ORIGINAL RESEARCH

Changes in Airway Dimensions Following Non-extraction Clear Aligner Therapy in Adult Patients with Mild-to-moderate Crowding

Suzzane Horani[1], Tarek El-Bialy[2], Abdul Basir Barmak[3], Paul Emile Rossouw[4], Dimitrios Michelogiannakis[5]

Abstract

Aim and objective: This retrospective study aimed to assess changes in airway dimensions with non-extraction clear-aligner-therapy (NE-CAT) in adult patients with mild-to-moderate crowding.

Materials and methods: Cone-beam computed tomographic images were evaluated for 24 adults (16 females and 8 males) with mild-to-moderate crowding, and Class I or mild skeletal Class II malocclusion before and after NE-CAT. Cross-sectional and volumetric airway measurements were performed at the level of the nasal cavity, upper pharyngeal airway space (UAS), and lower pharyngeal airway space (LAS). The Frankfort-mandibular plane angle (FMA), point A-nasion-point B (ANB) angle, and intermolar width were measured. A paired *t*-test was used to assess changes in airway measurements. Linear regression analyses were performed to identify predictors of the pharyngeal airway volume change at the levels of the UAS and LAS.

Results: There was a significant decrease ($p = 0.004$) in UAS mean volume (486.63 ± 752.73 mm^3), LAS mean volume ($p = 0.006$), and cross-sectional airway area ($p = 0.022$) (1536.92 ± 2512.02 mm^3 and 34.66 ± 69.35 mm^2, respectively) with NE-CAT. The mean airway volume of the nasal cavity, mean cross-sectional airway areas of the nasal cavity and UAS, and mean minimum cross-sectional pharyngeal airway area did not change significantly with NE-CAT. Changes in pharyngeal airway volume were not significantly associated with patients' age, gender, treatment duration, pretreatment ANB angle, and changes in FMA and maxillary first intermolar width with NE-CAT.

Conclusion: Significant changes in the pharyngeal airway dimensions of the UAS and LAS with NE-CAT in adult patients with mild-to-moderate crowding were identified.

Clinical significance: The results of the present study show that NE-CAT is not associated with an improvement in airway dimensions in adults with mild to moderate crowding.

Keywords: Airway dimensions, Clear aligner therapy, Cone-beam computed tomography, Invisalign, Non-extraction therapy, Retrospective study.

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Introduction

Adults commonly seek orthodontic treatment to improve dentofacial esthetics and function;[1] and clear-aligner-therapy (CAT) has gained popularity in adult patients due to its esthetic advantages and relative "invisibility" compared with conventional fixed orthodontic appliances.[2] It has been reported that CAT is effective in leveling and aligning the dental arches, intruding anterior teeth, and controlling maxillary molar bodily movement; while it is less effective in extruding and/or de-rotating anterior teeth.[3] Nonetheless, recent advances in CAT have facilitated greater control of tooth movement, and have permitted treatment of more complex dentoskeletal problems.

A normal breathing pattern and patent upper airway are essential aspects of normal growth and development;[4,5], and various orthodontic and combined orthodontic–orthognathic surgery treatment modalities may influence airway dimensions.[6] For instance, it has been shown that surgical mandibular set-back narrows the oropharyngeal airway; while, surgical mandibular advancement increases oropharyngeal airway volume.[7] Moreover, dentofacial orthopedic treatments, such as functional appliance therapy and facemask therapy may also increase upper airway volume in growing patients by protracting the mandible and maxilla, respectively.[7] Furthermore, it has been shown that maxillary expansion may increase upper airway volume due to an increase in the maxillary transverse dimension and forward repositioning of the tongue.[8]

[1,4,5]Department of Orthodontics and Dentofacial Orthopedics, Eastman Institute for Oral Health, University of Rochester, Rochester, New York, USA

[2]Department of Orthodontics, School of Dentistry, University of Alberta, Edmonton, Alberta, Canada

[3]Department of Dentistry, Eastman Institute for Oral Health, University of Rochester, Rochester, New York, USA

Corresponding Author: Dimitrios Michelogiannakis, Department of Orthodontics and Dentofacial Orthopedics, Eastman Institute for Oral Health, University of Rochester, Rochester, New York, USA, Phone: +1 (585) 275-5012, e-mail: Dimitrios_Michelogiannakis@URMC.Rochester.edu

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Conflict of interest: None

Ethical approval: This retrospective study was exempted after evaluation by an Institutional Review Board at the Eastman Institute for Oral Health, University of Rochester, NY (STUDY00004011).

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Non-extraction CAT (NE-CAT) is commonly performed in adult patients with mild to moderate crowding to relieve crowding, achieve dental maxillary expansion, and improve the alignment of teeth. In a recent study, Al-Jewair et al.[9] examined the influence of mandibular dentoalveolar advancement with CAT and Class II elastics on airway dimensions in adult patients with Class II division 1 malocclusion. The authors found no statistically significant changes in airway measurements with CAT; however, this pilot study was performed on 8 patients with no power analysis for sample size estimation.[9] To the authors' knowledge, there is a lack of power-adjusted clinical studies in indexed literature regarding the influence of NE-CAT on airway dimensions in adult patients.

The purpose of this study was to assess changes in airway dimensions with NE-CAT in adult patients with mild to moderate crowding using cone-beam computed tomography (CBCT).

Materials and Methods

This retrospective study was exempted after evaluation by an Institutional Review Board at the Eastman Institute for Oral Health, University of Rochester, NY (STUDY00004011). The present study's convenience sample was obtained from a private orthodontic clinic (Sphinx Orthodontics, Edmonton, Canada); and all patients were treated by the same experienced orthodontist (EB) using Invisalign (Align Technology Inc., Santa Clara, CA, USA). Treatment records between January 2012 and November 2019 were screened to assess eligibility; eligible patients were enrolled consecutively.

The inclusion criteria included: (a) adults (≥18-years-old)[9] with no systemic conditions/diseases and craniofacial syndromes that underwent NA-CAT; (b) patients with Class I or mild skeletal Class II relationship (ANB <7 degrees);[10] (c) patients with mild (<3 mm) to moderate (3–7.49 mm) pretreatment crowding;[11] and (d) CBCT images of adequate diagnostic quality available before (T1) and after (T2) NE-CAT. Patients with self-reported smoking habits, patients with Class III malocclusion and severe crowding requiring orthodontic therapy with extractions and orthognathic surgery, and patients with interdental spacing were excluded.

For each patient, CBCT images were obtained at T1 and T2 using the i-CAT FLX (Imaging Sciences International, Hatfield, PA, USA) with a scanning time of 3.7 seconds, 5 mA, 120 kVp, with a field of view of 16 cm × 16 cm and slice thickness of 0.3 mm. All CBCT images were taken by one trained and calibrated examiner (EB) using standardized imaging techniques. Briefly, the images were taken with the patients seated in an upright position with a natural head position, the tongue and facial muscles in a relaxed state, and the teeth in centric occlusion. The position of the mandible was stabilized using a chin holder, and the patients were instructed to avoid swallowing or moving during radiographic exposure. The CBCT images were saved as DICOM files and then transferred to Dolphin Imaging software (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, CA, USA).

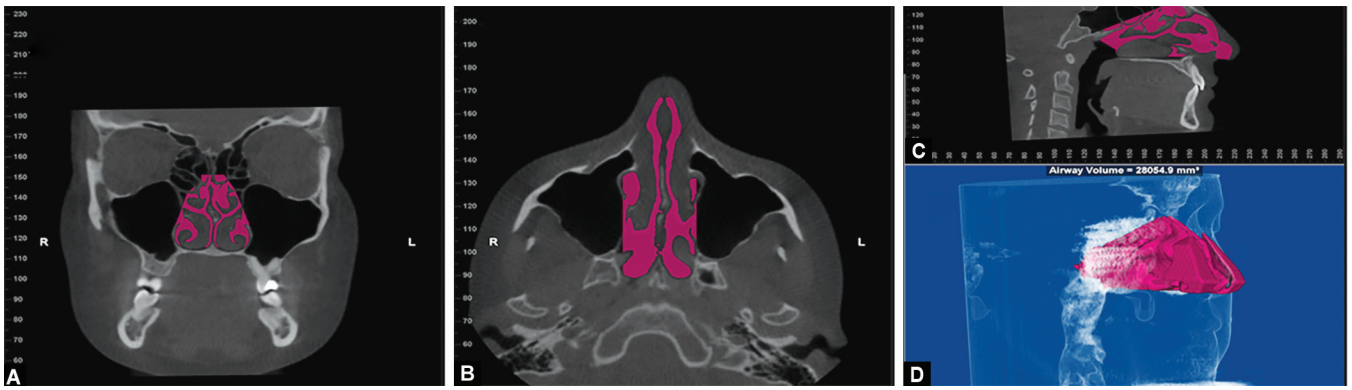
A trained and calibrated investigator (SH) assessed patients' records to identify and record patients' age, gender, medical history, amount of crowding, and treatment duration; and the same investigator (SH) performed all airway measurements. Before recording airway measurements, the orientation of the CBCT images was standardized. The sagittal plane was used to orient Frankfort horizontal plane parallel to the floor while the coronal and frontal planes were used to center the patient's head.

For each patient, the airway was divided into three regions (Table 1): the nasal cavity (Fig. 1), the upper pharyngeal airway space (UAS) including the nasopharynx (Fig. 2), and the lower pharyngeal airway space (LAS) including the oropharynx and velopharynx (Fig. 3).[12] Briefly, the inferior boundary of the LAS was defined by a plane drawn through the most anterior–inferior

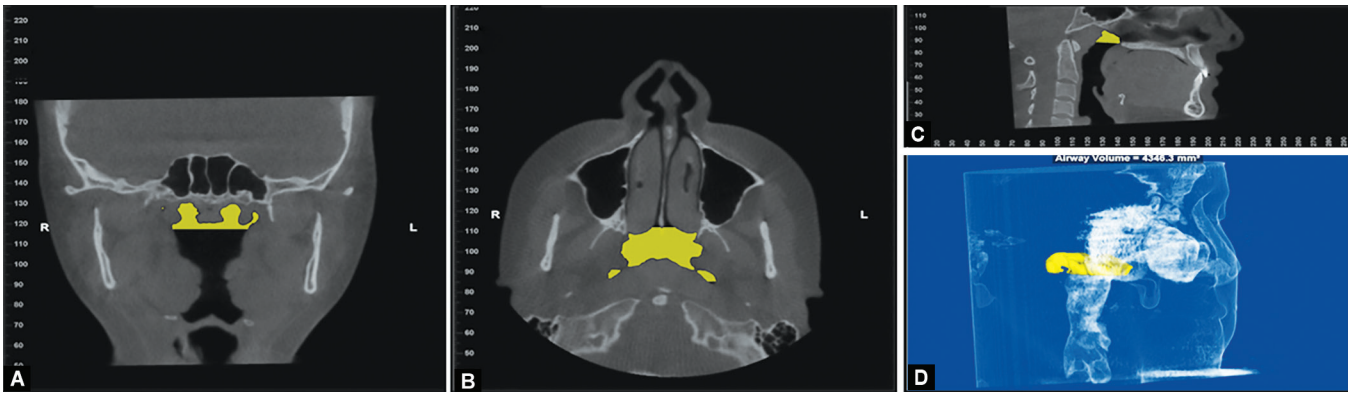
Table 1: Anatomic landmarks and planes defining the boundaries of the airway spaces

Region	*Superior boundary*	*Inferior boundary*	*Posterior boundary*	*Anterior boundary*
Nasal cavity	Nasion	ANS to PNS	SOS to superior edge of vomer bone to anterior edge of vomer bone	Tip of nose to base of the nose to ANS
Upper airway space	SOS to the superior edge of the vomer bone	PNS to the most superior point of the anterior arch of atlas	Atlas to basion	PNS to the anterior edge of the vomer bone
Lower airway space	PNS to the most superior point of the anterior arch of atlas	Most anterior–inferior point of C2 parallel to Frankfort plane	NA	NA

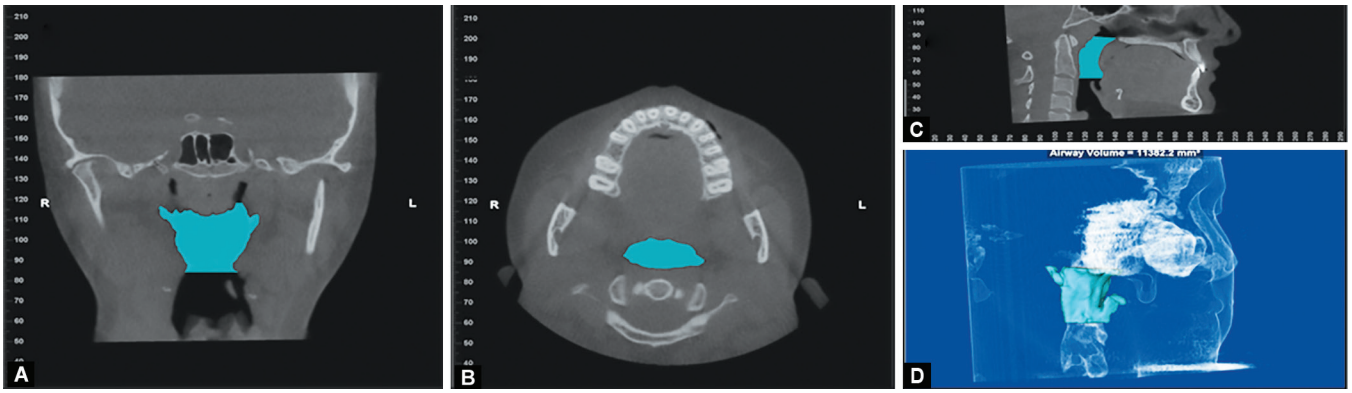
ANS, anterior nasal spine; C2, second cervical vertebra; NA, not applicable; PNS, posterior nasal spine; SOS, spheno-occipital synchondrosis



Figs 1A to D: Multiplanar cone-beam computed tomographic views of the airway space at the level of the nasal cavity (delineated in pink). (A) Coronal view; (B) Axial view; (C) Sagittal view; (D) Volumetric reconstruction of the respective airway space



Figs 2A to D: Multiplanar cone-beam computed tomographic views of the airway space at the level of the upper airway space (delineated in yellow). (A) Coronal view; (B) Axial view; (C) Sagittal view; (D) Volumetric reconstruction of the respective airway space



Figs 3A to D: Multiplanar cone-beam computed tomographic views of the airway space at the level of the lower airway space (delineated in blue). (A) Coronal view; (B) Axial view; (C) Sagittal view; (D) Volumetric reconstruction of the respective airway space

point of the second cervical vertebra and parallel to the Frankfort plane.[12] The superior boundary of the LAS was defined as a plane connecting the posterior nasal spine and the most superior point of the anterior arch of Atlas.[12] The superior boundary of the LAS is the inferior boundary of the UAS. The posterior–superior–anterior boundaries of the UAS were defined by lines connecting the Atlas, basion, spheno-occipital synchondrosis, superior and anterior edges of the vomer bone, and the posterior nasal spine.[12] The anterior boundary of the UAS is the posterior boundary of the nasal cavity, defined by the sphenooccipital synchondrosis, superior and anterior edges of the vomer bone, and the posterior nasal spine.[12] The anterior portion of the nasal cavity is defined by the nasion, tip of the nose, base of the nose, and the anterior nasal spine[13] (Fig. 4).

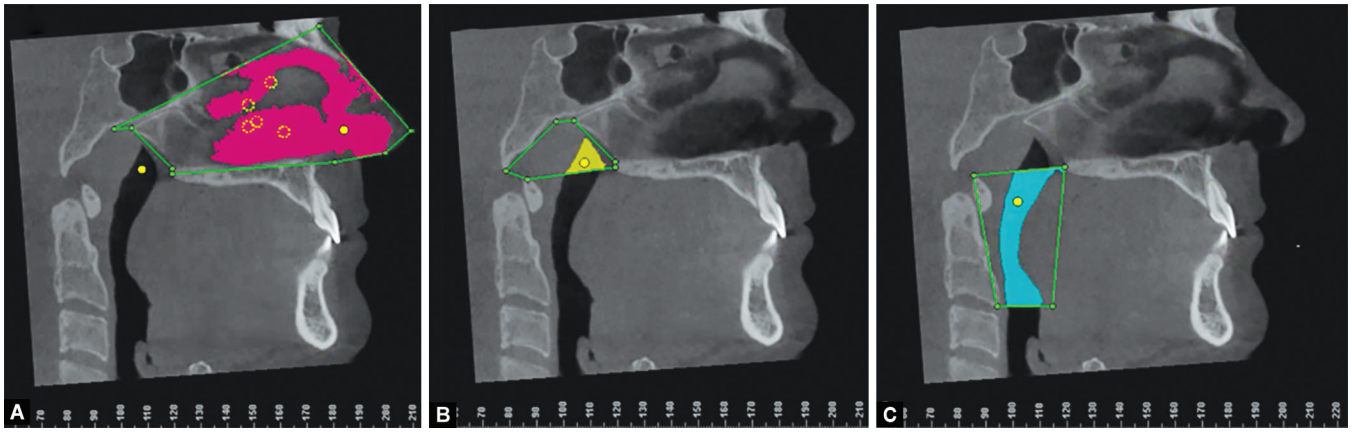
The sinus or airway tool on Dolphin Imaging software was used for the airway measurements; and the boundaries of the regions were analyzed in the frontal, sagittal, and coronal views. The boundaries were selected by viewing sequential slices until the landmarks were identified. Seed points were placed manually for the software to identify the patient's airway. Additional seed points were placed in hypodense regions. The threshold range was arbitrarily standardized to 40 units to best represent the airway region in all CBCT images. The imaging software was then used to calculate the airway volumes with the update airway tool in cubic millimeters and cross-sectional areas in square millimeters at T1 and T2, and the minimal cross-sectional pharyngeal airway area was also calculated. The maxillary first intermolar width (distance between the centers of the palatal cusps of the permanent maxillary first molars) was digitally measured at T1 and T2. Lateral cephalometric radiographs at T1 and T2 were extracted from the CBCT images to digitally assess the FMA and ANB angles.

The same examiner (SH) re-measured 10 randomly selected CBCT images one week later to assess intra-observer reliability. A second examiner (DM) re-measured 10 randomly selected images to assess interobserver reliability.

Data Analysis

Based on a power analysis, a total of 18 patients achieves 80% power, with a two-sided $\alpha = 0.05$, to detect volumetric changes in the LAS greater than 2000 mm^3 (effect size = 0.80)[13] with a standard deviation (SD) of 2500 mm^3,[14] using a paired *t*-test.[14] Mean [±standard deviation (SD)] values were calculated at each time point for intermolar width, minimum cross-sectional pharyngeal airway area, and airway volumes and cross-sectional areas of the nasal cavity, UAS, and LAS. The changes in airway space volumes or areas were recorded by subtracting the T2 values from the T1 values. A negative difference indicated an increase in airway space; whereas, a positive difference indicated a net decrease in airway space.

The normality distribution of the data was tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The paired *t*-test was used to assess the changes in airway space dimensions. Linear regression analyses were performed to examine the association between the change in UAS and LAS volumes and various



Figs 4A to C: Airway space boundaries and dimensions shown in the sagittal view of cone-beam computed tomographic images. (A) Nasal cavity; (B) Upper airway space; (C) Lower airway space

independent variables including age, gender, treatment duration, ANB angle, and changes in intermolar width and FMA with NE-CAT. The intraclass correlation coefficient (ICC) was used to assess intra- and interobserver reliabilities. Statistical significance was set at an $\alpha = 0.05$. Data analysis was implemented with IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp. statistical software.

Results

Very strong correlations (ICC > 0.99) ($p < 0.000$) were noted for all study measurements regarding intra- and interobserver reliabilities. All data were normally distributed.

Characteristics of the Sample

The records of 24 adults (16 females and 8 males) who were treated with NE-CAT were included. The mean (±SD) age of the patients was 35.33 (±11.14) years. The mean (±SD) pretreatment ANB angle of the patients was 2.57 (±1.61) degrees (range between 0.10 and 6.00 degrees); and the mean (±SD) FMA was 22.78 (±5.79) degrees (range between 14.80 and 36.50 degrees). Non-extraction CAT led to a significant ($p < 0.000$) increase in the mean first intermolar width of 2 (±1.20) mm [confidence interval (CI) from 1.60 to 2.63 mm]; and there was an increase of approximately 0.8 (±1.90) degrees in the mean FMA angle. The mean (±SD) total treatment duration was 1.82 (±0.74) years (ranging between 0.64 and 3.64 years).

Volumetric Changes in Airway Dimensions

There was a mean non-significant increase ($p = 0.590$) of 387.52 (±3476.20) mm^3 (CI from –1855.39 to 1080.35 mm^3) in the airway volume of the nasal cavity with NE-CAT. For the UAS, there was a significant decrease ($p = 0.004$) in the mean airway volume of 486.63 (±752.73148) mm^3 (CI from 168.77 to 804.48 mm^3). The LAS showed a significant decrease ($p = 0.006$) in the mean airway volume of 1536.92 (±2512.02) mm^3 (CI from 476.19 to 2597.65 mm^3) (Table 2).

Changes in Airway Space Cross-sectional Areas

The mean cross-sectional airway areas of the nasal cavity and UAS did not change significantly with NE-CAT ($p = 0.859$ and 0.068, respectively). In the LAS, there was a significant decrease ($p = 0.022$) in the mean cross-sectional airway area of 34.66 (±69.35) mm^2 (CI from 5.38 to 63.94 mm^2). There was no significant change ($p = 0.118$) in the mean minimum pharyngeal cross-sectional airway area (Table 3).

Potential Factors Associated with Volumetric Changes in Airway Dimensions

A large inter-individual variation was shown regarding the changes in airway dimensions as indicated by the SDs of the mean volumetric and cross-sectional airway area changes (Tables 2 and 3). The patients' age, gender, treatment duration, pretreatment ANB angle, and changes in FMA and maxillary first intermolar width with NE-CAT were not significantly associated with the changes in UAS and LAS volumes.

Inference of Reported Results

The results of the present study show that NE-CAT was not associated with an improvement in airway dimensions in adults with mild to moderate crowding.

Discussion

There is a controversy in indexed literature regarding the influence of fixed orthodontic therapy with or without premolar extractions on pharyngeal airway dimensions.[15,16] For instance, Stefanovic et al.[15] reported that fixed orthodontic therapy with or without

Table 2: Mean volumetric airway values (mm^3) before and after non-extraction CAT

	T1		*T2*		*T1 – T2*		*95% confidence interval*		
Region	Mean	SD	Mean	SD	Mean difference	SD	Lower	Upper	*p-value**
Nasal cavity	31425.50	6634.41	31813.02	5678.50	–387.52	3476.20	–1855.39	1080.35	0.590
Upper airway space	7360.76	1938.02	6874.14	1767.51	486.63	752.73	168.77	804.48	0.004
Lower airway space	13604.57	4018.85	12067.65	3647.00	1536.92	2512.02	476.19	2597.65	0.006

*Paired *t*-test; statistical significance ($p < 0.05$); CAT, clear aligner therapy; T1, before non-extraction CAT; T2, after non-extraction CAT; SD, standard deviation

Table 3: Mean cross-sectional airway area values (mm^2) before and after non-extraction CAT

	T1		*T2*		*T1 – T2*		*95% confidence interval*		
Region	Mean	SD	Mean	SD	Mean difference	SD	Lower	Upper	*p-value**
Nasal cavity	875.35	359.15	863.50	336.83	11.84	322.80	−124.47	148.15	0.859
Upper airway space	277.80	80.30	268.39	73.24	9.41	24.09	−0.76	19.58	0.068
Lower airway space	505.01	97.44	470.35	107.47	34.66	69.35	5.38	63.94	0.022
Minimum cross-sectional pharyngeal airway space	68.85	30.89	58.09	22.45	10.76	32.46	−2.94	24.47	0.118

*Paired *t*-test; statistical significance ($p < 0.05$); CAT, clear aligner therapy; T1, before non-extraction CAT; T2, after non-extraction CAT; SD, standard deviation.

premolar extractions does not significantly affect pharyngeal airway dimensions in growing patients. Conversely, Sun et al.[16] showed that incisor retraction after the closure of premolar extraction spaces leads to a decrease in the pharyngeal airway volume in adult patients with bimaxillary protrusion. In the present study, it was speculated that a NE treatment approach to relieve mild to moderate crowding with the use of clear aligners in adult patients would potentially improve airway dimensions. The results of the present study showed a statistically significant decrease in the pharyngeal airway dimensions including both the UAS and LAS following NE-CAT in adult patients with mild to moderate crowding. Studies[17,18] have found an association between decreased airway dimensions and the presence or severity of obstructive sleep apnea (OSA). However, in a CBCT-based study[19] that compared airway dimensions in patients with and without OSA, it was reported that only the minimum cross-sectional pharyngeal airway area differed among groups; which, suggests the clinical relevance of airway shape rather than volume.[19,20] In the present study, there were no significant changes in the minimum cross-sectional pharyngeal airway area with NE-CAT in adult patients with mild to moderate crowding. Based on these findings, the clinical implications of the observed decrease in pharyngeal airway volume with NE-CAT in the present study sample remains debatable. Moreover, in the present study, NE-CAT led to a significant increase in the maxillary first intermolar width (of approximately 2 mm) indicating a dentoalveolar expansion of the maxillary arch in the present sample of patients. It has been reported that skeletal maxillary expansion increases the airway volume of the nasal cavity.[21,22] The findings of the present study showed a non-significant increase in airway volume of the nasal cavity with NE-CAT that could be attributed to the lack of skeletal expansion in the present non-growing sample. Based on the present findings, the authors perceive that alternative treatment modalities, such as skeletal expansion and orthognathic surgery should be considered in conjunction with NE-CAT when the objective is to increase nasal and pharyngeal airway volume in susceptible patient populations, such as patients with OSA. Further studies are needed in this regard.

A large inter-individual variation was noted regarding the changes in airway dimensions with NE-CAT in the present study's sample. This is in accordance with previous studies.[20,23] Various factors, such as age, gender, and craniofacial morphology have been shown to influence pharyngeal airway dimensions.[24–28] For instance, Malhotra et al.[24] assessed changes in pharyngeal anatomy and predisposition of pharyngeal collapse in a sample of adults aged between 18 and 75 years. Results from the study by Malhotra et al.[24] suggest that age and gender are associated with changes in pharyngeal airway dimensions. The authors reported that older age is associated with increased pharyngeal airway collapsibility and deposition of fat around the upper airway, and the lengthening in the pharyngeal airway with age was significantly greater in female than male participants.[24] In a retrospective study, Firwana et al.[27] used CBCT images to compare pharyngeal airway volume among skeletal Class I and Class II subjects; and found a negative correlation between ANB angle and airway size. Grauer et al.[29] found that FMA influences airway shape but not volume in patients with various vertical jaw relationships. Changes in intermolar width have been positively associated with an increase in UAS in young children and adults.[30–32] The authors of the present study performed regression analyses to identify potential factors that may have influenced the changes in the pharyngeal airway volume at the levels of the UAS and LAS following NE-CAT. The results of these regression analyses indicate that age, gender, pretreatment skeletal relationship (ANB angle), treatment duration, and treatment changes in the intermolar width and FMA were not significantly associated with the reported decrease in airways volumes of the UAS and LAS in the present sample. However, due to sample size limitations, the results of the present regression analyses should be interpreted with caution. Furthermore, the body mass index (BMI) has also been shown to negatively influence pharyngeal airway dimensions;[33,34] and changes in the BMI of patients may occur during the course of orthodontic treatment.[35,36] Due to the retrospective nature of this study, it was challenging to evaluate changes in the BMI of the patients in the present sample. The authors perceive that possible changes in the BMI of the patients during the course of CAT could have influenced the reported results. Further studies are needed in this regard.

Due to the retrospective design, the results of the present study might have been subjected to certain types of inherent biases, such as selection bias.[37] Moreover, the importance of a contemporary and well-matched control group in clinical research has been well documented.[38] The inclusion of a control group was challenging in the present study; due to the ethical implications associated with unnecessarily exposing untreated individuals to non-ionizing radiation. It has been reported that CBCT is a useful diagnostic method to evaluate the airway in three-dimensions;[23] however, various factors, such as the breathing stage, head posture, deglutition, tongue position, and position of the mandible might influence airway measurements performed on CBCT images.[23,39] Obelenis Ryan et al.[40] measured the pharyngeal airway volume in 27 untreated patients at 2 different time points (ranging between 4 months and 6 months) using a standardized acquisition protocol. The authors reported an average variation in the oropharyngeal airway volume between the 2 timepoints or measurements

ranging from −5735.3 to +5103.6 mm^3. It is worth mentioning that the decrease in pharyngeal airway volume of the UAS [486.63 (±752.73148) mm^3] and LAS [1536.92 (±2512.02) mm^3] that was observed with NE-CAT in the present study falls between the aforementioned interval. Thus, caution is recommended in the interpretation of the present results.

To the authors' knowledge, this is the first power-adjusted study to assess changes in airway dimensions with CAT. The methodology adopted for image acquisition and conduction of airway measurements was standardized to minimize biases. Also, interobserver and intraobserver reliabilities were very strong (ICC > 0.99) minimizing the risk of measurement errors. In this study, airway measurements were performed in adult patients, with no self-reported smoking habits, with mild to moderate crowding and skeletal Class I or mild skeletal Class II malocclusion treated with NE-CAT by a single experienced practitioner. As expected from a convenience sample, the findings of the present study might not apply to all orthodontic patients. Moreover, there was variability in the age of the patients in the present study (35.33 ± 11.14 years) that may have influenced the reported results. Future studies are necessary to evaluate changes in airway dimensions among patients with different types of malocclusion, patients with and without smoking habits, and patients treated with different protocols, such as extraction vs NE-CAT.

Conclusion

A statistically significant decrease was noted in the pharyngeal airway dimensions of the UAS and LAS in adult patients with mild to moderate crowding who were treated with NE-CAT. In this regard, the authors suggest that alternative treatment modalities, such as skeletal expansion and orthognathic surgery should be considered in conjunction with NE-CAT when the objective is to increase nasal and pharyngeal airway volume in susceptible patient populations, such as patients with OSA.

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