

# Mandibular advancement appliance effects on obstructive sleep apnoea: a prospective three-dimensional computed tomography study

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**Background:** The aim of this study was to determine the effects of an elastic mandibular advancement (EMA) appliance on upper airway dimensions, most constricted area (MCA) of the airway, and snoring in a sample of obstructive sleep apnoea (OSA) patients of varying severity.

**Methods:** Forty-seven male subjects were classified into two groups comprising 12 controls and 35 suffering from OSA. The OSA group was further divided into three subgroups based on their apnoea-hypopnoea index (AHI). All subjects completed an Epworth questionnaire and an overnight home sleep test before (T1) and at the end of the study (T2). OSA subjects were provided with a custom-made EMA appliance. Cone beam computed tomographic images were obtained for each subject at T1 and T2. Airway parameters were measured and summarised by grouping. The differences in the measurements T1 – T2 were compared using repeated measures analysis of variance (rmANOVA) and  $p \leq 0.05$  was considered statistically significant.

**Results:** The use of the EMA produced a statistically significant increase in the nasopharyngeal, oropharyngeal, MCA, and total airway volume. Although sleep apnoea patients reported a reduction in snoring time, particularly in moderate and severe OSA groups, the level of improvement was not statistically significant. Patients with moderate and severe OSA demonstrated significant decreases in their AHI and Epworth scores.

**Conclusion:** EMA is effective in reducing OSA severity and changing airway dimensions in OSA patients, specifically in the moderate and severe cases.

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## Introduction

Obstructive sleep apnoea (OSA) is a common medical condition that is associated with adverse health consequences. It is characterised by repetitive, partial, or complete obstruction of the upper airway during sleep despite simultaneous respiratory efforts. OSA affects 2% to 4% of middle-aged adults and up to 28% of the population older than 65 years.<sup>1-4</sup> Patients with OSA suffer from snoring, nocturnal awakenings, excessive day-time sleepiness, memory lapses, difficulty in concentrating, depression, irritability, xerostomia,

gasping for breath at night, and witnessed apnoeas. OSA has also been linked to several cardiovascular diseases and hypertension.<sup>2,5-8</sup>

The key diagnostic tool used to describe the presence and severity of OSA is the apnoea-hypopnoea index (AHI), which is usually derived from polysomnography or a portable monitoring device such as the home Watermark Medical™ Apnoea Risk Evaluation System (AREST™) home sleep test, and is calculated based on the total number of apnoea and hypopnoea episodes per hour of sleep. The presence of OSA is

defined by an AHI of five or more events per hour in association with symptoms. The severity of OSA is judged by a composite of the severity of symptoms and the polysomnography/portable monitoring findings.<sup>7-10</sup>

Craniofacial abnormalities including micrognathia, retrognathia, and narrowing of the upper airway have been reported to be associated with OSA.<sup>11</sup> There is also strong evidence that morbid obesity, increased body mass index (BMI) calculated as weight divided by the square of height, large neck circumference, and greater waist-to-hip ratio are considered risk or even causal factors in OSA. Other suspected risk factors include genetics, smoking, menopause, alcohol use before sleep, and night-time nasal congestion.<sup>3,12-15</sup>

Treatment options range from general measures such as weight loss, avoidance of sleep in the supine position, and nasal continuous positive airway pressure (CPAP) to the more invasive surgical approaches, or the use of oral appliances. Oral appliances could be considered a potentially useful option especially for patients with mild-to-moderate disease and patients who do not tolerate CPAP machines, who decline or are unsuccessfully treated by surgery.<sup>9,15-18</sup> Oral appliances relieve airway collapse during sleep by holding the mandible in a more forward position and so modify the position of the tongue and the pharyngeal structures.<sup>16,18</sup> The clinical effects of a mandibular advancement appliance on the severity of OSA, widening the most constricted area (MCA) of the airway and improving snoring remain uncertain and require further validation. The objectives of the present study were to evaluate the effects of using an elastic mandibular advancement (EMA) appliance on upper airway dimensions and the MCA of airway as well as on improving snoring symptoms in a group of sleep apnoea patients with varying OSA severity.

## Materials and methods

Forty-seven subjects were recruited from the Indiana University School of Medicine Sleep Clinic and the Indiana University School of Dentistry. Inclusion criteria identified Caucasians, males whose age ranged from 27–65 years and who underwent polysomnography. All were diagnosed by a sleep medicine physician as having AHI > 5 for the OSA group and < 5 for the control group. The exclusion criteria identified subjects who had mandibular

protrusion (Class III malocclusion), inadequate teeth for appliance retention, were unable to move the mandible forward, had major dental and/or periodontal disease or recent surgery, a history of temporo-mandibular disorders, a history of heart failure, significant medical or renal disease, pharyngeal and/or nasal disease, and subjects on medications that depress respiration. The study was approved by the Indiana University Institutional Review Board and written informed consent was obtained from each subject.

A sleep medicine physician examined and diagnosed the subjects as having or not having OSA. Patient neck size, height and weight were measured and body mass index (BMI) calculated. Subjective sleepiness was assessed by the Epworth Sleepiness Scale (ESS). Following instruction, all subjects were given the AREST™ (Watermark Medical®, FL, USA) home sleep test device to monitor their overnight sleep apnoea state. The Watermark device provided data regarding AHI, the respiratory disturbance index (RDI) and the percentage snoring time. A diary to record mandibular appliance wear was provided to the OSA patients to assess compliance, adverse effects, the level of discomfort and snoring (as indicated by sleeping partners).

The subjects were divided into four groups based on the severity of the disease according to their AHI level. Group 1 (N=12): control subjects with AHI <5, group 2 (N=12): mild OSA subjects with AHI = >5 – <15, group 3 (N=12): moderate OSA subjects with AHI >15 – <30, and group 4 (N=11): severe OSA subjects with AHI = 30 or greater. Following an orthodontic examination and impressions, OSA subjects were provided with an EMA appliance comprised of two plastic trays custom moulded to the patient's maxillary and mandibular arches to utilise the dental undercut areas for retention (Figure 1). Mandibular advancement was achieved by providing the patient with same size elastic straps (21 mm) to hold the mandible 4 mm in a forward direction while the same vertical opening was adjusted using bite planes. The forward position of the mandible was achieved in all patients without causing discomfort and the patients were instructed to wear the EMA appliance every night for two months.

The iCAT CBCT machine (Imaging Sciences International, PA, USA) and 3dMD imaging system (3dMD, GA, USA) were used to scan each subject



Figure 1. EMA Appliance.

twice, with two months' interval between the initial (T1) and the final visit (T2). The scans were acquired with the EMA in place for the OSA group and without the EMA for the control group. The CBCT scans had a voxel size of 0.3 mm and were exposed for 8.9 seconds. A 12-inch receptor field was applied to include the cervical vertebrae 4 (CV4) to the cranial base and the soft-tissue contours of the face. The CBCT images were uploaded into Dolphin 3D software (Dolphin Imaging & Management System, CA, USA) and digital 3D models of the airway and the surrounding craniofacial structures were reconstructed. The airway volume, MCA, and selected craniofacial parameters were evaluated using the same software. The 3D volumetric images were oriented for each individual so that the midsagittal plane was aligned to the skeletal midline (N-ANS-Ba) of the face, the axial plane was aligned to the level of FH plane (Po-Or), and the coronal plane was aligned to the level of the furcation point of the right maxillary first molar. The boundaries of each airway segment (nasal cavity, nasopharynx, oropharynx, hypopharynx and the maxillary sinuses) and the MCA, as well as the definition of the craniofacial parameters used in the study, are described in Tables I and II, and Figures 2–6.

### Statistical analysis

To assess the intra-rater reliability, landmarks were identified and the airway volume as well as the selected parameters were measured twice by the same investigator following an interval of two weeks on 10 selected CBCT scans. Intra-class correlation coefficients and Bland-Altman plots were used to

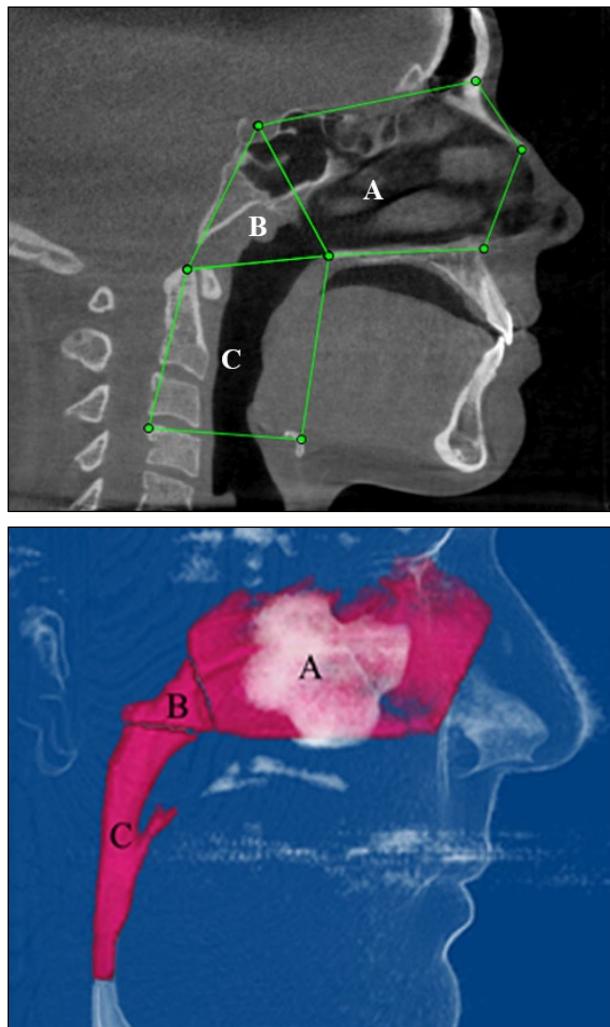


Figure 2. Airway segments; (A) nasal cavity; (B) nasopharynx; (C) oropharynx.

determine reliability. The CBCT volumetric and linear measurements of the airway as well as the size of the MCA were summarised (mean  $\pm$  standard deviation) by grouping. The differences in the T1 and T2 measurements were compared using repeated measures analysis of variance (rmANOVA) to analyse the effects of the appliance in each group. The statistical significance level was set at  $p \leq 0.05$ .

### Results

The ICC values showed high intra-rater reliability ( $> 0.90$ ) for all parameters. Statistically significant decreases were detected between T2 and T1 in the Epworth score for all test groups but groups 3 and 4 showed a statistically significant decrease in AHI and RDI (Table III).

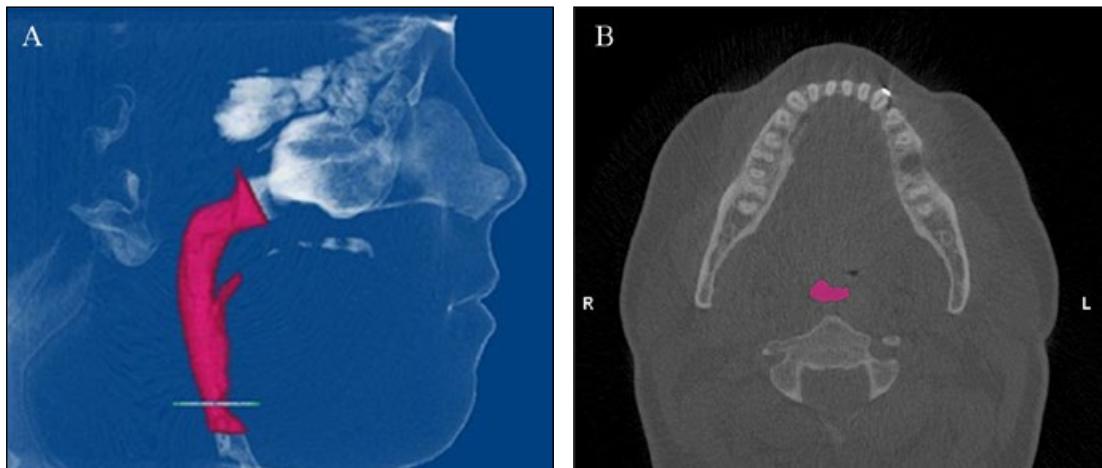


Figure 3. (A) Total airway volume and (B) cross sectional view of the most constricted area.



Figure 4. Soft palate surface area.



Figure 5. Soft tissue thicknesses and sagittal depth of the airway at the levels of nasopharynx and oropharynx.

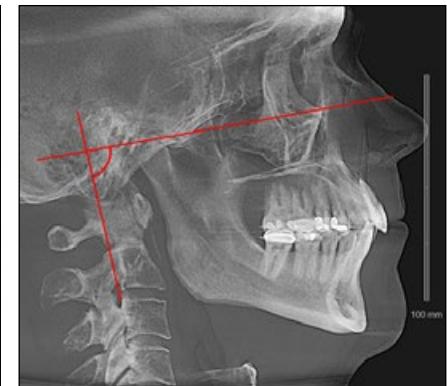


Figure 6. Cervical vertebrae angulation.

Table I. Definitions of anatomical areas used in the study.

Anatomical area	Anterior boundary	Posterior boundary	Superior boundary	Inferior boundary
Nasal cavity (mm <sup>3</sup> )	anterior nasal spine (ANS) – the tip of the nasal bone – Nasion (N)	Sella point (S) – posterior nasal spine (PNS)	Nasion (N) – Sella point (S)	anterior nasal spine (ANS) – posterior nasal spine (PNS)
Nasopharynx (mm <sup>3</sup> )	S – PNS	S – tip of the odontoid process		PNS – tip of the odontoid process
Oropharynx (mm <sup>3</sup> )	PNS – hyoid bone (hy)	tip of the odontoid process – C4ps	PNS – tip of the odontoid process	hy – C4ps
Total airway (mm <sup>3</sup> )	S – PNS – hyoid bone (hy)	S – tip of the odontoid process – C4ps		hy – C4ps
MCA (mm <sup>2</sup> )	The most constricted area (MCA) will be detected automatically by the software along the airway passage			
Soft Palate area (mm <sup>2</sup> )	Confined by the soft palate that starts and ends at PNS through the uvula tip			

Following the use of the EMA appliance, statistically significant increases were found in the volume of the nasopharynx, oropharynx, and total airway in all OSA groups. The MCA of the airway increased significantly in groups 2 and 3 and non-significantly in group 4.

The soft palate area decreased significantly in the OSA groups (Table IV).

All craniofacial parameters except CVT-FH changed significantly for all OSA subjects. The sagittal depth of the airway significantly increased in groups 2

**Table II.** The 3D measurements of the craniofacial complex used in the study.

Parameters	Description
Ba – ppw (mm)	Thickness of the soft tissue of the posterior wall of the airway at the nasopharynx level from Basion.
PNS – ppw (mm)	Sagittal depth of the airway at the nasopharynx level.
CV2ia – ppw (mm)	Thickness of the soft tissue of the posterior wall of the airway at the oropharynx level.
CV2ia - AW (mm)	Sagittal depth of the airway at the oropharynx level.
CVT – FH (°)	The inclination of the cervical column represented as the angle between the cervical vertebrae tangent (CVT), the line connects the most posterior and superior point on CV2 and the most posterior and superior point on CV4, and the FH Plane.
Overjet (mm)	The horizontal distance between the incisal edges of the maxillary and mandibular central incisors as projected on the facial plane (nasion – pogonion).
Overbite (mm)	The vertical distance between the incisal edges of the maxillary and mandibular central incisors as projected on the facial plane (nasion – pogonion).

**Table III.** Comparison of sleep test parameters between T1 and T2.

Groups	Parameters	T1		T2		Change		p-value
		Mean	SD	Mean	SD	Mean	SD	
G1	BMI (Kg/m <sup>2</sup> )	24.9	3.1	25.1	2.9	0.2	0.4	0.32
	Neck size (inch)	15.6	0.8	15.6	0.9	0	0.4	0.46
	AHI	1.5	1	1.6	1	0.2	0.6	0.94
	RDI	5.8	2.4	7.7	2.5	1.9	2.1	0.57
	Epworth score	3.3	1.8	2.6	2.2	-0.6	1	0.00*
G2	Snoring (%)	5.9	8.6	7.8	12.1	1.9	7.7	0.69
	BMI (Kg/m <sup>2</sup> )	30.4	4.6	29.9	4.8	-0.5	0.7	0.29
	Neck size (inch)	17.0	1.1	17.2	1.5	0.2	0.8	0.49
	AHI	7.7	2.6	5.8	2.3	-1.9	4.1	0.41
	RDI	18.2	5.3	14.2	8.2	-4.0	7.0	0.22
G3	Epworth score	8.8	3.1	5.4	2.8	-3.3	2.5	0.00*
	Snoring (%)	23.1	10.9	23.2	19.8	0.0	14.8	0.69
	BMI (Kg/m <sup>2</sup> )	31.6	6.7	31.6	6.4	0.0	1.0	0.29
	Neck size (inch)	17.7	1.6	17.5	1.5	-0.1	0.4	0.49
	AHI	19.8	4.6	9.3	3.9	-10.5	6.1	0.00*
G4	RDI	35.9	10.1	18.5	6.9	-17.4	12.9	0.00*
	Epworth score	8.9	5.9	6.3	5.2	-2.7	3.3	0.00*
	Snoring (%)	32.4	12.2	29.3	17.0	-3.1	10.6	0.64
	BMI (Kg/m <sup>2</sup> )	35.8	6.9	35.8	7.0	-0.1	0.3	0.29
	Neck size (inch)	18.1	1.1	18.3	1.9	0.3	1.2	0.49
G5	AHI	52.3	15.3	32.8	26.4	-19.6	14.2	0.00*
	RDI	62.0	14.5	43.4	27.7	-18.6	16.6	0.00*
	Epworth score	11.8	6.4	8.2	4.0	-3.6	4.5	0.00*
	Snoring (%)	40.6	11.1	39.0	12.2	-1.6	9.8	0.64

\*Statistically significant at  $p \leq 0.05$ , BMI: body mass index, AHI: apnoea-hypopnoea index, RDI: respiratory disturbance index

Table IV. Comparison of airway volumes and soft palate area between T1 and T2.

Groups	Parameters	T1		T2		Change		p-value
		Mean	SD	Mean	SD	Mean	SD	
G1	Nasal cavity (mm <sup>3</sup> )	27657.8	3989	27652.8	3979.6	-5	17.6	0.98
	Nasopharynx (mm <sup>3</sup> )	11296.7	3194.4	11296.3	3192.1	-0.5	3.4	0.99
	Oropharynx (mm <sup>3</sup> )	31797.3	11023	30874.3	10031	-923	3060.2	0.42
	Total airway (mm <sup>3</sup> )	43094	13651.4	42170.6	12367.3	-923.4	3063.2	0.44
	MCA (mm <sup>2</sup> )	328.3	120.3	322.3	113.6	-6	19.6	0.65
	S Palate area (mm <sup>2</sup> )	321.4	69.7	327.3	70.5	5.8	19.5	0.57
G2	Nasal cavity (mm <sup>3</sup> )	21085.0	4150.0	20828.0	4097.0	-257	510	0.35
	Nasopharynx (mm <sup>3</sup> )	8621.0	2723.0	9488.0	2276.0	868	917	0.00*
	Oropharynx (mm <sup>3</sup> )	17030.0	5264.0	22464.0	5833.0	5434.0	4656.0	0.00*
	Total airway (mm <sup>3</sup> )	25651.0	6855.0	31952.0	6585.0	6301.0	4917.0	0.00*
	MCA (mm <sup>2</sup> )	154.8	73.5	209.7	86.6	55.0	71.0	0.00*
	S Palate area (mm <sup>2</sup> )	348.3	107.3	306.4	83.1	-42.0	53.0	0.00*
G3	Nasal cavity (mm <sup>3</sup> )	21958.0	5503.0	21909.0	5447.0	-49.0	102.0	0.35
	Nasopharynx (mm <sup>3</sup> )	8519.0	2787.0	9397.0	3325.0	878.0	947.0	0.00*
	Oropharynx (mm <sup>3</sup> )	17349.0	8022.0	20844.0	9454.0	3495.0	2403.0	0.00*
	Total airway (mm <sup>3</sup> )	25868.0	10458.0	30241.0	12437.0	4373.0	3234.0	0.00*
	MCA (mm <sup>2</sup> )	151.1	80.3	188.0	114.4	37.0	93.0	0.00*
	S Palate area (mm <sup>2</sup> )	348.8	101.7	318.7	84.4	-30.0	28.0	0.00*
G4	Nasal cavity (mm <sup>3</sup> )	21909.0	4510.0	21646.0	4423.0	-263.0	528.0	0.35
	Nasopharynx (mm <sup>3</sup> )	5783.0	3645.0	6332.0	3922.0	549.0	662.0	0.01*
	Oropharynx (mm <sup>3</sup> )	10435.0	5269.0	13972.0	3375.0	3537.0	5276.0	0.00*
	Total airway (mm <sup>3</sup> )	16187.0	7509.0	20556.0	4803.0	4368.0	5873.0	0.01*
	MCA (mm <sup>2</sup> )	84.4	32.2	92.2	29.8	8.0	11.0	0.52
	S Palate area (mm <sup>2</sup> )	428.9	67.7	410.2	71.6	-19.0	19.0	0.05*

\*Statistically significant at  $p \leq 0.05$

and 3 at the level of the nasopharynx, and increased significantly in all OSA groups at the level of the oropharynx. The soft tissue thickness of the airway decreased significantly in groups 2 and 3 at the level of the nasopharynx, and decreased significantly in all OSA groups at the level of the oropharynx. Overbite and overjet decreased significantly in all OSA groups (Table V).

## Discussion

OSA is a common disorder associated with serious medical consequences and a number of related risk factors. Oral appliances are increasingly considered as viable treatment options for mandibular deficiency and OSA. The anterior displacement of the mandible and forward positioning of the tongue has been

recommended for the relief of upper airway obstruction.<sup>19-21</sup> OSA patients who cannot tolerate a CPAP machine are usually offered alternative treatment options that may include upper airway surgery in the form of maxillomandibular advancement, uvulopharyngopalatoplasty, laser-assisted uvulopalatoplasty, and radiofrequency ablation.<sup>22</sup> The temperature-controlled radiofrequency tissue volume reduction for the soft palate and base of the tongue is also considered a treatment option for mild to moderate OSA.<sup>23</sup> In addition to the low percentage rate of success, the literature has also reported a number of side effects and adverse events following surgery to the upper airway, such as difficulty swallowing, nasal regurgitation, taste disturbances, voice changes, post-operative bleeding, morbidity, and mortality.<sup>22,24-26</sup>

Table V. Comparison of craniofacial parameters between T1 and T2.

Groups	Parameters	T1		T2		Change		p-value
		Mean	SD	Mean	SD	Mean	SD	
G1	Ba-ppw (mm)	20.3	2.8	20.3	2.8	0	0.1	98
	PNS-ppw (mm)	31.9	2.7	31	4.6	-0.9	3	0.15
	CV2ia-ppw (mm)	4.6	1	4.6	1	0	0.2	0.34
	CV2ia-AW (mm)	14.4	4.1	14.4	4.1	0	0.1	0.92
	CVT-FH (°)	84.8	4.8	84.8	3.8	0	0.1	0.1
	OJ (mm)	2.7	1.5	2.7	1.5	0	0.1	0.99
	OB (mm)	3.6	1.8	3.6	1.8	0	0.1	98
G2	Ba-ppw (mm)	20.2	2.8	19	2	-1.2	1.7	0.00*
	PNS-ppw (mm)	30.8	5.7	32.4	4.8	1.6	2.3	0.01*
	CV2ia-ppw (mm)	4.5	1.2	4.1	0.9	-0.4	0.5	0.00*
	CV2ia-AW (mm)	13.4	4.3	14.8	3.3	1.4	2.1	0.00*
	CVT-FH (°)	80.2	5	81.2	4.5	1.1	2	0.06
	OJ (mm)	3.3	1.6	-0.1	2.9	-3.5	3	0.00*
	OB (mm)	4.2	2	-6.2	5.1	-10.4	4.8	0.00*
G3	Ba-ppw (mm)	20.8	3.1	19.4	2.9	-1.5	1.6	0.00*
	PNS-ppw (mm)	27.6	3.8	28.8	3.5	1.2	1	0.04*
	CV2ia-ppw (mm)	4.7	1.2	4	1	-0.7	0.9	0.00*
	CV2ia-AW (mm)	9.8	2.5	11.9	2.7	2.1	1.5	0.00*
	CVT-FH (°)	84	3.9	84.7	4.2	0.8	2	0.06
	OJ (mm)	3.7	1	2.5	2.1	-1.2	1.7	0.03*
	OB (mm)	3.7	0.8	-6.9	1.8	-10.6	1.5	0.00*
G4	Ba-ppw (mm)	20.9	2.1	20.3	1.8	-0.6	0.5	0.08
	PNS-ppw (mm)	24.9	2.5	25.6	2.4	0.7	1.2	0.23
	CV2ia-ppw (mm)	5.6	1	5.1	0.8	-0.5	0.9	0.00*
	CV2ia-AW (mm)	11.6	2.8	12.5	3.1	1	1.3	0.03*
	CVT-FH (°)	81.3	5.4	81.2	5.7	-0.1	1.4	0.06
	OJ (mm)	3.9	1.3	2.6	1.4	-1.3	1.2	0.02*
	OB (mm)	3.8	1.3	-8	2.4	-11.8	1.8	0.00*

\*Statistically significant at  $p \leq 0.05$

Portable home systems to monitor OSA are currently used to minimise patient medical costs, time off work, and the obvious problems of uncomfortably sleeping in a strange environment. The AREST™ system (Watermark Medical, FL, USA), an approved Food and Drug Administration (FDA) device, is a wireless recorder worn on the forehead with cannulas inserted into the nasal apertures. The recorder is equipped with reflectance pulse oximetry to measure blood oxygen saturation and pulse rate, a pressure transducer to the nasal cannula to measure airflow, calibrated acoustic microphone and two dual-access

accelerometers to measure snoring levels, head movement and position. Frontal lobe derivations record encephalogram data and an internal algorithm estimates sleep time based on non-movement and regularity of nasal flow and/or snoring. The recorder can hold as many as three nights of data.<sup>27</sup> The concordance with laboratory polysomnography has been found to be high (ICC = 0.8) and the sensitivity of the in-home AREST™ for Sleep Disordered Breathing is reported as 85% and the specificity as 91%.<sup>28</sup>

The EMA appliance used in the present study advanced the mandible by means of elastic straps

attached to upper and lower custom-made stents. These pulled the mandible in a forward position and made the appliance less bulky and more comfortable for patients compared with appliances which utilise threaded screws or telescopic arms. Variable lengths of elastic strap allowed control over the desired amount of advancement. The achieved mandibular advancement was standardised by providing same-length elastic strap (21 mm) to hold the mandible 4 mm in a forward position while vertical opening was adjusted by using same-size bite planes.

The new generations of the CBCT scanners and the advances in 3D imaging software enable the accurate volumetric evaluation of the airway and its surrounding tissues with low radiation exposure. In addition, the scans allow accurate visualisation of the airway and more precise analysis.<sup>29-32</sup> Calculation of MCA and cross-sectional areas of the airway in three planes of space is facilitated. The axial plane, which is not visualised on a lateral cephalogram, is the most physiologically relevant plane because it is perpendicular to the airflow. It has been previously reported that the accuracy and reliability of digital measurements of airway volume on CBCTs compared with the volume measured manually of an airway model was excellent.<sup>30-32</sup> CBCT was therefore chosen as the method of evaluation in the current research. However, the use of CBCT should also be considered a limitation as patients were scanned awake and in an upright position, which may not represent the situation and position during sleep.

The ESS is a standardised self-rating system used to assess subjective sleepiness by using 0-3 scale in which (0) indicates 'would never doze' and (1, 2 and 3) indicate that there is a slight, moderate, and high chance of dozing throughout the day or during critical activities.<sup>33</sup> The ESS, although subjective, is considered a reliable method for measuring persistent daytime sleepiness in adults.<sup>34</sup> In the current study, Epworth scale showed a statistically significant decrease following the use of EMA appliance and inducing an obvious improvement in OSA symptoms. The mean score of the Epworth scale decreased significantly for the OSA groups.

As shown in Table III, the EMA was effective in decreasing the number of apnoea and hypopnoea episodes per hour of sleep. The level of reduction in AHI (an objective score) was statistically significant in groups 3 and 4, which reinforced the changes seen in

the ESS scores. This indicated that the use of the EMA is expected to reduce the severity of the condition by one category for more severe cases by reducing severe OSA to moderate and moderate OSA to mild. Although there was an improvement in snoring as reported by the OSA group, the improvement was not statistically significant.

Ferguson et al.<sup>16</sup> reported that the efficiency of oral appliances might be affected by several factors related to the severity of OSA, the extent of appliance mandibular advancement, the position of individuals during sleep, and the body mass index (BMI). In agreement with these findings, the current data demonstrated that the number of apnoea-hypopnoea events per hour during sleep decreased as the severity of OSA increased with an average amount of mandibular advancement and mandibular opening for the OSA groups. Although BMI and neck size, in this study, showed an inconsiderable increase associated with the increase in OSA severity, the increase in BMI and neck size were not significant for all groups. Solow et al.<sup>35</sup> reported that airway obstruction at the level of the nasopharynx was affected by the crano-cervical angulation. The present data demonstrated that the inclination of the cervical column showed non-significant changes in all groups, which negated the effect of head posture changes on the airway size.

The results of the present study demonstrated statistically significant decreases in the soft tissue thickness of the posterior wall of the airway at the levels of the nasopharynx and oropharynx with a concomitant significant increase in the airway lumen at those levels. The results might be explained by the function of the appliance, which causes forward and downward displacement of the mandible and an associated downward and forward positioning of the tongue that consequently leads to an increase in airway size. The appliance also causes stretching of the soft tissue, which could possibly explain the significant decrease in soft palate size.

In conclusion, the results of the current study confirmed the effectiveness of EMA in increasing airway volume, widening MCA of the airway and improving snoring and sleep quality, although the snoring improvement was statistically not significant. Orthodontists have the opportunity to recognise abnormal airway anatomy and refer patients for OSA evaluation by a sleep medicine physician. A collaborative approach with physicians might provide effective non-invasive

treatment that objectively produces sleeping improvement which patients subjectively recognise.

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