheostomy in obstructive sleep apnea syndrome: nasal continuous positive airway pressure in young children. *Pediatrics* 78:797–802
19. Kakkar RK, Berry RB (2007) Positive airway pressure treatment for obstructive sleep apnea. *Chest* 132:1057–1072. <https://doi.org/10.1378/chest.06-2432>
20. Nino-Murcia G, McCann CC, Bliwise DL, Guilleminault C, Dement WC (1989) Compliance and side effects in sleep apnea patients treated with nasal continuous positive airway pressure. *West J Med* 150:165–169
21. Harrison W, Pence N, Kovacich S (2007) Anterior segment complications secondary to continuous positive airway pressure machine treatment in patients with obstructive sleep apnea. *Optometry* 78:352–355. <https://doi.org/10.1016/j.optm.2006.12.015>
22. FW N (1986) The lacrimal apparatus. *Ophthalmology: principles and concepts*, 6th edn. FW N, editor. St. Louis
23. Cannon PS, Madge SN, Selva D (2010) Air regurgitation in patients on continuous positive airway pressure (CPAP) therapy following dacryocystorhinostomy with or without Lester-Jones tube insertion. *Br J Ophthalmol* 94:891–893. <https://doi.org/10.1136/bjo.2009.166082>
24. Bhardwaj A, Sharma MK, Gupta M (2013) Endoscopic evaluation of therapeutic effects of Anuloma-Viloma Pranayama in Pratishyaya w.s.r. To mucociliary clearance mechanism and bernoulli's principle. *Ayu* 34:361–367. <https://doi.org/10.4103/0974-8520.127714>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.