

CASE REPORT

Open Access



Quantitative effects of head rotation angle on apnea hypopnea index in positional obstructive sleep apnea – a preliminary case series

Christopher Lyons¹, Kelly Flanagan², Ellen Lyons^{1*} , Michael Lawee³ and Payam Aghassi^{3,4}

Abstract

Objectives: Quantify the effects of head rotation and head incline on obstructive sleep apnea (OSA) severity.

Design: Single-arm, intervention study.

Setting: Pulmonary specialty clinic.

Case presentation: Ten adults diagnosed with positional OSA ranging from 32 to 64 years of age 6 females, 4 males reporting persistent daytime sleepiness and health issues with consistent use of CPAP.

Intervention: Standard polysomnography with a head angle sensor attached to the forehead and coaching to fall asleep with head at various rotation and incline angles and torso in supine and non-supine positions.

Measurements: OSA severity was scored according to American Academy of Sleep Medicine guidelines. Apnea hypopnea index (AHI) and peripheral capillary oxygen (SpO₂) saturation were measured during each sleep epoch of unique head rotation, head incline, and torso position.

Results: Two participants (1 with no apneas and 1 with central sleep apnea) were excluded. Among the remaining 8 participants, average reduction in peak AHI was 66% (range 18–88%) with head rotation $\leq 20^\circ$ above the horizon compared with $> 20^\circ$ above the horizon. The average of peak AHI values with head rotation $\leq 20^\circ$ was significantly lower than with head rotation $> 20^\circ$ (20.0 vs 45.3, $P=0.002$). Minimum SpO₂ was significantly higher for head rotation $\leq 20^\circ$ compared with $> 20^\circ$ (mean: 90.6% vs 84.3%, $P=0.03$). In the torso supine position, average peak AHI was significantly lower with head rotation $\leq 20^\circ$ compared with $> 20^\circ$ (7.1 vs 52.1, $P<0.001$). In the torso non-supine position, lower average peak AHI with head rotation $\leq 20^\circ$ was not statistically significant (22.3 vs 38.4, $P=0.09$).

Conclusion: These results support further exploration of maintaining head position $\leq 20^\circ$ above the horizon to minimize AHI and oxygen desaturation in OSA patients.

Trial registration: Apnea Hypopnea Index Severity Versus Head Position During Sleep.

ClinicalTrials.gov Identifier: NCT04086407 September 11, 2019 Registered retrospectively.

*Correspondence: e.lyons@sleepsystems-llc.com

¹ Massachusetts Medical Device Development Center, 110 Canal Street, 4th Floor, Lowell, MA 01852, USA

Full list of author information is available at the end of the article



© The Author(s) 2022. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

Keywords: Obstructive sleep apnea, Head rotation, Head incline, Torso position, Apnea hypopnea index, Oxygen saturation, Sleep disordered breathing, Case series

Background

Obstructive sleep apnea (OSA) is common in the general population, with prevalence in the United States of 3–7% in men and 2–5% in women (Punjabi 2008). OSA is defined as a sleep-related breathing disorder (SBD) that results in decreased or complete cessation of airflow while the patient has ongoing breathing effort. The cessation of airflow results from upper airway obstruction due to inadequate motor tone of the tongue and/or airway dilator muscles in the oropharynx during sleep (Park et al. 2011). Various factors contribute to OSA, including high body mass index (BMI), craniofacial anomalies, excess neck and/or tongue tissue, enlarged palatine tonsils, or sleeping in the supine position (Epstein et al. 2009). Among persons 30–70 years of age, the prevalence of mild to severe SBD (apnea–hypopnea index [AHI] ≥ 5 to < 15) is estimated to be 26% and prevalence of moderate to severe SBD (AHI ≥ 15) is estimated at 10% (Peppard et al. 2013).

It is well documented that trunk position significantly affects the severity of OSA. In fact, 50–75% of individuals with an OSA diagnosis exhibit supine predominance or worsened AHI when sleeping in the supine position (Raveslout et al. 2013). Positional OSA is defined as an AHI ≥ 5 with $> 50\%$ AHI reduction between the supine and non-supine positions and AHI that normalizes (AHI < 5) in the non-supine position (Peppard et al. 2013). Identification of positional OSA, especially in the mild and moderate OSA populations, has led to research and development on positional therapies (Cartwright et al. 1991, 1985), including physical barriers to lying supine, such as a tennis ball attached to the patient's back (Raveslout et al. 2013; Eijsvogel et al. 2015), and small vibrating devices attached to the neck or back that arouse the patient if they are sleeping supine (Raveslout et al. 2013, 2017; Bignold et al. 2011; Levendowski et al. 2014; van Maanen et al. 2012).

Recent research regarding the effect of head position, rather than torso position, on OSA severity may help improve upon the currently available positional therapies. A study using dual head and trunk position sensors to determine head and trunk position dependence in OSA patients identified 6.5% of OSA patients with solely head supine position dependence (van Kesteren et al. 2011). The study also showed that head position significantly influenced AHI in 46.2% of patients with trunk supine position dependence. When these patients were sleeping in the supine position, rotation of the head from

supine (90° as shown in 1A) to lateral resulted in a significantly decreased mean AHI in both male and female patients. The authors defined these patients' OSA as head position-aggravated, trunk supine position-dependent OSA (van Kesteren et al. 2011). This study also showed that the average AHI when the head was supine (regardless of trunk position) was significantly higher than when the trunk was supine (regardless of head position) (van Kesteren et al. 2011). Furthermore, a study of 67 patients with positional OSA who completed drug-induced sleep endoscopy found that lateral head position was associated with decreased frequency of complete anteroposterior collapse at the velum ($P < 0.01$), tongue base ($P < 0.01$), and epiglottis ($P < 0.01$) levels compared with supine head position (Safiruddin et al. 2014).

While these studies support the impact of head position on positional OSA severity, they do not describe specific head rotation angles that must be achieved in order to obtain clinical improvements in AHI in positional OSA patients. Both studies describe lateral versus supine head positions determined either by sensors with a threshold angle of $\pm 10^\circ$ from the 45°-position boundary (van Maanen et al. 2012) or through video of the sleeping patient (Gandotra et al. 2018). Therefore, neither could identify the specific head rotation angles needed to significantly improve positional OSA severity. These metrics are essential for designing clinical therapies to reduce apneas for these patients.

The primary aim of this preliminary study was to determine the head rotation angles that reduce AHI and oxygen desaturation severity in positional OSA patients. Ultimately, the goal is to identify a “safe zone” of head rotation that can be used to support development of a head positional therapy for positional OSA patients.

Case presentation

Study design and participants

In this preliminary single-arm, non-randomized study, all participants completed overnight polysomnography with recording of head angles during sleep at the Mass Lung & Allergy, P.C. Sleep Disorders Center (Worcester, MA) between November 2016 and November 2017. The study was conducted in accordance with the Declaration of Helsinki and International Conference on Harmonisation (ICH) guidelines for Good Clinical Practice, and the study protocol was reviewed and approved by the New England IRB (Newton, MA). Participants were informed of the purpose of the study and provided written

informed consent. Eligible participants were 21–60 years of age with a diagnosis of positional OSA from recent polysomnography results using the AASM guidelines of positional OSA defined as a lower AHI in the non-supine position than in supine (de Vries et al. 2015). Participants self-reported daytime drowsiness that persisted with use of continuous positive airway pressure (CPAP) therapy. They had to show compliance with CPAP use in the week prior to the screening visit, follow directions during an overnight sleep study, and discontinue CPAP therapy for two consecutive nights. Exclusion criteria included documented diagnosis of insomnia, chronic ear infections, persistent neck pain, persistent chronic posture physical issues, previous C-spine fusion, history of cardiac arrhythmia, history of seizures, allergy to standard tape used in sleep centers, non-English speaking, hospitalization within the previous 4 weeks, use of antibiotics or steroids within the previous 4 weeks, any major uncontrolled disease or condition, such as congestive heart failure, malignancy, end-stage heart disease, amyotrophic lateral sclerosis (ALS), or severe stroke, or other condition as deemed appropriate by investigator, history of severe osteoporosis, excessive alcohol intake (>6 oz hard

liquor, 48 oz beer or 20 oz wine daily), or illicit drug use, and daily use of prescribed narcotics (>30 mg morphine equivalent).

Sleep study and head rotation measurement

A proprietary sensor patch (Sleep Systems, LLC, Bedford, NH, USA) was developed for this trial and integrated with a dual axis inclinometer (SignalQuest, Lebanon, NH, USA), which was then packaged by Sleep Systems, LLC into a bedside unit fitted to the Embla communication system for the polysomnography montage. Before sleep, the sensor patch was attached to the participant's forehead with adhesive and tape. The sensor was calibrated for each participant for head rotation angles 0° to 180° and head incline angles of 0° to 90° . Head rotation of 90° corresponds to lying supine with the head facing the ceiling; head rotation of 0° and 180° correspond to the head rotated fully to the right or left horizon, respectively (Fig. 1A). Using Fowler's positioning model, head incline of 0° corresponds to lying supine with head facing the ceiling and 90° represents sitting upright (Fig. 1B).

Each participant was asked to fall asleep in their usual torso and head position for sleeping. Once asleep, data

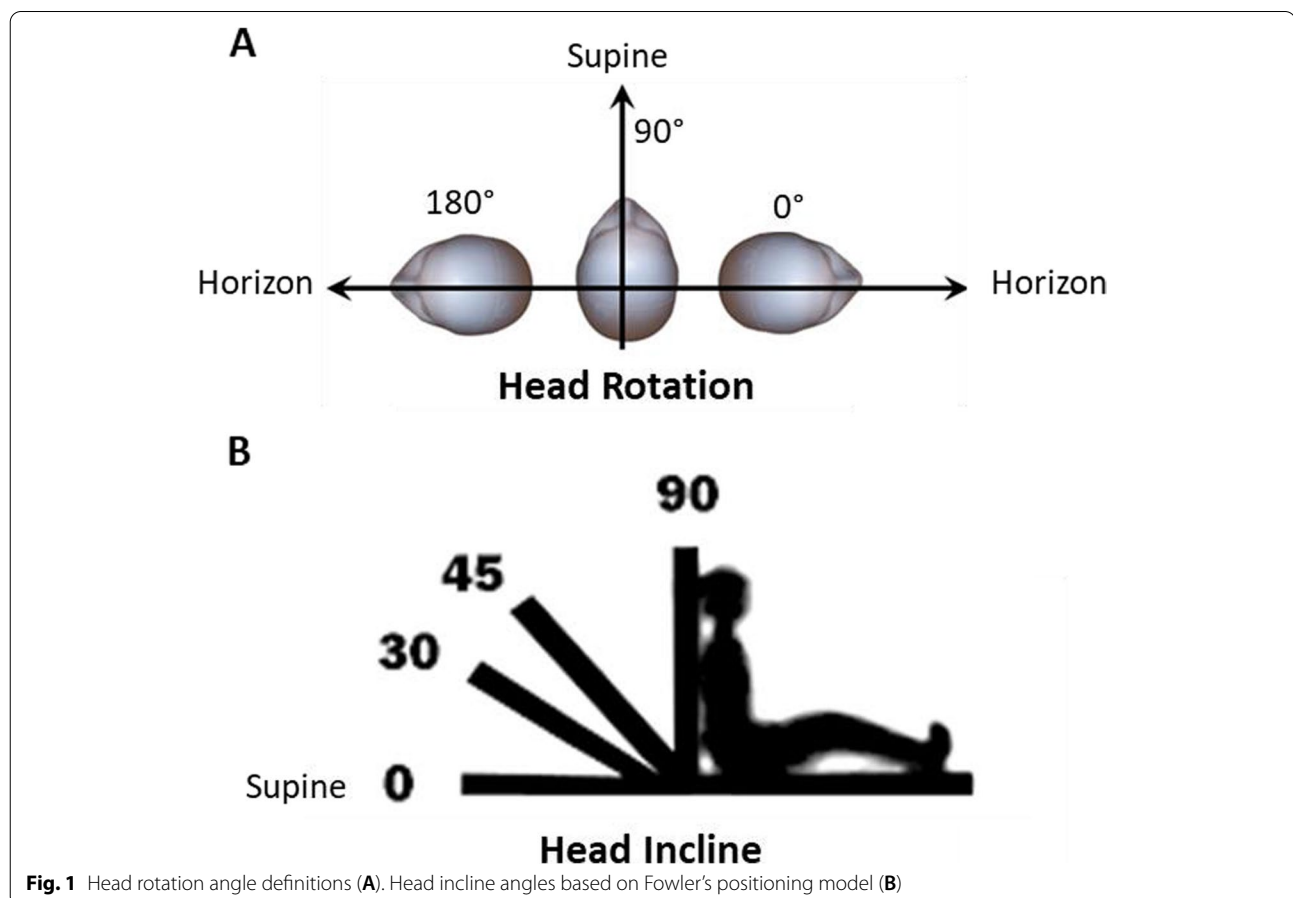


Fig. 1 Head rotation angle definitions (A). Head incline angles based on Fowler's positioning model (B)

were recorded for all head and torso positions at as many of these positions as allowed. Each participant was coached in all sleeping positions for at least 30 min to collect data. Standard polysomnogram data were collected during the overnight study by a sleep research technologist, including 6-channel electroencephalogram (EEG), left and right electrooculogram (EOG), three chin electromyography (EMG), snoring sensor, airflow measured by oronasal thermistor and nasal pressure transducer, respiratory effort measured by thoracic and abdominal respiratory inductance plethysmography, pulse oximetry, left and right anterior tibialis EMG, electrocardiogram, body position and integrated digital audio and video recordings.

Sleep research technologists, who were blinded to head position associated with each sleep epoch, performed sleep and event scoring in accordance with The American Academy of Sleep Medicine Manual for the Scoring of Sleep and Events Version 2.0.3 (The and Manual for the Scoring of Sleep and Associated Events: Rules, Terminology, and Technical Specifications. Darien, IL: American Academy of Sleep Medicine 2014). In addition to standard polysomnogram data collection, AHI (total number of apnea and hypopnea episodes per hour of sleep), SpO₂, torso position, and head rotation angle and head incline angle as determined by the forehead sensor, were recorded for each sleep epoch (defined as a period of sleep that maintained head angle with angular consistency $\leq 2^\circ$). The peak AHI was calculated for every epoch as the highest AHI of each head rotational subgroup.

The polysomnogram montages were specifically altered to include investigational channels for head rotation and head incline angles. A custom interface was developed to maintain compatibility with specific bedside polysomnography recorder auxiliary inputs. Small sponge wedges were added to compensate for individual forehead shape to keep angular errors $\leq 2^\circ$.

Body and head positioning during sleep

During the overnight sleep test, participants were coached by sleep research technologists to sleep with head rotation angles of $\leq 20^\circ$, $30\text{--}150^\circ$, and $\geq 160^\circ$, where horizon refers to head rotation fully to the left (180°) or right (0°). Each rotation angle was measured and recorded by the participant's forehead sensor. Each head position was attempted with the torso in both supine and non-supine positions. The sleep research technologist-initiated changes in head position from right to left at specific degrees after a minimum sleep epoch duration of 10 min (goal 30 min) by placement of pillow wedges to keep the head stable at each angle. However, participants were able to change position while they slept. All

positions, both coached and natural, were recorded for each sleep epoch.

Primary and secondary outcomes

The primary outcome was change in AHI severity with head rotation $\leq 20^\circ$ above the horizon compared with $> 20^\circ$ above the horizon. The secondary outcome was change in SpO₂ associated with head rotation $\leq 20^\circ$ above the horizon vs $> 20^\circ$ above the horizon. To determine the effect of torso position on AHI, the peak AHI was calculated for sleep epochs when the participant was sleeping with torso supine compared with sleep epochs with torso non-supine (i.e., sleeping on right or left side or prone).

Statistical analysis

Formal power calculations were not performed for this exploratory analysis. All analyses were two-sided with a significance level at $P < 0.05$ and reported with 95% confidence levels. Data were analyzed for AHI and SpO₂ dependence on head rotation $\leq 20^\circ$ and $> 20^\circ$ above the horizon. Mean AHI was also calculated for supine versus non-supine torso positions overall and within the head rotation angle subgroups of $\leq 20^\circ$ and $> 20^\circ$ above the horizon.

Results

Of the ten participants who enrolled and completed the overnight polysomnogram, data from two participants was excluded due to no apneic episodes observed in one patient and central apnea observed in another patient. Of the eight participants included in the analysis, six were female and two were male, with an average age of 48.5 years and average of BMI 32.5 kg/m². Three participants were found to be torso position sensitive with supine to non-supine AHI ratio > 2 . The remaining five participants had an AHI ratio < 1.6 .

As shown in Table 1, participants spent more of their sleep time with head rotation $> 20^\circ$ above the horizon than $\leq 20^\circ$ above the horizon. Peak AHI improved markedly for all patients when head rotation was $\leq 20^\circ$ above the horizon compared with $> 20^\circ$ above the horizon (mean improvement: 66%, range: 18% to 88%). Seventy-five percent of participants had peak AHI improvement of at least 70% when head rotation was $\leq 20^\circ$ above the horizon. Of note, both the peak and the minimum AHI improvements were observed in patients with the highest BMI (49.2 kg/m² and 42.5 kg/m², respectively). The minimum SpO₂ with head position $\leq 20^\circ$ above the horizon was significantly higher than the minimum SpO₂ with head position $> 20^\circ$ above the horizon (mean: 90.6% vs 84.3%, $P = 0.03$). Figure 2 shows peak AHI and minimum SpO₂ for each patient for each 20° head rotation segment. With respect to torso position, six of the eight patients

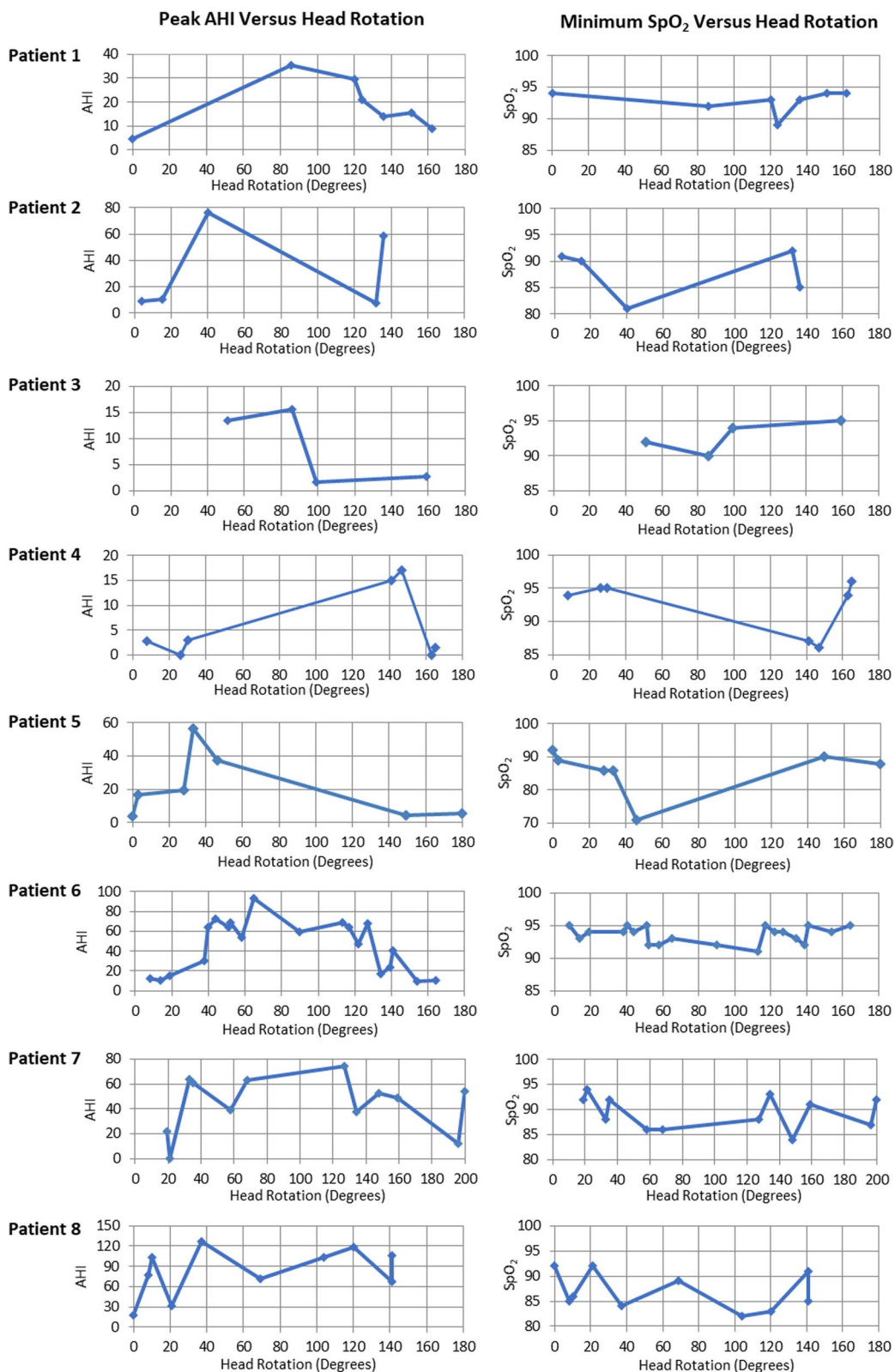


Fig. 2 Individual participants' peak apnea-hypopnea index (AHI) and minimum oxygen saturation (SpO₂) by head rotation angle

Table 1 Individual patient AHI and SpO₂ values by head rotation angle > 20° and ≤ 20° off the horizon

Patient	Sex	Age (years)	BMI (kg/m ²)	Mean (range) Head Incline*	Sleep Time (min)		Peak AHI			Minimum SpO ₂ (%)		
					Head Angle		Head Angle		Improvement	Head Angle		Improvement
					>20°	≤20°	>20°	≤20°	≤20° vs >20°	>20°	≤20°	≤20° vs >20°
1	F	43	23.9	16° (10–41)	130.5	58.5	35	9	74.0%	89	93	4.5%
2	M	51	42.5	11° (5–15)	87.1	81.3	77	9	88.0%	81	90	11.1%
3	F	50	33.2	4° (-4–20)	177.4	42.3	13.4	2.8	79.0%	90	95	5.6%
4	F	39	34	6° (0–13)	204.2	157	17.1	2.8	83.6%	86	94	9.3%
5	M	56	26	2° (-22–32)	195	95.6	57	17.1	70.0%	71	88	23.9%
6	F	53	24.8	6° (-9–25)	241.4	140.2	93.1	15.6	83.0%	91	93	2.2%
7	F	64	26.6	21° (16–27)	179	86.3	74.3	49	34.0%	84	87	3.6%
8	F	32	49.2	1° (-25–26)	137.8	105.2	127	104	18.0%	82	85	3.7%

*Based on Fowler’s positioning model.

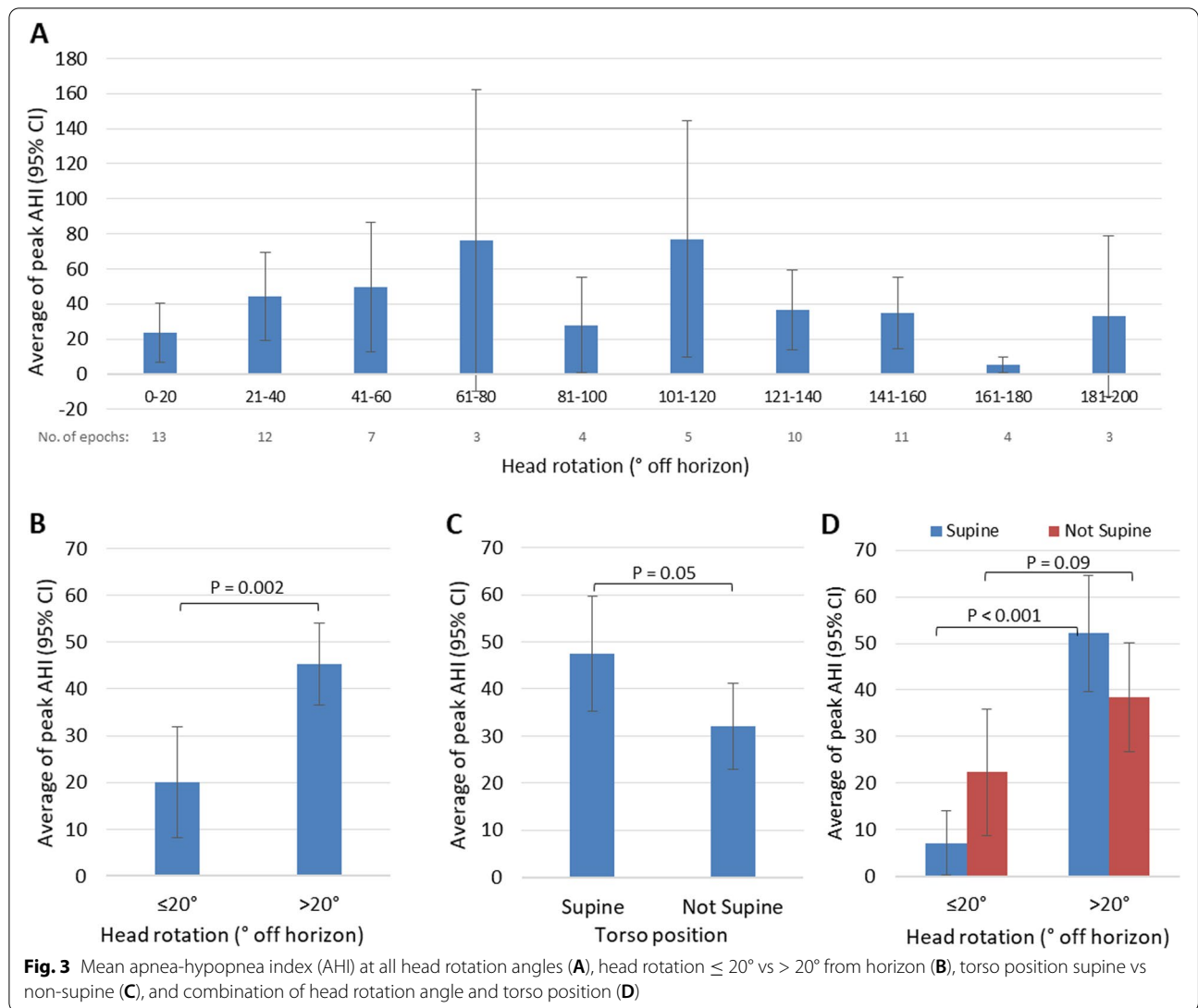
spent more of their sleep time in the non-supine position, and peak AHI was lower in the non-supine position for seven of eight participants (Table 2).

When peak AHI was analyzed for sleep epochs by 20° segments of rotation, head rotation angles 61–80° and 101–120° had the highest average peak AHI values (Fig. 3A). When rotation was 81–100°, many patients experienced gasping and inability to sleep due to discomfort, as observed by the sleep research technologist. As a result, there were fewer sleep epochs with head rotation near 90°, resulting in less opportunity for apneas (Fig. 4A). The average of peak AHI values

during the 20 sleep epochs in which head rotation was ≤ 20° above the horizon was significantly lower than during the 52 sleep epochs in which head rotation was > 20° above the horizon (20.0 vs 45.3, P = 0.002) (Fig. 3B). While the average of peak AHI values was lower for sleep epochs in the torso non-supine compared with supine position, regardless of head position, this difference was not statistically significant (47.5 vs 32.0, P = 0.05) (Fig. 3C). In the supine position, the average of peak AHI values was significantly lower when head rotation was ≤ 20° compared with > 20° (7.1 vs 52.1, P < 0.001) (Fig. 3D). In the non-supine position,

Table 2 Polysomnographic results and peak AHI in the torso supine vs non-supine versus torso positions

Participant	Peak AHI Torso Supine	Peak AHI Torso Non-Supine	AHI Improvement Torso Non-Supine (%)	Sleep Time Torso Supine (Minutes)	Sleep Time Torso Non-Supine (Minutes)
1	35.4	29.4	16.9	72.5	116.5
2	76.6	58.5	23.6	23.5	144.9
3	15.6	2.8	82.1	142.5	77.2
4	17	2.8	82.4	155.7	205.5
5	56.8	37.6	33.8	49.6	241
6	72.5	93.1	-28.4	218.9	162.7
7	74.3	60.7	18.3	110.3	152.3
8	126.5	106.7	15.7	89.3	153.7



the lower average of peak AHI values for head rotation ≤ 20° was not statistically significant (22.3 vs 38.4, *P* = 0.09) (Fig. 3D).

Mean head incline was between 1° and 21° for all participants and maximum head incline was between 13° and 41° (Table 1). Changes in AHI and SpO₂ were not observed across head incline angles (data not shown), likely owing to a narrow range of values that was < 35° in all but one patient who had a maximum head incline of 41°. According to the equation $F_{\text{airway}} = F_{\text{grav}} \cdot \sin[\text{head rotation angle}] \cdot \cos[\text{head incline angle}]$, at head incline < 25°, 90% of gravitational forces would be applied to the structures of the upper airway, resulting in upper airway collapse.

Discussion

This preliminary proof-of-concept study was conducted to evaluate the feasibility and acceptability of the association of head position with apnea severity. The outcome of this study has provided preliminary validation data and knowledge to refine the methodology and design for future main studies including participant enrollment, instrumentation, data collection and participant positioning procedures. This preliminary study demonstrates that AHI and SpO₂ de-saturation severity can be significantly improved by maintaining head rotation ≤ 20° above the horizon in participants with positional OSA. It is hypothesized that this is due to a significant reduction in the compressive force of oral cavity and oropharyngeal

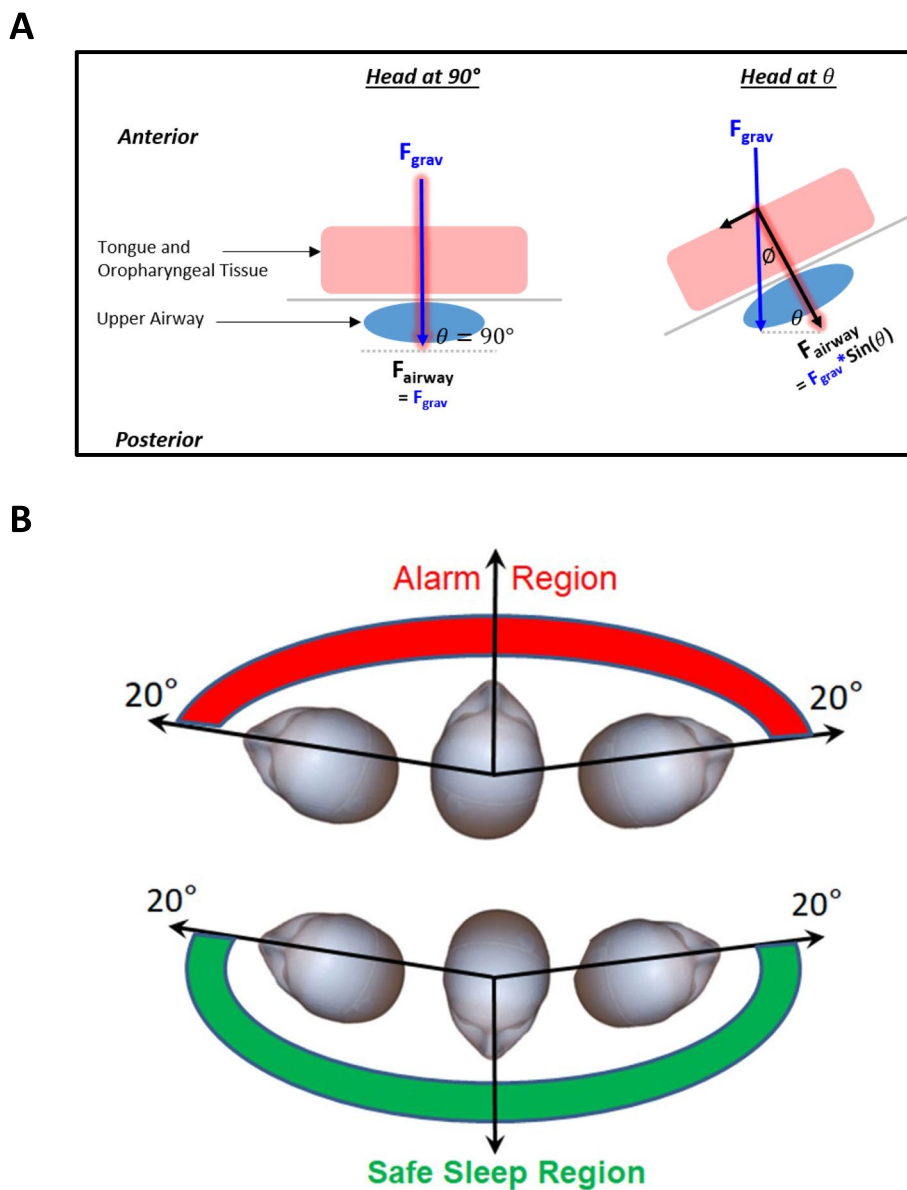


Fig. 4 Force of gravity acting on oropharyngeal tissue to compress upper airway when head is supine compared to laterally rotated head (A). Proposed "Safe Sleep Region" of head rotation angles to reduce apnea - hypopnea index in positional OSA patients (B)

tissue on the upper airway as the head rotates away from the 90° position. Due to the perpendicular force of gravity on the jaw, tongue and soft palate, which are positioned directly anterior to the upper airway when a patient is sleeping with his or her head at the 90° position, 100% of the gravitational force is acting on this tissue to compress and, therefore, obstruct the airway (Fig. 4A) (Marques et al. 2017). As a patient rolls his or her head to the right or left, the position of this tissue changes such that the gravitational force results in progressively less compression of the upper airway. In a study of OSA patients who

underwent upper airway endoscopy during natural sleep, epiglottic collapse was virtually abolished and ventilation increased by 45% with lateral positioning (i.e. lying on right side with the head in a lateral neutral position) compared to supine positioning (Marques et al. 2017). Our preliminary study expands on the current understanding of anatomical collapse of the upper airway by analyzing the influence of specific head rotation angles on AHI and SpO₂.

As the head is rotated away from 90°, gravitational force also pushes the tongue and soft palate tissue laterally in

the mouth and oropharynx rather than completely posteriorly towards the upper airway. The more the gravitational force acts on these tissues laterally, the less the tissues are pushed into the upper airway where they can cause apnea or hypopnea events. When the patient's head position is not 90°, tongue and soft palate tissue act as an object on an incline (Fig. 4A). When on this incline, which is defined by the head rotation angle, the perpendicular force of gravity (F_{airway}), which acts to compress the airway, is less than the total gravitational force (F_{grav}) ($F_{\text{airway}} = F_{\text{grav}} \cdot \sin [\text{head rotation angle}]$) (Fig. 4A). These calculations suggest that the airway collapsibility when head rotation is 20° above the horizon is 34% of the airway collapsibility when head rotation is at 90°. Such a reduction in airway collapsibility would be expected to significantly reduce the number of apnea and hypopnea events, which we observed in our study for head rotation $\leq 20^\circ$ above the horizon. In a similar study, 26 participants underwent an overnight polysomnography calculating AHI with all trunk and head positions (supine and lateral) compared with the complete supine position (i.e., head and trunk supine) (Zhu et al. 2017). Lateral rotation of the head to the right or left with the trunk supine resulted in a significant reduction in mean AHI from 36.0 (22.5) to 25.8 (16.6) ($P=0.008$), and an AHI decrease of 10 in 27% of patients. The trunk lateral-head lateral position resulted in a more dramatic reduction in mean AHI from 31.6 (20.2) to 4.1 (4.1) (Zhu et al. 2017).

Future studies should include a significantly larger sample size and open the inclusion criteria to all subjects diagnosed with OSA since most subjects showed a higher positional sensitivity ratio of AHI when monitoring head rotation as compared to torso rotation. Head rotation angles greater than 45° above the horizon should be minimized since most subjects experience maximum apnea severity within this range. The primary focus of future studies should show that AHI and SpO₂ desaturation can be consistently minimized by limiting head rotation to angles less than 20° above the horizon.

Conclusion

In conclusion, this preliminary study has provided evidence that severity of AHI and SpO₂ desaturation can be significantly minimized in positional OSA patients by positioning the head at angles $\leq 20^\circ$ above the horizon when the torso is both supine and non-supine. Based on these results, we propose a “Safe Sleep Region” for OSA patients that encompasses all head positions $\leq 20^\circ$ from the horizon to reduce AHI, thereby reducing severity of OSA. These results reinforce the influence of the head position on AHI.

Abbreviations

AASM: American Academy of Sleep Medicine; AHI: Apnea Hypopnea Index; BMI: Body mass index; CFR: Code for Federal Regulations; CPAP: Continuous positive airway pressure; EMG: Electromyography; OSA: Obstructive sleep apnea; PAP: Positive airway pressure; POSA: Positional obstructive sleep apnea; PP: Per protocol; SDB: Sleep disordered breathing; SpO₂: Peripheral capillary oxygen saturation.

Acknowledgements

The authors express thanks to Laurie LaRusso, MS EL., for medical writing support and draft manuscript. The authors would also like to express our appreciation to sleep technicians Andria Walsh, Carolyn Moss, Madilyn Lombard, Barbara Scher.

Non-financial disclosure

None.

Authors' contributions

Sleep Systems, LLC paid for clinical study protocol development by authors P.A. and M.L., of Mass Lung & Allergy, P.C. Sleep Disorders Center (Worcester, MA) and New England IRB. Data collection by authors P.A. and M.L. of Mass Lung & Allergy, P.C. Sleep Disorders Center. Medical writing support by K.F. (University of Massachusetts). C.L. and E.L. (Sleep Systems, LLC) and K.F. analyzed and interpreted the data. All authors critically reviewed and approved draft and final manuscripts and agree with the decision to submit the article for publication.

Funding

No funding or grants were received for this study.

Availability of data and materials

Data available on request from the authors.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and International Conference on Harmonisation (ICH) guidelines for Good Clinical Practice, and the study protocol was reviewed and approved by the New England IRB (Newton, MA). IRB#: 120160813.

Consent for publication

Participants provided signed written informed consent to participate and to publishing their data.

Competing interests

Christopher Lyons and Ellen Lyons own and operate Sleep Systems, LLC and hold multiple US and international patents claiming that head angle position independent of torso position is relative to AHI and SpO₂ severity. All other authors report no conflicts of interest.

Author details

¹Massachusetts Medical Device Development Center, 110 Canal Street, 4th Floor, Lowell, MA 01852, USA. ²University of Massachusetts Medical School, 55 North Lake Ave., Worcester, MA 01655, USA. ³Mass Lung and Allergy, PC, 85 Prescott St, Suite 302, Worcester, MA 01605, USA. ⁴University of Massachusetts Memorial Medical Center, Worcester, MA 01655, USA.

Received: 25 July 2021 Accepted: 9 February 2022

Published online: 15 April 2022

References

- Bignold JJ, Mercer JD, Antic NA, McEvoy RD, Catcheside PG. Accurate position monitoring and improved supine-dependent obstructive sleep apnea with a new position recording and supine avoidance device. *J Clin Sleep Med*. 2011;7(4):376–83.
- Cartwright RD, Lloyd S, Lillie J, Kravitz H. Sleep position training as treatment for sleep apnea syndrome: a preliminary study. *Sleep*. 1985;8(2):87–94.

- Cartwright R, Ristanovic R, Diaz F, Caldarelli D, Alder G. A comparative study of treatments for positional sleep apnea. *Sleep*. 1991;14(6):546–52.
- de Vries GE, et al. "Usage of positional therapy in adults with obstructive sleep apnea." *J Clin Sleep Med*. 2015;11(2):131–7. <https://doi.org/10.5664/jcsm.4458>.
- Eijsvogel MM, Ubbink R, Dekker J, et al. Sleep position trainer versus tennis ball technique in positional obstructive sleep apnea syndrome. *J Clin Sleep Med*. 2015;11(2):139–47.
- Epstein LJ, Kristo D, Strollo PJ Jr, et al. Clinical guideline for the evaluation, management and long-term care of obstructive sleep apnea in adults. *J Clin Sleep Med*. 2009;5(3):263–76.
- Gandotra K, May A, Auckley D. Variable Response to CPAP in a Case of Severe Obstructive Sleep Apnea: An Unusual Cause. *J Clin Sleep Med*. 2018;14(1):145–8.
- Levendowski DJ, Seagraves S, Popovic D, Westbrook PR. Assessment of a neck-based treatment and monitoring device for positional obstructive sleep apnea. *J Clin Sleep Med*. 2014;10(8):863–71.
- Marques M, Genta PR, Sands SA, et al. Effect of Sleeping Position on Upper Airway Patency in Obstructive Sleep Apnea Is Determined by the Pharyngeal Structure Causing Collapse. *Sleep*. 2017;40(3):zsx005.
- Park JG, Ramar K, Olson EJ. Updates on definition, consequences, and management of obstructive sleep apnea. *Mayo Clin Proc*. 2011;86(6):549–54 quiz 554–545.
- 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):1006–14.
- Punjabi NM. The epidemiology of adult obstructive sleep apnea. *Proc Am Thorac Soc*. 2008;5(2):136–43.
- Ravesloot MJ, van Maanen JP, Dun L, de Vries N. The undervalued potential of positional therapy in position-dependent snoring and obstructive sleep apnea—a review of the literature. *Sleep Breath*. 2013;17(1):39–49.
- Ravesloot MJL, White D, Heinzer R, Oksenberg A, Pepin JL. Efficacy of the New Generation of Devices for Positional Therapy for Patients With Positional Obstructive Sleep Apnea: A Systematic Review of the Literature and Meta-Analysis. *J Clin Sleep Med*. 2017;13(6):813–24.
- Safiruddin F, Koutsourelakis I, de Vries N. Analysis of the influence of head rotation during drug-induced sleep endoscopy in obstructive sleep apnea. *Laryngoscope*. 2014;124(9):2195–9.
- The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology, and Technical Specifications. Darien, IL: American Academy of Sleep Medicine; 2014.
- van Kesteren ER, van Maanen JP, Hilgevoord AA, Laman DM, de Vries N. Quantitative effects of trunk and head position on the apnea hypopnea index in obstructive sleep apnea. *Sleep*. 2011;34(8):1075–81.
- van Maanen JP, Richard W, Van Kesteren ER, et al. Evaluation of a new simple treatment for positional sleep apnoea patients. *J Sleep Res*. 2012;21(3):322–9.
- Zhu K, Bradley TD, Patel M, Alshaer H. Influence of head position on obstructive sleep apnea severity. *Sleep Breath*. 2017;21(4):821–8.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

