Published in final edited form as:

Sleep Breath. 2016 March ; 20(1): 79–85. doi:10.1007/s11325-015-1187-x.

Comparison of the Upper Airway Dynamics of Oronasal and Nasal Masks with Positive Airway Pressure Treatment using cine Magnetic Resonance Imaging

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Abstract

Purpose—It is known that oronasal masks are not as effective at opening the upper airway compared to nasal only continuous positive airway pressure (CPAP) masks in patients with sleep disordered breathing. However, the physiological mechanism for this difference in efficacy is not known; although, it has been hypothesized to involve the retroglossal and/or retropalatal region of the upper airway. The objective of this study was to investigate differences in retroglossal and retropalatal anterior-posterior space with the use of oronasal vs. nasal CPAP masks using real-time cine Magnetic Resonance Imaging (cMRI).

Methods—10-Subjects (8-men, 2-women) with obstructive sleep apnea (OSA) were given cMRI with both nasal and oronasal CPAP masks. Each subject was imaged with each interface at pressures of 5, 10 and 15 cm of H₂O, while in the supine position along the sagittal plane.

Results—The oronasal mask produced significantly less airway opening in the retropalatal region of the upper airway compared to the nasal mask interface. During exhalation, mask style had a significant effect on anterior-posterior distance $p=0.016$. No differences were found in the retroglossal region between mask styles.

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Financial Disclosures: The authors of this study have no financial disclosures.

Conflicts of Interest: None

This study was registered on Clinicaltrials.gov on August 13th 2013 (#NCT01939938)

Author Contribution:

Matthew R. Ebben-Involved with all aspects of this study, and agrees to be accountable for all aspects of this work.

Sara Milrad- Contributed to acquisition and analysis of data, revised the manuscript for intellectual content, and approved the final version of the manuscript and agrees to be accountable for all aspects of this work.

Jonathan P. Dyke: Contributed to acquisition and analysis of data, revised the manuscript for intellectual content, and approved the final version of the manuscript and agrees to be accountable for all aspects of this work.

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Ana C. Krieger: Contributed to conception and design of the study, revised the manuscript for intellectual content, and approved the final version of the manuscript and agrees to be accountable for all aspects of this work.

Conclusions—Our study confirmed previous findings showing differences in treatment efficacy between oronasal and nasal mask styles. We have shown anatomic evidence that the nasal mask is more effective in opening the upper airway compared to the oronasal mask in the retropalatal region.

Keywords

Apnea; mask; cine Magnetic Resonance Imaging; oronasal; nasal; obstructive sleep apnea

Introduction

Positive airway pressure (PAP) is the gold standard treatment for obstructive sleep apnea (OSA) [1]. The benefits of PAP treatment on measures of daytime function for patients treated for OSA are well known [2–5]. Untreated OSA is associated with adverse medical conditions including congestive heart failure [6–8], stroke [9,10], pulmonary [11–13] and systemic [14–16] hypertension, cancer [17], and increased mortality [18]. PAP therapy is essentially a medical quality air compressor that pressurizes the upper airway. In order to deliver the pressurized air to the patient, one of the following four mask types are used: oral (covers only the mouth), nasal (covers only the nose), nasal pillows (seals at the nares), or oronasal (covers both the nose and mouth).

Since the initial conception of continuous positive airway pressure (CPAP) as a treatment for OSA some researchers have deliberated whether oronasal masks could be used to successfully pressurize the upper airway [19]. The initial studies investigating this question showed conflicting results, likely due to differences in study design [20–22]. More recently, Teo et al [23] conducted a study showing that when oronasal vs. nasal masks are compared with the use of auto-titrating CPAP, the use of the oronasal mask resulted in a significantly higher apnea hypopnea index (AHI) compared to the nasal mask, which suggests that mask style may result in an inadequate auto-titration. A similar outcome was also found by Bakker et al [24], however in this study, although a significant difference was found in residual AHI between mask styles, residual events continued to be within the proper treatment range with all tested masks. Our group [25] found that when patients are manually titrated on CPAP, the oronasal mask resulted in significantly higher pressures for patients with moderate to severe obstructive sleep apnea compared to standard nasal and nasal pillows masks. This finding was confirmed by a large scale correlational study [26].

We recently followed up our initial study with a randomized crossover study testing differences in residual respiratory events between nasal and oronasal masks, using a fixed pressure [27]. Our findings showed that significantly higher residual respiratory events were present when an oronasal mask was used compared to a standard nasal mask. Therefore, it is clear that although oronasal masks can effectively treat OSA, they are not as effective as nasal only masks.

Two theories have been proposed to explain the differences in efficacy between these two mask types. The original theory, proposed by Kuna and Remmers in the 1980's [19], speculated that oronasal masks would not successfully treat OSA because the airway dynamics of pressure applied orally and nasally simultaneously causes a posterior force

against the soft tissues in the upper airway, which would prevent the opening of the airway. It has also been hypothesized that the placement of the lower portion of the oronasal mask against the mandible may compromise the retroglossal space, thereby increasing upper airway resistance.

The objective of our current study was to visualize the upper airway using cMRI with both nasal and oronasal masks. We hypothesized that the oronasal mask will cause a reduction in the anterior-posterior (A-P) distance in the retroglossal and/or retropalatal region of the airway compared to the nasal only mask.

Methods

The Institutional Review Board at Weill Cornell Medical College granted approval for this study with full informed consent being obtained for each participant. A total of 10-subjects [8M/2F] of average age 59.1 years [43–77 years] participated in this study from October 2013 to January 2014. All subjects were previously diagnosed and treated for OSA at the Weill Cornell Center for Sleep Medicine, and were successfully using CPAP at home. Subjects with a history of upper airway surgery were excluded, as were subjects with metal implants or any contraindication for MRI. Demographic information for all subjects including their baseline and residual AHI index and preferred CPAP pressures are given in Table 1.

Resmed Mirage™ FX (nasal) and Quattro™ FX (ornasal) CPAP interfaces were used for all subjects in this study. All masks were fitted with an unintentional leak rate of <20 L/min. A Phillips-Respironics REMstar® Auto machine (New Kensington, PA) set in CPAP mode was used during imaging. A 19-foot CPAP hose was used to reach from the MRI control room directly into the scanner suite. The CPAP machine was calibrated with a digital manometer (Respironics Inc. Murrysville, PA) to compensate for the pressure drop due to the long hose.

Magnetic Resonance Imaging Methods

Subjects were fitted with a nasal mask, and situated in the MRI scanner in the supine position. All subjects were imaged in a 12-channel head coil in a Siemens TIM Trio 3.0® Tesla MRI scanner. An additional anterior/posterior neck coil was also used to achieve maximal signal in the airway of taller subjects. A single mid-sagittal plane was acquired using a fast radial k-space sampled T₁-weighted gradient echo cine MRI sequence (LiveView®; Siemens Healthcare, Erlangen, Germany). The image slice was adjusted for each subject so that the soft palate and the retroglossal area could be best visualized. The cMRI sequence acquired a single 8-mm slice with a 25.6 cm field of view and a 128×128 matrix yielding an in-plane voxel size of 2.0 mm × 2.0 mm. A flip angle of 5° was used with repetition and echo times of 2.1 ms and 1.3 ms respectively. This produced a frame speed of 52.3 ms/frame (19 frames/second). Real-time physiologic respiratory and peripheral pulse data were continuously recorded from the MRI scanner during all imaging experiments.

Imaging was performed continuously for one-minute at three different pressure settings of CPAP at 5, 10 and 15 cm of H₂O. Subjects were asked to breathe through their nose for 10-

seconds without swallowing at each pressure. After the nasal mask condition was completed, the subjects were then fitted with the oronasal mask. During this condition subjects were also given the same three pressures (5, 10, and 15 cm of H₂O), and were scanned for a minute on each pressure. However, during the one-minute period each subject was asked to breathe through their nose only, mouth only, and mouth and nose simultaneously for 10-seconds. Before each mask trial, the subjects were instructed as to the protocol for breathing during imaging. Moreover, during each imaging sequence the subject was informed over the loud speaker when to begin and end a specific breathing method. After the trial was completed, the protocol was again reviewed with the subject to insure that they followed the correct breathing sequence during testing.

Magnetic Resonance Analysis Methods

Synchronization of physiologic data with DICOM image data was performed using the ExVult software (D. Hu.; University of Pennsylvania) along with in-house MATLAB scripts. Identification of specific airway images at each point in the respiratory cycle was obtained by plotting respiratory traces as a function of scan time and converting to image number. Measurements of the A-P distance in the retroglossal and retropalatal regions (see Figures 1 & 2) were made using the ImageJ software (W. Rasband; NIH, Bethesda MD).

Statistical Analysis

Data analyses were performed using SPSS 22 (IBM, Corp., Armonk, New York). Airway measurements were sampled at four points in the respiratory cycle. These included the nadir and zenith of a breath, and a mid-breath measurement both as the subject inhaled and exhaled. This was done to control for changes in the shape of the upper airway over the course of the respiratory cycle. The airway measurements included retroglossal and retropalatal, A-P distance (see figures 1 and 2). A two-way repeated measures ANOVA was conducted to evaluate the effect of CPAP mask style and pressure setting on the size of the upper airway in the retroglossal and retropalatal A-P space (see figures 1 and 2). The within-subject factors were mask style and breathing technique with four levels (nasal breathing with a nasal mask, oronasal mask with nasal breathing, oronasal mask with mouth breathing, and oronasal mask with nasal and mouth breathing), and pressure setting with three levels (5, 10 and 15 cm of H₂O). The mask style×pressure setting interaction was tested using the multivariate criterion of Wilks' lambda (Λ). Pairwise comparisons were conducted to further evaluate both main effects and interactions. A Sidak correction was used to control for familywise type I error with pairwise comparisons.

Results

The pressure setting effect on A-P distance was significant in the retroglossal region at the zenith of a breath, $\Lambda=0.218, F(2,5)=8.97, p=0.022$. The effect of mask style ($\Lambda=0.911, F(3,4)=0.13, p=0.94$) and the interaction of mask style and pressure setting ($\Lambda=0.011, F(6,1)=14.98, p=0.20$) was not significant at a p -value of <0.05 . Pairwise comparisons of the pressure levels revealed a significant difference between 10 and 15 cm of H₂O ($p=0.017$). There was no significant difference between 5 and 10cm of H₂O ($p=0.426$). The comparison between 5 and 15cm of H₂O approached significance ($p=0.053$).

In the retropalatal region, during exhalation, mask style had a significant effect on A-P distance $\Lambda=.093$, $F(3,4)=13.03$, $p=0.016$. Neither the pressure setting ($\Lambda=0.930$, $F(2,5)=0.189$, $p=0.83$) nor the interaction between mask style and pressure setting ($\Lambda=0.232$, $F(6,1)=0.551$, $p=0.77$) were significant at a p-value of <0.05 . Pairwise comparisons revealed significant differences in A-P distance between the nasal mask and the oronasal mask while breathing through the mouth ($p=0.004$) and with the oronasal mask while breathing through both the nose and mouth ($p=0.008$). There was not a significant difference between the nasal mask and the oronasal mask with nasal only breathing ($p=0.998$). However, a significant difference in A-P space was found between nasal only breathing with the oronasal mask and both mouth breathing ($p=0.038$), and nasal and mouth breathing ($p=0.040$) with the oronasal mask.

No other significant differences in A-P distance were found in either the retroglossal or retropalatal region at any other point in the respiratory cycle. However, the effect of mask style on A-P distance approached significance in the retropalatal area at the zenith of a breath $\Lambda=0.197$, $F(3,4)=6.10$, $p=0.057$ and during inhalation $\Lambda=0.150$, $F(3,3)=5.665$, $p=0.094$. Pairwise comparisons at the breath zenith found a significant difference between nasal breathing with the oronasal mask and mouth breathing only with the oronasal mask ($p=0.016$). The difference in A-P space between the nasal mask and the oronasal mask with mouth breathing only approached significance ($p=0.057$). During inhalation the only significant difference in A-P space was between nasal breathing with the oronasal mask and nose and mouth breathing with the oronasal mask ($p=0.032$). Tables 2 and 3 show the means and SD's (with the results of paired t-tests, if $p<0.05$) for A-P distance in the retropalatal and retroglossal region by the point in the respiratory cycle at the time the measurement was taken.

Discussion

There have been several studies using advanced imaging techniques to investigate the upper airway in adult patients with OSA [28–30]. However, our study is the first to use imaging to examine differences in airway space produced by oronasal vs. nasal mask interfaces. This is of particular importance because a better understanding of how these interfaces effect dynamic changes in the upper airway may lead to advances in mask design, which may moderate the current differences in efficacy between these styles.

Our data show significant changes during exhalation in the retropalatal region of the upper airway. However, no significant changes in the retroglossal area were found. This suggests that the Remmers and Kuna [19] model is correct. Breathing through the mouth, or nose and mouth with an oronasal mask causes the soft palate to be forced into the posterior region of the airway. When the patient used the oronasal mask while breathing through both the nose and mouth, the soft palate swung in a flagging motion from the anterior to posterior region of the upper airway. The turbulence from the swinging motion of the soft palate likely accounts, in part, for the reduced efficacy of the oronasal mask compared to the standard nasal style mask. This turbulence appeared to be the worst when the subject was breathing through the nose and mouth concurrently.

Differences in retropalatal space between mask styles appeared the greatest at the mid-point of expiration. Some previous studies have shown greater risk for airway closure during exhalation in patients with and without OSA [31–33]. Therefore, the greater ability of the nasal mask to open (or to maintain patency of) the upper airway at this point in the respiratory cycle may account for the improved efficacy of the nasal mask compared to the oronasal mask. Interestingly, as seen in Table 2, when subjects were using the oronasal mask with nasal-only breathing during the zenith and mid-point of exhalation, the retropalatal space became progressively larger at higher pressures. However, the opposite occurred (it became progressively smaller) in the same breathing conditions when breathing through the mouth-only with the oronasal mask. While breathing through the nose and mouth simultaneously with the oronasal mask, during the zenith of breathing the retropalatal space also became progressively smaller. However the same trend did not occur during the mid-point of exhalation. This is likely due to the fact that the distribution of airflow through the mouth and nose likely fluctuated within subjects during this breathing condition.

Compared to the nasal only mask, no significant differences were found when subjects were breathing through their nose only with the oronasal vs. the differences found when breathing through the month, or nose and mouth simultaneously with this mask style. In other words, the oronasal mask appears to open the airway as well as the nasal mask only when the patient is breathing exclusively through the nose. This may explain the differences in efficacy of oronasal masks found in previous investigations [21,20,22], with some studies finding the oronasal mask to be completely ineffective in opening the upper airway during apneas, and others showing this mask style to work adequately in treating patients with OSA. Experienced clinicians who have regularly used the oronasal interface with PAP treatment in patients with OSA have seen this mask style treat apnea effectively. However, due do the increased pressure required to open the airway in patients with moderate to severe OSA with the oronasal interface compared to the nasal mask [25], certain patients needing high levels of PAP may reach the upper limit of the machine's pressure capabilities before adequate opening of the airway is achieved.

It should be noted that all subjects were awake for this study, which may have allowed compensatory muscle activation in the jaw, preventing the force applied from the lower portion of the oronasal mask from driving the mandible into the airway, and potentially reducing the space in the retroglossal region. During sleep these muscles may be quiescent, allowing the force of the mask against the jaw to contribute to the reduced efficacy of the oronasal mask in opening the upper airway. Sleep also causes reduced tone to other upper airway muscles as well as reduced respiratory drive to the diaphragm. Although sleep affects upper airway muscle tone, there is little reason to believe that this difference in sleep vs. wake muscle tone would differentially effect one mask style over another in our study since all masks were tested during wakefulness. Another limitation of our study is that only A-P space was measured. Measurement along the coronal plane may show different patterns of occlusion; however this was not measured in our study.

Conclusion

In summary, we have shown anatomic evidence that the nasal mask is more effective in opening the upper airway compared to the oronasal mask. Based on our findings, it appears that the change in airway space occurs primarily in the retropalatal region. However, this finding needs to be confirmed by imaging subjects with OSA using both mask interfaces during sleep.

Acknowledgments

Support provided by the National Institutes of Health - National Center for Advancing Translational Sciences, Grant # UL1 TR000457-06

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Nasal 15 cm of H₂O

Figure 1.

Oronasal 15 cm of H₂O

Figure 2.

Table 1

Demographic Characteristics of Subjects 1–10

Subject	Age	Ethnicity	Gender	BMI (Kg/m ²)	Neck Size (cm)	Baseline AHI (events/hr)	Residual AHI (events/hr)	Mask Style Currently Used at Home	Prescribed Pressure (cm2 H2O)
1	45	Hispanic	M	38.4	148.5	105	1	Full Face	8
2	67	Caucasian	M	24.3	130.6	38	1	Nasal	6
3	48	African Amer	M	24.5	110.8	18	4	Nasal	8
4	55	Caucasian	F	40.0	142.6	9	0	Full Face	15/11
5	77	Caucasian	M	27.0	135.2	21	0	Full Face	5
6	62	Caucasian	M	32.0	154.8	63	2	Nasal	12
7*	62	Caucasian	M	34.0	165.2	39	5.5	Nasal	6
8*	62	Asian	F	21.2	99.1	29	0	Nasal	15
9	65	Caucasian	M	39.0	180.3	67	0.3	Full Face	8
10*	44	Hispanic	M	33.0	140.8	34	2	Full Face	6

* Subjects who did not undergo the nose, mouth, and nose and mouth condition on the oronasal portion of the cMRI study

Table 2

Retropalatal space for each CPAP setting by mask style and mode of breathing

		Point in the respiratory cycle	Nasal		Oronasal-Nasal Breathing Only		Oronasal-Mouth Breathing		Oronasal-Nasal and Mouth Breathing	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
CPAP Setting	5 cm of H ₂ O	Nadir	4.41	3.12	3.81	2.11	2.63	1.74	2.86	2.56
		Mid-point of inspiration	3.97	2.53	3.88	1.99	2.00	1.34	2.62	2.13
		Zenith	4.49	2.38	3.18	2.08	2.34	1.53	2.76	2.22
		Mid-point of exhalation	4.53	2.19	3.97	2.22	2.74	1.81	2.24	1.55
	10 cm of H ₂ O	Nadir	4.11	1.09	3.81	1.99	3.14	1.74	3.87	2.87
		Mid-point of inspiration	3.71	1.09	3.76	2.64	3.35	2.28	2.72	2.22
		Zenith	3.64	0.96	3.59	1.24	1.71*	1.56	2.23*	1.86
		Mid-point of exhalation	4.25	2.16	4.25	2.16	1.46*	1.01	2.51*	2.28
	15 cm of H ₂ O	Nadir	4.17	0.74	5.82	1.54	3.14	2.24	3.38	1.67
		Mid-point of inspiration	3.96	1.34	4.01	1.72	2.04*	1.12	3.23	2.19
		Zenith	3.90	1.06	5.34	2.29	2.23*	1.63	1.99*	1.70
		Mid-point of exhalation	4.64	1.51	4.58	2.43	1.17*	0.86	1.90*	1.67

* Indicates a significant difference compared to the nasal mask interface at a p<0.05. All measurements are listed in millimeters.

Table 3

Retroglossal space for each CPAP setting by mask style and mode of breathing

		Point in the respiratory cycle	Nasal		Oronasal-Nasal Breathing Only		Oronasal-Mouth Breathing		Oronasal-Nasal and Mouth Breathing	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
CPAP Setting	5 cm of H ₂ O	Nadir	9.04	3.17	9.62	4.43	10.49	4.74	10.21	5.28
		Mid-point of inspiration	9.59	4.33	8.79	3.95	9.07	4.12	9.83	4.84
		Zenith	10.98	4.33	9.71	4.01	10.09	5.07	9.76	4.08
		Mid-point of exhalation	10.52	4.21	10.38	3.17	9.83	5.14	9.62	3.73
		Nadir	8.52	3.20	11.13	5.22	11.78	6.74	10.43	4.68
		Mid-point of inspiration	10.49	6.13	10.07	5.08	10.43	5.85	10.39	4.41
	10 cm of H ₂ O	Zenith	9.83	4.35	10.41	4.31	10.88	4.61	11.26	4.74
		Mid-point of exhalation	9.75	3.59	9.52	3.94	9.96	4.27	11.31	4.92
		Nadir	9.83	4.18	10.50	4.98	11.91	5.88	10.42	4.38
	15 cm of H ₂ O	Mid-point of inspiration	9.07	4.29	11.23	3.95	9.19	4.56	9.76	4.54
		Zenith	9.48	4.79	10.26	4.12	9.24	4.32	8.53	4.34
		Mid-point of exhalation	9.67	3.66	10.64	4.53	9.51	5.00	9.69	3.81

All measurements are listed in millimeters.