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Changes in sleep and airway variables in patients with obstructive sleep apnea after mandibular advancement splint treatment

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Introduction: Obstructive sleep apnea (OSA) is an extensive public health problem that imposes considerable morbidity. Mandibular advancement splint (MAS) therapy is a well tolerated treatment, but success rates are difficult to predict. Our objective was to investigate the relationship of oropharyngeal airway dimensions, sleep characteristics, patient biometrics, and treatment response within an OSA patient sample. **Methods:** Records of 33 adults were assessed retrospectively with the use of Dolphin 3D and Image J to measure the airway on pretreatment supine cone-beam computed tomography images and derived lateral cephalograms. The patients used Somnodent (Somnomed; Crows Nest, Australia) MAS appliances, which were titrated over 6-8 weeks. Appliance titration measurements and pre- and posttreatment polysomnograms were assessed. Respiratory disturbance index (RDI), absolute and percentage changes in RDI, non–rapid eye movement (NREM) RDI, rapid eye movement (REM) RDI, supine and nonsupine NREM and REM RDI, and minimal blood-oxygen saturation variables were evaluated. The associations of measurements from 2D and 3D minimal anterior-posterior linear distance and 3D airway variables with MAS treatment response were estimated. **Results and Conclusions:** Combined effects of baseline total airway volume, body mass index, neck circumference, location of minimal cross sectional area, and OSA severity were associated with treatment response. Patients with higher initial OSA and more superiorly located airway constriction showed enhanced treatment response to MAS therapy. Airway constriction due to maxillofacial disproportions rather than soft tissue obstruction also showed better treatment response. No significant relationships were found in lateral cephalogram measurements. (Am J Orthod Dentofacial Orthop 2019;155:498-508)

Obstructive sleep apnea (OSA) is an extensive public health problem that imposes considerable morbidity. Although continuous positive airway pressure (CPAP) is the criterion standard of treatment, it often produces suboptimal results because of variable patient adherence.[1] The American Academy of Dental Sleep Medicine (AADSM)[2] has recommended oral appliance therapy for mild-moderate OSA, but the understanding of underlying mechanisms that offer treatment through oral appliances is poorly understood.[3]

Orofacial anatomy is an important factor to consider. OSA patients are thought to have a significantly larger tongue, creating an anatomic imbalance of the upper airway.[4-6] According to Tsuiki et al,[7] a more caudal and larger tongue correlates with increased lower face dimensions, significantly longer mandibular plane to hyoid bone (MP-H) distance, and excessive soft tissue. A reduction in diaphragm and upper airway muscle activity during the transition from awake to non–rapid eye movement (NREM) sleep also leads to a 2- to 5-fold increase in upper airway resistance. Apneic events are more

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prevalent and severe during rapid eye movement (REM) sleep than during NREM sleep.[8]

Sleep position also affects apneic status as a result of gravity changing soft tissue draping in the airway. Lee et al[9] showed that supine respiratory disturbance index (RDI) was 2 times greater than nonsupine RDI in 50%-70% of OSA patients. When controlling for REM- versus NREM-related OSA events, Oksenberg et al[10] showed that RDI REM supine was higher than RDI NREM supine, followed by RDI REM lateral and consequently RDI NREM lateral. In addition, minimal blood-oxygen saturation (SaO_2) levels were lower in the supine compared with lateral sleep position in both REM-related and NREM-related OSA patients.

It is also important to consider airway anatomy to better understand dynamics and possible structural predisposition to airway collapse during OSA events. Cone-beam computed tomography (CBCT) has become well accepted in orofacial diagnosis and treatment planning owing to lower effective radiation dose, lower costs, easier access, and shorter acquisition times[11] than conventional computed tomographic scans. According to Makdissi,[12] CBCT has become increasingly popular in clinical orthodontic diagnostics owing to its simplicity and high-quality imaging. Guijarro-Martínez and Swennen[13] highlight major obstacles with CBCT upper airway analysis, which include respiration phase, tongue position and mandibular morphology, and 3-dimensional (3D) anatomic definitions. Most studies address the volumetric changes in the airway but lack follow-up sleep evaluations to assess clinical OSA status. In addition, it is important to note that volume of the pharyngeal airway itself does not predict OSA severity.[14] This is likely due to the dynamic nature of the airway. When comparing the oropharynx in OSA and non-OSA patients, 2 studies showed a statistically significant smaller minimal cross-sectional area (CSA) in OSA patients.[15] Tikku et al[5] also confirmed these findings. Ogawa et al[16] showed significant differences in total airway volume and AP diameter of the smallest CSA. Tikku et al[5] found that the nasopharyngeal to oropharyngeal angle became more obtuse in OSA patients, which increases the airway and consequently airflow resistance. In terms of assessing orofacial volumetric skeletal measurements, Bruwier et al[6] concluded that CBCT is an efficient means to measure bony volumes and showed that OSA patients have a narrower maxilla-palatine core volume when adjusted for age, sex, height, and body mass index (BMI). Furthermore, they suggested that this anatomic difference may be a consequence of oral breathing patterns adopted in childhood.

Evaluating airway anatomic changes while undergoing OSA treatment may offer explanations to OSA therapy mechanisms as well as causes of this multifactorial disease. Mandibular advancement splint (MAS) therapy has been accepted for use in mild-moderate OSA patients. However, there are few studies that assess changes in the airway with the use of MAS therapy in combination with clinical outcomes. Chan et al[3] performed a supine magnetic resonance imaging evaluation of the upper airway with and without MAS. MAS therapy increased the upper airway volume particularly at the velopharynx in the lateral dimension, which did not occur in the nonresponders.

Abi-Ramia et al[17] demonstrated increases in airway volume after 7 months of appliance therapy of 1.1 ± 0.2 cm^3 ($15 \pm 6\%$). However, these measurements were not validated clinically, because change in OSA status was not measured. Haskell et al[18] similarly saw increases in airway volume. The largest changes occurred in the lateral rather than AP dimension, particularly at the level of the C2 vertebra; the airway acquired a more elliptical cross-sectional shape.[18] Shete and Bhad[19] had similar findings in patients in their study, and recognized that increases in airway volume corresponded with increased SaO_2. Suleiman et al[20] also found that increased vertical dimensions of the airway, in particular the posterior nasal spine distance to anteroinferior aspect of the second cervical vertebra (PNS-C2), was associated with increased likelihood of exhibiting OSA after adjusting for BMI and neck circumference. They assumed that this hard tissue reference would indirectly reflect the length of the soft tissue airway.

The present study aimed to identify treatment response based on patients' baseline craniofacial and biometric characteristics with the use of raw data from a published OSA study.[21] We hypothesized that oropharyngeal cross-sectional and 3D airway variables are associated with MAS treatment response in terms of change in RDI and change in minimal SaO_2. In addition, we hypothesized that the association between oropharyngeal cross-sectional and 3D airway variables with MAS treatment response depends on sleep position, sleep state, appliance advancement, initial OSA severity, BMI, age, and neck circumference. Finally, these findings were compared with analyses using 2-dimensional (2D) measurements from lateral cephalograms derived from the same CBCT images to assess whether there is any association between 2D and 3D data.

MATERIAL AND METHODS

Thirty-three records of adult subjects available for this study were obtained from a prospective clinical study published by Ma et al in 2013.[21] These patients

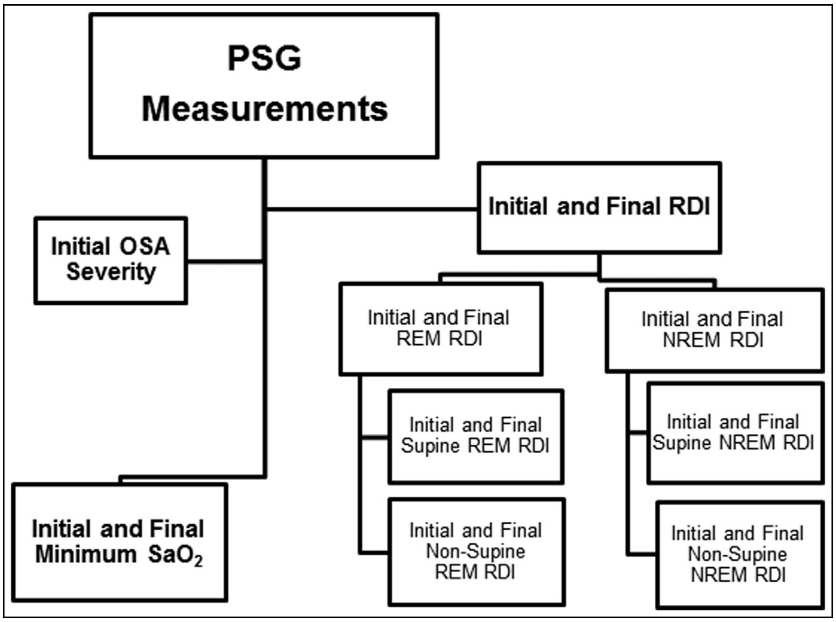

Fig 1. Stratification of PSG variables.

wore MAS appliances for 4-8 weeks. The final records were taken 4-8 weeks after the pretreatment records were taken. No supplemental devices, therapies, or medications for breathing rehabilitation were used. If they underwent a rhinoplasty, they were excluded from the final subject group.[21] Five subjects were excluded from the original 38 who completed the 2013 study because of inadequate compliance (n = 1), interceptive medical treatment before follow-up polysomnography (PSG; n = 1), poor-quality CBCT (n = 2), and missing PSG data (n = 1). The data used were deidentified coded CBCT scans taken in supine position (Newtom 3G; QR, Verona, Italy), pre- and post-MAS treatment PSG data, patient demographics, and appliance titration. The Office for the Protection of Research Subjects at the University of Illinois, Chicago, concluded that our protocol was Institutional Review Board exempt, because the research activity did not involve any identifiers or human subjects. In addition to the inclusion and exclusion criteria published by Ma et al,[21] the presence of the C4 vertebra on CBCT was also required.

Deidentified initial and final PSGs were obtained. All PSGs were scored according to standard criteria.[22] Apneas were defined by a cession of airflow that lasted ≥10 seconds in association with oxygen desaturation of ≥3% or an arousal.[23] Hypopneas were defined by a reduction in the amplitude of airflow, as assessed by means of nasal pressure or thoracoabdominal wall movement of >50% of baseline for >10 seconds in association with oxygen desaturation. Patients were categorized by initial OSA severity as mild (RDI of 5-15/h), moderate (RDI of 15-30/h), or severe (RDI >30/h), according to the method of Flemons et al.[24] Treatment response was assessed by the absolute change in RDI and percentage change in RDI. The absolute and percentage changes in RDI were further categorized by sleep phase as well as sleep position. Because some of the sleep centers did not describe RDI in terms of supine or nonsupine without phasic data embedded in the PSG report, supine RDI and nonsupine RDI could not be assessed in this study. Finally, treatment response was assessed by measuring the change in minimal SaO_2. Figure 1 illustrates the stratification of the PSG variables.

Volumetric upper airway measurements were performed with the use of Dolphin 3D Sinus/Airway Analysis (Chatsworth, Calif) as previously published.[3,11,19,22] All airway measurements were made by 1 study coinvestigator, who was blinded to the subject's apneic status and was assessed for reliability by repeated measurements for n = 10 after 1 week under the same conditions. Interreliability was also assessed for n = 10 by a second study coinvestigator.

Figure 2 illustrates the different CBCT-derived cross-sectional and 3D measurements. Skull images were oriented parallel to the Frankfurt Horizontal in the sagittal view, similarly to the methods of Suleiman et al.[20] CBCT scans were further converted into lateral cephalograms. The upper airway was divided into 3 segments (Fig 3),

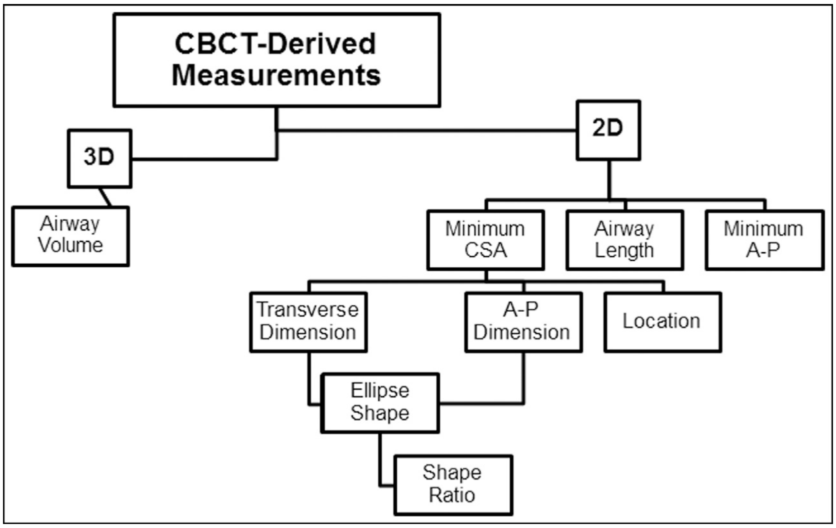

Fig 2. CBCT measurements.

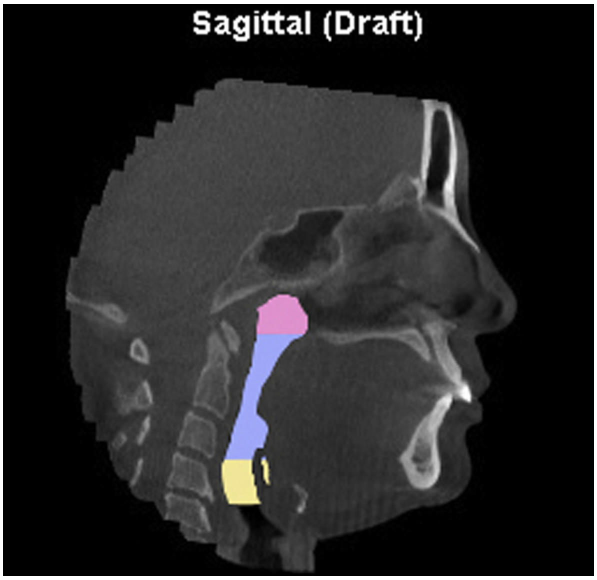

Fig 3. Airway segments: nasopharynx (pink), oropharynx (blue), and hypopharynx (yellow). Image rendered with the use of Dolphin 3D imaging software.

adapted from the methods of Guijarro-Martínez and Swennen,[11] with airway sensitivity based on percentage of airway selected. Noise in the airway slices was minimized while airway volume was selected.

Cross-sectional evaluation of the 3 airway segments (Fig 4) identified the location and value of minimal axial cross-sectional area (CSA), conforming to the methods of Mattos et al.[25] At the level of the minimal CSA, the maximal transverse and anteroposterior (AP) linear dimensions were recorded to assess the shape of the ellipse. The shape ratio was defined by dividing the AP and transverse linear dimensions. In addition, summations of the total pharyngeal airway volume and total length of the segments in the vertical dimension were calculated. Airway volume, minimal CSA, and the AP and transverse linear dimensions of the minimal CSA were measured in the axial view (Fig 5). Paralleling the methods of Suleiman et al,[20] vertical measurements were assessed in the sagittal dimension and used reproducible bony references PNS and the anteroinferior cervical vertebral surfaces as vertical landmarks.

A separate exercise was conducted to compare information derived from 2D and 3D data. Lateral cephalograms derived from the same CBCT images were produced and Image J software (National Institutes of Health, Bethesda, Md) was used to calibrate and measure the minimal AP linear distance of the airway. This linear value as well as its airway region location were recorded.

Based only on the significant coefficients of correlation, multiple linear regressions were conducted to investigate the relationships of MAS treatment response variables. Statistical significance was set at 0.05. IBM SPSS Statistics for Windows (version 22.0; IBM Corp, Armonk NY) was used for data analyses.

RESULTS

Coefficient of correlation as an intraclass correlation (ICC) for both intra- and interrater reliabilities were investigated to assess whether the degrees of correlation on the method were high ($r > 0.80$), indicating a good degree of test-retest reliability from the investigators. The Pearson correlation for intrarater reliability showed

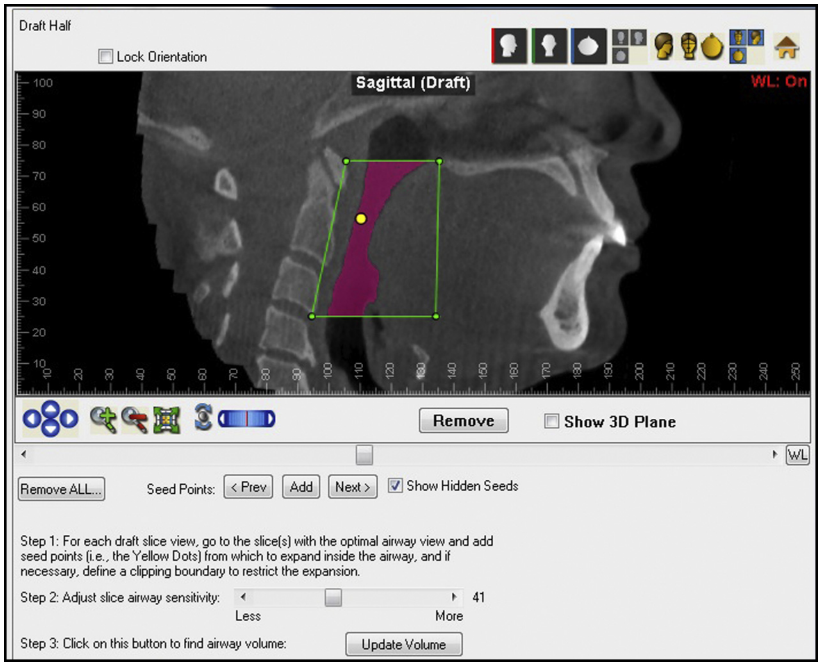

Fig 4. Clipping boundary, seed point, and sliding bar for sensitivity adjustment. Image rendered with the use of Dolphin software.

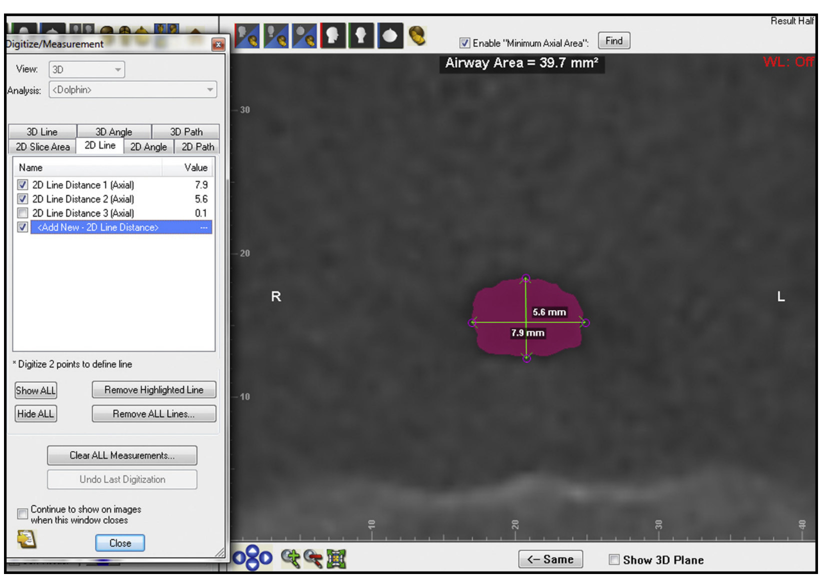

Fig 5. Minimal cross-sectional area and anteroposterior and transverse linear measurements. Imaged rendered with the use of Dolphin software.

a degree of correlation of 0.959 and mean difference, median, and range values (mms) between the test and retest of 0.7340, 0.5625, and 0.1750-2.0940, respectively. The Pearson correlation for interrater reliability showed a degree of correlation of 0.963 and mean difference, median, and range values (mms), between the test and retest of 0.7261, 0.4510, and 0.089-2.3890, respectively.

Descriptive statistics were computed for all 2D and 3D variables, (Table 1).

Table I. Descriptive statistics

Variable	n	Min	Max	Mean	SD
2D (from CBCT-derived lateral cephalogram)					
Min AP linear distance (mm)	33	2.07	12.05	5.46	2.46
3D					
Min CSA-AP linear distance (mm)	33	2.60	16.90	8.15	3.63
Shape ratio	33	0.15	2.93	0.61	0.46
Total airway length (mm)	33	78.80	105.10	91.56	7.19
Total airway volume (mm^3)	33	10,507.70	32,868.20	21,660.65	6048.28
Total appliance advancement (mm)	33	5.30	16.00	9.96	2.76
Age (y)	33	28.70	67.30	51.11	9.89
Neck circumference (cm)	33	34.00	48.00	39.52	4.07
Initial BMI	33	20.82	38.42	27.98	4.54
Change in RDI	33	−62.60	4.80	−16.54	14.27
% change RDI	33	−91.79	31.17	−58.06	29.79
Change NREM RDI	33	−69.00	6.10	−16.38	15.21
% change NREM RDI	33	−95.27	84.72	−61.75	38.80
Change REM RDI	32	−54.50	20.00	−15.16	19.09
% change REM RDI	31	−96.75	142.86	−31.02	53.90
Change S NREM RDI	28	−83.60	62.00	−20.59	27.57
% change S NREM RDI	28	−100.00	413.33	−39.74	100.63
Change NS NREM RDI	31	−72.80	2.80	−12.03	17.31
% change NS NREM RDI	26	−100.00	375.00	−56.91	93.45
Change S REM RDI	25	−104.60	37.50	−28.39	33.42
% change S REM RDI	19	−97.70	74.29	−51.32	45.73
Change NS REM RDI	26	−45.90	33.20	−11.10	18.40
% change NS REM RDI	21	−100.00	325.00	−23.18	104.32
Change min SaO_2 (%)	33	−8	37	4.33	8.48

Of the 33 participants in this study, 23 (69.7%) were male and 10 (30.3%) female. There were 10 (30.3%), 15 (45.5%), and 8 (24.2%) patients initially diagnosed with mild, moderate, and severe OSA, respectively. When assessing the 3D airway in 22 patients (66.7%), the minimal CSA was located within the oropharynx, the other locations were distributed as follows: 5 patients' minimal CSAs were found in the nasopharynx (15.2%), and 6 (18.2%) were found in the hypopharynx location.

Table II. Distribution, n (%)

Variable	n	%
Gender		
Female	10	30.3
Male	23	69.7
Total	33	100.0
Response status		
Complete	10	30.3
Partial	11	33.3
Failure	12	36.4
Total	33	100.0
Shape		
1 (transv > AP)	32	97.0
2 (AP > transv)	1	3.0
Total	33	100.0
Location of minimal AP CSA in 2D		
Nasopharynx	0	0
Oropharynx	31	93.9
Hypopharynx	2	6.1
Total	33	100.0
Location of minimal CSA in 3D		
Nasopharynx	5	15.2
Oropharynx	22	66.7
Hypopharynx	6	18.2
Total	33	100.0
Initial OSA severity		
Mild	10	30.3
Moderate	15	45.5
Severe	8	24.2
Total	33	100.0

Furthermore, the CSA ellipse shape illustrated a wider transverse dimension than AP dimension (Table II).

Statistically significant associations were found between some of the MAS treatment response and biometric variables, such as: change in RDI, change in non-REM RDI, change in supine non-REM RDI, change in nonsupine non-REM RDI, minimal SaO_2, total volume, initial neck circumference, initial BMI, and age. The range of these coefficients of correlation (r) was −0.74 to 0.47, and P values ranged from 0.046 to <0.001, as presented in Table III.

As presented in Table IV, most of the associations between the study variables did not indicate statistically significant associations, with the coefficients of correlation (r) and significances (P) ranging from −0.510 to 0.471 and 0.003 to 0.966, respectively.

Multiple regression models are presented in Table V. Initial OSA severity, total airway volume, initial neck circumference, initial BMI, and location of minimal CSA were identified as variables showing a good relationship with some of the PSG variables in the study. The multivariate regression results indicated that only change in supine non-REM RDI may explain the combination of total airway volume, initial BMI, and neck circumference (Table V).

Table III. Significant bivariate treatment response associations

Bivariate correlation	*Coefficient of correlation (R)*	P*
Change NS NREM RDI and Minimal CSA AP	0.37	0.039
Change NS NREM RDI and Initial neck circumference	−0.50	0.004
Change NS NREM RDI and Initial BMI	−0.51	0.003
Change NS NREM RDI and Initial OSA severity	−0.53	0.002
% change NS NREM RDI and Location of minimal CSA	0.44	0.026
% change NS NREM RDI and Total appliance advancement	0.45	0.023
Change S NREM RDI and Total volume	0.42	0.028
Change S NREM RDI and Initial OSA severity	−0.49	0.008
Change S REM RDI and Total volume	0.40	0.046
Change in RDI and Initial OSA severity	−0.74	<0.001
Change NREM RDI and Initial OSA severity	−0.68	<0.001
% change S NREM RDI and Initial BMI	0.47	0.011

NS, Nonsupine; *S*, supine.
*Statistically significant ($P < 0.05$).

DISCUSSION

The aim of this study was to identify cross-sectional and 3D measurements of the airway, along with the amount of appliance advancement, initial OSA severity, BMI, neck circumference, age, and sleep characteristics that may explain or associate with MAS treatment response. Most studies that predict MAS therapeutic response derived cross-sectional assessments of the airway based on lateral cephalometry in an upright cephalostat. Many 3D studies evaluate airway changes with treatment but lack a follow-up sleep study to assess the clinical outcome of MAS treatment. The present study combined customary measures as well as contemporary cross-sectional and 3D measurements as they relate to treatment response.

The sample size to detect a correlation of ±0.5 with power 0.8 (alpha 0.05) based on Cohen method is ∼28 subjects, and this study had 33 subjects, thus having more than adequate sample size. The majority of participants (75.8%) in the study were initially diagnosed with mild-moderate OSA, which is a representative sample of the recommended MAS treatment population for OSA according to the AADSM.[2] The Newtom CBCT is ideal for OSA studies because it is the only CBCT machine that assesses patients in the supine position,[13] which better estimates airway anatomy while asleep.[26-28]

Based on the present results, measuring total airway volume may aid in assessing airway anatomy in terms of the site as well as relative amount of constriction. OSA patients exhibit an overall decrease in airway volume as well as a decreased AP dimension at the location of the minimal CSA.[12] Similarly, the upper airway in OSA patients has been shown to be more elliptical than in non-OSA patients,[13] which was a consistent feature with our sample: 32 of the 33 patients exhibited a wider ellipse in the transverse dimension. Suleiman et al[20] discussed the inconsistencies of cross-sectional airway shape evaluation due to positional changes or anatomic shifts as a consequence of aging or increased BMI. They refer to the conclusions made by Shigeta et al[29] that axial slices inferior to the C2 vertebra represent a constant anatomic location that does not change position with time.

Percentage change in supine non-REM RDI was associated with initial BMI and total airway volume. These relationships indicate that there may be greater treatment capacity for patients with a lower initial BMI, more superiorly located minimal CSA, and less mandibular protrusion. Hoekema et al[30] also found that smaller BMI values were predictive of RDI <5 with MAS treatment.

Changes in supine non-REM RDI and SREM RDI were both associated with initial total airway volume. Although change in supine RDI was not directly documented in the PSG reports, one may infer from the above correlations that change in supine RDI was correlated with total airway volume because this relationship was not present in nonsupine sleep. The association suggests that, while in the supine sleep position, larger initial airway volume measured in the supine posture may reflect decreased therapeutic potential for mandibular advancement therapy. This interpretation is plausible, because individuals with relatively normal airway volume at baseline would not be expected to benefit as much from mandibular repositioning.

There was also a positive correlation for initial BMI and the percentage change in supine non-REM RDI. Therefore, when controlling for initial OSA severity, in the supine position patients with higher BMIs had decreased improvement in treatment response. These results suggest that for any given initial OSA severity, individuals with a higher BMI are likely to show less improvement with MAS treatment. This is reasonable because BMI correlates with parapharyngeal fat depositions, which may impair the improvement that is expected from MAS therapy. The MAS therapy, by design, advances the tongue, and alleviates this site of obstruction. When controlling for initial OSA severity, patients with increased BMI sleeping in the supine position may not be able to overcome the anatomic burden as effectively as individuals with lower BMI. As a result, MAS therapy may not reach its potential effectiveness.

Table IV. Correlations (*r*) of polysomnogram variables with biometric study variables

	Sleep characteristics and subject biometrics															
Variable	*RDI*	*% RDI*	*REM RDI*	*% REM RDI*	*NREM RDI*	*% NREM RDI*	*S REM RDI*	*% S REM RDI*	*NS REM RDI*	*% NS REM RDI*	*S NREM RDI*	*% S NREM RDI*	*NS NREM RDI*	*% NS NREM RDI*	*Min SaO_2*	*% Min SaO_2*
Minimun AP linear distance																
r	0.168	−0.008	0.064	0.067	0.156	−0.023	−0.018	−0.045	0.033	−0.067	0.108	−0.111	0.347	−0.033	0.021	0.006
*P**	0.349	0.966	0.728	0.719	0.387	0.899	0.932	0.843	0.872	0.772	0.585	0.574	0.055	0.872	0.909	0.974
n	33	33	32	31	33	33	25	22	26	21	28	28	31	26	33	33
Neck circumference																
r	−0.272	0.092	−0.075	0.134	−0.181	0.247	−0.140	-0.053	-0.260	−0.094	−0.183	0.304	−0.499	−0.138	0.136	0.214
*P**	0.126	0.612	0.685	0.473	0.314	0.166	0.504	0.815	0.200	0.684	0.350	0.116	0.004	0.502	0.452	0.231
n	33	33	32	31	33	33	25	22	26	21	28	28	31	26	33	33
BMI initial																
r	−0.209	0.087	−0.117	0.022	−0.152	0.258	−0.180	−0.176	−0.357	−0.089	0.044	0.471	−0.510	−0.332	0.027	0.096
*P**	0.243	0.631	0.523	0.906	0.398	0.148	0.390	0.432	0.074	0.700	0.823	0.011	0.003	0.098	0.883	0.596
n	33	33	32	31	33	33	25	22	26	21	28	28	31	26	33	33
Total airway volume																
r	0.173	0.185	0.059	0.029	0.109	0.088	0.403	0.083	0.228	0.231	0.415	0.112	0.288	−0.019	0.217	0.177
*P**	0.336	0.302	0.750	0.877	0.546	0.625	0.046	0.714	0.263	0.313	0.028	0.572	0.116	0.928	0.225	0.325
n	33	33	32	31	33	33	25	22	26	21	28	28	31	26	33	33

*Statistically significant at $P < 0.05$.

Table V. Multivariate regression model analyses

Variables		Model summary			ANOVA		Coefficients		
Dependents	*Independents*	*R*	*Adj. R^2*	*df*	*F*	P*	*Beta*	*t*	P*
Change in RDI	Total volume	0.74	0.52	2, 30	18.398	<0.001	0.087	0.708	0.484
	Initial OSA severity						−0.727	−5.899	<0.001
Change in S NREM RDI	Total volume	0.62	0.39	3, 24	5.013	0.008	0.563	3.106	0.005
	Initial BMI						0.816	2.877	0.008
	Neck circ.						−0.630	−2.335	0.028
% change in S NREM RDI	Total volume	0.62	0.30	3,24	4.921	0.008	0.429	2.355	0.027
	Initial BMI						0.849	2.985	0.006
	Neck circ.						−0.220	−0.812	0.425
%change in S NREM RDI	Total volume	0.69	0.39	4, 23	5.294	0.004	0.484	2.581	0.017
	Initial BMI						0.796	4.278	<0.001
	Initial OSA severity						−0.236	−1.518	0.143
	Location of min. CSA						0.253	1.501	0.147

*Statistically significant at $P < 0.05$.

Initial OSA severity is used as a widespread clinical indicator of association with treatment response,[27] which is reinforced in many of the regression analysis models because it was a significant contributor to the relationship. In the models explaining change in supine non-REM RDI as well as percentage change in supine non-REM RDI, both initial BMI and total airway volume from CBCT images were 2 significant associations.

In the multivariate models, total airway volume contributed to regressions in change and percentage change in supine non-REM RDI in addition to total RDI. Both the total volume and initial BMI had a statistically significant contribution to the 2 regressions involving change in supine non-REM RDI and percentage change in supine non-REM RDI. This suggests that increases in initial BMI and airway volume account for decreases in absolute and relative treatment response potential in terms of supine non-REM RDI. As previously mentioned, Hoekema et al[30] saw that smaller BMI values were predictive of RDI <5 with MAS treatment. Therefore, patients with an initially smaller BMI and airway volume may have enhanced treatment outcome potential with MAS treatment when assessed in the supine position. This combination of features may help to explain MAS therapeutic mechanisms. We propose that mandibular advancement therapy will have a proportionately diminishing response based on initial airway volume and BMI. This may be due to a higher absolute potential to increase the airway dimension by means of MAS therapy with an initially smaller airway volume, especially if coupled with a lower BMI and consequently decreased soft tissue obstructions. This suggests that a poorly positioned (ie, retrognathic) mandible may account for decreased airway volume. A well positioned jaw may be associated with an optimized airway volume and minimal CSA and may have reduced therapeutic potential. A follow-up CBCT comparative assessment of the airway with the MAS appliance in place would help to validate this conjecture.

Ferguson et al[31] showed that the amount of MAS advancement is associated with treatment response. This implies that the mechanisms of MAS and orofacial anatomy are intertwined, because tongue muscles are repositioned more anteriorly.[3] Based on the MAS appliance mechanism, our results reinforce that MAS treatment is useful for treating airway constriction that is located in the more superior regions of the airway.

Because no scientific research study is perfect, this study has its limitations. First, participants elected MAS treatment over CPAP, allowing for potential sample bias. Next, more than 1 sleep center was used for initial and follow-up PSG, which may lead to decreased standardization in technique or differences in manual scoring, an example of which is the lack of RDI based on sleep position alone, without sleep phase. Also, a posttitration CBCT would provide information to better understand MAS treatment mechanics and restrictions, but requiring more radiation exposure for the patient. There were limitations with both the software and image quality of the CBCTs. The Newtom 3G is an older machine, possibly accounting for the grainy quality and lack in sharp soft tissue detail in the CBCTs. Consequently, defining the airway density in Dolphin3D was challenging, particularly in the nasopharynx. The advantage of the Newtom, as mentioned above, is that the images were taken with the patient in supine position, thus more closely replicating sleep position. In future studies, it would be useful to develop a standardized airway analysis protocol with better-quality CBCTs. Future studies with a non-OSA group as a control could be useful in understanding these relationships. However, it may be difficult to justify obtaining CBCT studies on a control patient population.

CONCLUSIONS

Using data from CBCT images taken in supine position, we determined that oropharyngeal 3D cross-sectional and airway variables including total volume, initial BMI, and location and value of the minimal CSA AP linear distance were associated with treatment response in terms of change and percentage change in RDI. Significant relationships were also found when RDI was stratified based on sleep phase, sleep position, and initial OSA severity. There were also positive correlations between appliance activation and initial biometrics with treatment response variables. Although statistically significant, the above-mentioned findings showed mild ranges of association.

Multivariate models explained treatment response, wherein initial OSA severity was associated in 2 models, and the combination of total airway volume and initial BMI was additionally associated in 3 models.

No significant relationships could be demonstrated with the use of 2D measurements from lateral cephalograms derived from the same CBCT images.

Patients with higher initial OSA severity may have increased treatment response to MAS therapy. Decreases in airway volume due to skeletal rather than soft tissue obstruction may also be better MAS treatment responders. Because the MAS targets the upper airway, more inferiorly located airway constriction requires increases in splint titration to achieve a desirable clinical outcome, but that ultimately decreases treatment response potential. Future studies are indicated to further explore these relationships.

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