ORIGINAL ARTICLE AJO-DO

Effect of orthodontic treatment on the upper airway volume in adults

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Introduction: The aim of this study was to examine the effects of orthodontic treatment with and without extractions on the anatomic characteristics of the upper airway in adults. **Methods:** For this retrospective study, the pretreatment and posttreatment cone-beam computed tomography scans of 74 adult patients meeting defined eligibility criteria were analyzed. Imaging software was used to segment and measure upper airway regions including the nasopharynx, the retropalatal, and retroglossal areas of the oropharynx, as well as the total airway. The Wilcoxon signed rank test was used to compare volumetric and minimal cross-sectional area changes from pretreatment to posttreatment. **Results:** The reliability values were high for all measurements, with intraclass correlation coefficients of 0.82 or greater. The volumetric treatment changes for the extraction and nonextraction groups were as follows: total airway, 1039.6 ± 3674.3 mm^3 vs 1719.2 ± 4979.2 mm^3; nasopharynx, 136.1 ± 1379.3 mm^3 vs −36.5 ± 1139.8 mm^3; retropalatal, 412.7 ± 3042.5 mm^3 vs 399.3 ± 3294.6 mm^3; and retroglossal, 412.5 ± 1503.2 mm^3 vs 1109.3 ± 2328.6 mm^3. The treatment changes in volume or minimal cross-sectional area for all airway regions examined were not significantly ($P > 0.05$) different between the extraction and nonextraction groups. **Conclusions:** Orthodontic treatment in adults does not cause clinically significant changes to the volume or the minimally constricted area of the upper airway. These results suggest that dental extractions in conjunction with orthodontic treatment have a negligible effect on the upper airway in adults. (Am J Orthod Dentofacial Orthop 2016;150:937-44)

The proposed benefits and negative sequelae associated with the extraction of teeth have long been debated in orthodontics. Dental extractions are typically used to provide space to align crowded teeth, reduce incisor protrusion, and correct anteroposterior interarch discrepancies. However, crowded teeth may also be aligned by dental expansion of the arches, although there are physiologic limits to this process. Despite a significant amount of research investigating the effects of extractions in terms of treatment stability,[1] smile esthetics,[2] temporomandibular joint health,[3] and soft tissue profile,[4,5] a consensus on when to extract teeth eludes the specialty.[6]

More recently, the prevalence and health effects of obstructive sleep apnea have become more widely known among dental professionals. The discussion of the effects of extractions in orthodontics has shifted to include the volume and function of the upper airway. Anecdotally, severely constricted dental arches that result in the tongue crowding the oropharynx are posited as the link between the dentoalveolar anatomy and the airway. However, since altered dentofacial morphology is associated with obstructive sleep apnea in both children[7] and adults,[8,9] it is desirable to understand what impact, if any, orthodontic treatment with extractions may have on the airway.

Initial investigations on the effects of orthodontic treatment on the pharyngeal airway space have used lateral cephalometrics. One study[10] found a reduction in the dimension of the pharyngeal airway space after orthodontic treatment with the extraction of 4 premolars, whereas others have found either no change in airway dimensions[11] or differing results depending on the specific mechanics used during treatment.[12] The significant limitation shared by these studies is that

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assessments were based on 2-dimensional lateral cephalographs; therefore, only the sagittal and vertical dimensions of the airway were evaluated.

With the advent of cone-beam computed tomography (CBCT) imaging, our understanding of airway morphology has been expanded to 3 dimensions to include the overall volume and, perhaps most physiologically relevant, the cross-sectional area perpendicular to the direction of airflow as visualized in the axial plane.[13] Valiathan et al[14] used CBCT to compare airway changes of 20 adolescents undergoing orthodontic treatment with premolar extractions with age-matched, nonextraction controls. They reported no difference in the oropharyngeal airway volume changes between the 2 groups despite differences in incisor angulations and protrusion. Other similar studies involving adolescents have also found no differences in dimensional changes in the airways between extraction and nonextraction orthodontic treatments.[15,16] However, a potential confounding factor common among these studies has been the inclusion of growing subjects. Because the airway volumes of most patients in these studies was found to increase regardless of the treatment, it is possible that treatment effects were masked by ongoing growth. Therefore, it may be desirable to eliminate the confounding effect of growth in future studies. The aim of our study was to investigate the effects of orthodontic treatment with and without extractions on the volume and minimal cross-sectional area of the upper airway in a cohort of nongrowing adult patients.

MATERIAL AND METHODS

Initial compilation of the study data consisted of application of screening criteria to all patients treated from September 2008 to June 2012 at the Division of Orthodontics, University of Minnesota, in Minneapolis, Minn. Initial eligibility criteria included at least 18 years of age at treatment start, complete pretreatment and posttreatment CBCT scans available, no missing teeth (excluding third molars), and a negative history of previous orthodontic treatment or orthognathic or airway surgery. Patients with a Class III skeletal relationship (ANB angle, $<0^\circ$) or a history of cleft lip or palate or any craniofacial syndrome were also excluded. Within this time period, 202 patients were adults, and 74 met the eligibility criteria. Patients in the extraction group had at least 2 premolars extracted as part of their orthodontic treatment. For this sample, the pretreatment and posttreatment DICOM files were exported, and the following deidentified data were collected: age, sex, amounts of dental crowding in the maxillary and mandibular arches, amounts of overbite and overjet, treatment time, number of teeth removed, and orthodontic appliances used. The Research Ethics Board at the University of British Columbia (H12-00951) approved the study protocol.

All CBCT scans were taken using an i-CAT Next Generation CBCT unit (Imaging Sciences International, Hatfield, Pa) with a 17-cm field of view and scan times of 8.9 to 17.8 seconds. At the time of image acquisition, no specific instructions had been given to patients in regard to mode of breathing or tongue position beyond "remain perfectly still and breathe quietly through your nose." DICOM files were imported into and analyzed using Dolphin software (version 11.5; Dolphin Imaging and Management Solutions, Chatsworth, Calif) for this study. Before we generated the lateral cephalometric and airway images, the 3-dimensional images were all standardized in orientation with the midsagittal plane determined from the skeletal midline of the face using a line connecting the incisive foramen to opisthion. The axial plane was adjusted with a line connecting the inferior border of the left and right orbits parallel to the horizontal grid. The coronal plane was adjusted from the Frankfort horizontal plane (right porion to right orbitale) perpendicular to a line passing through the level of the furcation point of the maxillary right first molar. Lateral cephalographs were generated from the DICOM files of each patient, and the cephalometric analysis was performed according to the guidelines of the American Board of Orthodontics.

Airway volumetric renderings of the subjects' CBCT scans were developed to measure the volume and minimum axial areas using the airway function of the Dolphin software program.[17] The anatomic landmarks (Table I) were identified, and airways were measured in the nasopharygeal, retropalatal, retroglossal, and total airway regions as defined by Arens and Marcus[18] (Fig). The posterior superior pharyngeal wall point is defined as a line extending posteriorly from the palatal plane to the posterior pharyngeal wall. The palatal plane is defined as a line connecting the anterior nasal spine to the posterior nasal spine. The posterior middle pharyngeal wall point is defined as a line extending from the posterior inferior tip of the soft palate to the posterior pharyngeal wall and parallel to the palatal plane. The posterior inferior pharyngeal wall point is defined as a line extending posteriorly from the tip of the epiglottis to the posterior pharyngeal wall and parallel to the palatal plane. Airway segmentation threshold values were adjusted to eliminate imaging artifacts and ranged from 50 to 75. The airway volume was then calculated in cubic millimeters, and the most constricted axial area of the airway was calculated in square millimeters.

Table I. Anatomic landmarks and regions of the upper airway

	Anterior boundary	*Posterior boundary*	*Superior boundary*	*Inferior boundary*
Nasopharynx	Line from sella (S) to posterior nasal spine (PNS)	Line from S to the posterior superior pharyngeal wall	Sella	Line from PNS to the posterior superior pharyngeal wall (SP)
Retropalatal	Line from PNS to the most posterior inferior point of the soft palate	Line from SP to the posterior middle pharyngeal wall (MP)	Line from PNS to SP	Line from the posterior inferior point of the soft palate to MP
Retroglossal	Line from the posterior inferior point of the soft palate to the tip of the epiglottis	Line from MP to the posterior inferior pharyngeal wall (IP)	Line from IP of the soft palate to MP	Line from the tip of the epiglottis to IP
Total airway	Line from S to PNS to the tip of the epiglottis	Line from S to SP to IP	Sella	Line from the tip of the epiglottis to IP

Statistical analysis

The influence of potentially confounding variables such as skeletal classification Class I (ANB angle, 0°-4°) vs Class II (ANB angle, $>4°$), and sex classification (male vs female) on the baseline (T0) characteristics of the airway were assessed with the unpaired Student *t* test. Analysis of variance (ANOVA) was used to assess T0 differences between patients with low, normal, and high mandibular plane angles (low angle, $\leq 27°$; normal angle, $>27°$ to $<38°$; and high angle, $\geq 38°$). The significance of treatment changes (T0 to posttreatment [T1]) of all variables was determined with the paired Student *t* test. The Wilcoxon signed rank test was used for comparing any nonnormally distributed variable changes. The Bonferroni adjustment was applied to multiple comparisons, and statistical significance was set at $P < 0.05$. Spearman correlation coefficients were calculated to evaluate the relationships between baseline crowding and changes (T0-T1) in volume and minimal cross sectional areas of the airway.

To assess the measurement error of the cephalometric and airway analyses, 40 CBCT scans were randomly selected, and their cephalometric variables and airway dimensions were remeasured 2 weeks after the initial measurements by the same investigator (I.T.T.). Method errors were calculated using Dahlberg's statistic.[19] The range of errors of the cephalometric analysis was 0.51° to 1.24° for angular measurements. The errors for airway volume were 294.3 mm^3 for total airway, 221.4 mm^3 for the nasopharyngeal airway, 281.3 mm^3 for the retropalatal airway, and 201.4 mm^3 for the retroglossal airway. Measurement errors of the minimal cross-sectional area ranged from 17.6 to 46.7 mm^2.

RESULTS

The upper airways were studied in 74 healthy adults treated orthodontically with and without dental extractions (Table II). No significant differences were found in the mean initial and final airway volumes between mandibular plane angles (normal vs high vs low), anteroposterior skeletal relationships (Class I vs Class II), and the sexes. Consequently, female and male patients, all 3 mandibular plane angle groups, and the Class I and Class II groups were combined as 1 sample to examine the effects of extraction and nonextraction treatments on the airway volumetric changes.

The nonextraction group was composed of 17 men and 31 women who were treated orthodontically without the removal of any teeth, excluding third molars. The extraction group consisted of 8 men and 18 women who had at least 2 premolars extracted in conjunction with their orthodontic treatment. At T0, the mean ages were 31.9 ± 12.0 years for the nonextraction group and 27.4 ± 9.7 years for the extraction group. The average treatment times for the nonextraction and extraction groups were 18.7 ± 5.4 months and 23.5 ± 4.5 months, respectively, and this difference was statistically significant ($P < 0.05$).

The volumetric measurements and minimal cross-sectional areas, as well as treatment changes for the various regions of the airway are described in Table III. The initial and final volumes and the minimal cross-sectional areas were not significantly ($P > 0.05$) different for the nasopharyngeal, retropalatal, retroglossal, and total airway regions between the extraction and nonextraction groups. The volumes of the total airway were found to decrease by 6.6% (1704.1 mm^3) and 6.8% (1366.3 mm^3) for the nonextraction and extraction groups, respectively, and the difference was not significant. Similarly, with a large individual variations, the treatment changes for the nasopharyngeal, retropalatal, retroglossal, and total airway regions examined were also not significantly ($P > 0.05$) different between the 2 groups. The changes in the minimum cross-sectional area also followed this same trend. Reductions in

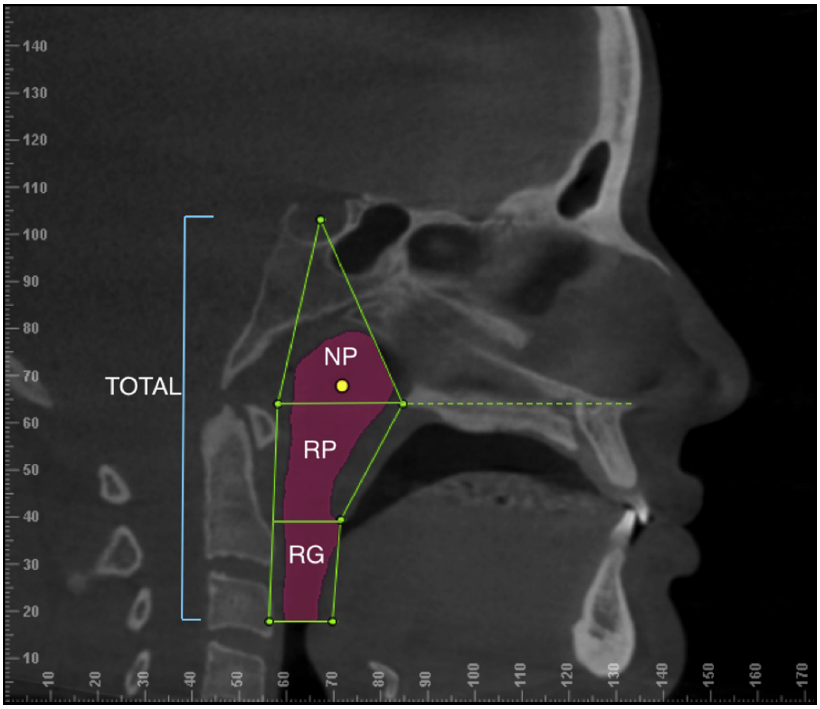

Fig. Defined total airway, consisting of the nasopharyngeal (*NP*), as well as the retropalatal (*RP*) and retroglossal (*RG*) regions of the oropharynx. The palatal plane set as the horizontal, with measurements taken in the midsagittal plane.

minimal cross-sectional area for the total airway of 13.1% (32.3 mm^2) for the nonextraction group, and 16.0% (33.1 mm^2) in patients with extractions were observed, and differences between groups were not significant for all airway regions.

To assess the possible impact of the amount of initial dental crowding on the magnitude and direction of dimensional changes of the upper airway, differences between the initial crowding and the airway change for both extraction and nonextraction groups were tested. Dental crowding was divided into 4 groups: dentitions with spacing, minimal (≥ 0 to ≤ 3 mm), moderate (> 3 to ≤ 7 mm), and severe (> 7 mm). There was no statistically significant correlation between crowding and the nonextraction group for all regions of the airway. However, for the extraction group, only the change in volume of the retroglossal region had a significant ($P = 0.003$) negative correlation ($r = 0.34$) to the amount of crowding. In the retroglossal region, there were a decrease in mean volume change with minimal initial crowding (-1880.3 ± 586 mm^3) and an increase in severe crowding (875.2 ± 2165.7 mm^3) when extractions were part of the orthodontic treatment. For all other sections of the airway analyzed with respect to volume and minimum axial areas, no significant relationships between crowding and changes in airway volume or minimum axial areas were observed.

DISCUSSION

The indications and merits of dental extractions to facilitate orthodontic treatment have long been debated. More recently, discussion on the supposed restrictive effects of extractions has shifted to focus on the upper airway and the possible associations with obstructive sleep apnea. Using 3-dimensional analysis of the upper airway with CBCT imaging, we have demonstrated that the treatment effects on the upper airway are not significantly different with extraction compared with nonextraction treatment. In our sample of 74 adults, all had nominal decreases in the total volume of their airway and the minimal cross-sectional area regardless of treatment modality.

In contrast to our study in adults, most previous studies examining airway volumetric changes with CBCT did so in adolescent patients. Shannon[15] investigated the relationship between orthodontic extraction treatment and the oropharyngeal airway volume in 27 extraction and 61 nonextraction patients. The author found net increases in oropharyngeal widths, cross-sectional areas, and oropharyngeal volumes for both

Table II. Baseline demographic information of the sample

	Total n (%)	*Nonextraction n (%)*	*Extraction n (%)*
Patients	74	48	26
Male/female ratio	25/49	17/31	8/18
Age (y)	30.4 ± 11.4	31.9 ± 12.0	27.4 ± 9.7
Treatment length (mo)	20.4 ± 5.6	18.7 ± 5.4	23.5 ± 4.5
Class I skeletal relationship	38 (51.4)	29 (60.4)	9 (34.6)
Class II skeletal relationship	36 (48.6)	19 (39.6)	17 (65.4)
Low mandibular plane angle (≤27°)	15 (20.3)	13 (27.1)	2 (7.7)
Normal mandibular plane angle (27°-38°)	45 (60.8)	29 (60.4)	16 (61.5)
High mandibular plane angle (≥38°)	14 (18.9)	6 (12.5)	8 (30.8)

treatment groups. However, as in our study, no significant difference in treatment effects to the airway was observed between patients with and without extractions. Similar findings were reported by Stefanovic et al[16] after their examination of 31 adolescents, with no statistically significant differences in the pharyngeal airway between extraction and nonextraction groups at either the beginning or the end of treatment. Although it was concluded that reducing dental arch perimeter with dental extractions has no effect on oropharyngeal size, these patients were studied during a period of ongoing craniofacial growth. Therefore, growth of the hard and soft tissues surrounding the airway may have partially masked the treatment effects.

Conversely, Chen et al,[20] using multislice computed tomography, investigated the effect of large incisor retractions on the upper airways in adults. With a sample of 30 bimaxillary protrusive patients with 4 first premolars extracted followed by space closure with maximum anchorage supported by skeletal implants, they observed decreases in mean cross-sectional areas of the palatopharynx (21%), glossopharynx (25%), and hypopharynx (38%). Although there were no volumetric measurements, they concluded that the narrowing of the upper airway was possible with extraction orthodontics. However, since minimum cross-sectional areas have been found to be the least reliable measurement in airway analysis,[21] the decision of Chen et al to use only measurements of cross-sectional areas of the airway to represent treatment changes and not to have a control group without extractions can be seen as major limitations. In contrast, for this study, we analyzed both volumetric and cross-sectional measurements to represent changes in the airways to fully account for the typical irregular airway lumen, and these changes were compared with those in a nonextraction group. Overall, the volumetric measurements of this study were similar to those in studies that also segmented the airway into nasopharynx (3221 ± 1660 mm^3), oropharynx (10688 ± 6019 mm^3), hypopharynx (3319 ± 1216 mm^3), and total airway (17228 mm^3).[22]

We aimed to focus on Class II (ANB angle, >4°) craniofacial morphologies because previous studies have suggested that retrognathia may be 1 anatomic risk for acquiring obstructive sleep apnea.[23-26] Skeletal Class III patients were excluded from analysis because of their minimal representation in the sample. The Class I (ANB angle, >0° to <4°) and Class II (ANB angle, ≥4°) skeletal relationships were divided into 2 groups to evaluate the effects on upper airway volumes. We found no significant differences in the initial airway volumes between the Class II and Class I patients, nor did we find any significant differences between the changes caused by treatment in the upper airway volume.

We investigated the initial volumes and changes in volume between patients with high (SN-MP, ≥38°), normal (SN-MP, <38° to >27°), and low (SN-MP, ≤26°) mandibular plane angles. It was previously reported that significant differences in the pharyngeal airway volume exist among patients with different vertical skeletal patterns, with high angle patients having a reduced airway volume compared with normal and low angle patients.[27] This disagrees with our current findings; we found no significant difference between the initial volumes of patients with high, normal, and low angles. Similarly, no significant differences were found between the changes in volume among the 3 mandibular plane angle groups. As with anteroposterior skeletal relationships, the large variations in airway measurements and relatively small sample sizes may have prevented detection of differences previously reported in the literature.

Although we demonstrated no significant changes in the airways between the extraction and nonextraction orthodontic groups, volumetric assessment of the airway is complicated by several factors. Any increases or decreases in the airway volume could be attributed to mode of breathing, variations in the position of the tongue during image acquisition, measurement errors, or changes in the soft tissues caused by adiposity and general inflammation over the approximately 2 years of treatment.

The lack of significant differences in airway volume in the extraction group compared with the nonextraction patients may be explained by the mechanics of closing extraction spaces. When extraction spaces are closed

Table III. Initial, final, and change in airway measurements between the extraction and nonextraction groups

	Extraction (n = 26)	*Nonextraction (n = 48)*	P *value*
Nasopharyngeal volume (mm^3)			
Baseline, T0	5937.6 (2117.1)	7124.5 (2962.1)	NS
Posttreatment, T1	5801.4 (2009.8)	7161.0 (2623.2)	NS
Treatment change, T0-T1	−136.1 (1379.3)	36.5 (1139.8)	NS
Retropalatal volume (mm^3)			
Baseline T0	9866.1 (3965.1)	10110.6 (4137.2)	NS
Posttreatment T1	9453.5 (4760.3)	9711.3 (3788.7)	NS
Treatment change T0-T1	−412.7 (3042.5)	−399.3 (3294.6)	NS
Retropalatal MCA (mm^2)			
Baseline, T0	202.46 (95.2)	226.2 (117.4)	NS
Posttreatment, T1	182.3 (102.2)	203.3 (109.3)	NS
Treatment change, T0-T1	−20.8 (84.7)	−22.9 (81.80)	NS
Retroglossal volume (mm^3)			
Baseline, T0	4356.1 (2334.8)	5594.8 (3340.6)	NS
Posttreatment, T1	3943.6 (2582.8)	4485.6 (2793.0)	NS
Treatment change, T0-T1	−412.5 (1503.2)	−1109.3 (2328.6)	NS
Retroglossal MCA (mm^2)			
Baseline, T0	206.2 (93.4)	227.1 (112.9)	NS
Posttreatment, T1	173.9 (98.9)	189.2 (105.3)	NS
Treatment change, T0-T1	−32.3 (72.6)	−37.8 (97.1)	NS
Total airway volume (mm^3)			
Baseline, T0	20056.4 (6848.8)	25951.3 (8160.3)	NS
Posttreatment, T1	18690.2 (7285.0)	24247.3 (7075.3)	NS
Treatment change, T0-T1	−1366.3 (4061.2)	−1704.1 (5466.1)	NS
Total airway MCA (mm^2)			
Baseline, T0	206.6 (98.4)	246.6 (113.5)	NS
Posttreatment, T1	160.6 (92.4)	202.1 (95.6)	NS
Treatment change, T0-T1	−33.1 (53.4)	−32.3 (80.0)	NS

Measurements given in means (and standard deviations).
MCA, minimal cross-sectional area; *NS*, not significant.

after removal of a permanent first premolar, reciprocal anchorage mechanics are in play, as seen when the posterior teeth move mesially as the anterior teeth are retracted distally. Hence, anchorage loss of the posterior segment is seen as the anterior segment is retracted. Frequently, the extraction space is required to resolve crowding of the anterior segment; thus, the posterior segment needs to move mesially to close the extraction space. The mesial movement of the posterior segment and the effects of anchorage loss decrease the impact of the anterior segment displacing the tongue posteriorly into the oropharynx. In comparison with the previously discussed study by Chen et al,[20] who found a reduction in airway volume when extraction spaces were closed using maximum anchorage, the anchorage used with our sample was not uniform and thus may have had an influence on our results.

The diagnosis leading to the decision of extraction therapy directly influences the choice of orthodontic mechanics used in closing extraction spaces. Typical reasons for extraction of teeth in orthodontics are to correct anteroposterior occlusal discrepancies, dental crowding, or both. We looked at the correlation between crowding and change in airway and found significant differences in volume changes between patients with minimal or severe crowding when extractions were used during orthodontic treatment. The patients with severe crowding tended to have an increase in airway after orthodontic treatment. Conversely, patients with minimal crowding tended to see a decrease in airway volume. This can be explained by space closure mechanics; when extractions are performed in patients with minimal crowding, a greater amount of the extraction space will be present after dental alignment, resulting in greater retraction of the anterior teeth and constriction of the arches. If extractions are planned for crowding reasons, there may be no expected decrease in airway, because the extractions would have alleviated the space for the adjacent teeth to align and maintain the original airway dimensions.

As with any retrospective study, these findings have several limitations. Factors that influenced the records include the patient's mode of breathing, body mass index, adiposity, soft tissue changes over the 2 years of treatment, and minor effects of the tongue position. All these factors could influence increases and decreases in airway changes. Although not routinely incorporated in pretreatment orthodontic records, future CBCT studies would benefit if height and weight data were available to correlate body mass index and change in airway between extraction and nonextraction groups. We also wanted to limit our sample to nongrowing subjects to address the confounders of growth in previous studies. This is a challenging task because most patients who seek orthodontic care are children and adolescents, thus limiting our sample size. The CBCT images were taken with the patients in an upright position while awake. How the shape and function of the airway during this scenario relates to those of a patient who is supine and sleeping is not known; very little correlation may exist. Therefore, caution is warranted when extending the findings of this or any other examination of airway anatomy while the patient is upright and awake. The nonsignificant findings between extraction and nonextraction orthodontic treatments on airway changes apply to anatomic findings alone and not necessarily to airway function, particularly to the complex neuromuscular functional deficits associated with obstructive sleep apnea. To truly assess the implications of orthodontic treatment with extractions on airway function, future studies with larger samples are required. Furthermore, these studies should assess not only anatomic changes but also changes in respiratory function during sleep.

CONCLUSIONS

Airway structures were analyzed in 74 healthy adults before and after orthodontic treatment. Using CBCT imaging, cephalometric variables and volumetric and minimum axial area measurements of the airway were analyzed. There was no evidence of differing effects on the nasopharynx, or the retropalatal and retroglossal regions of the oropharynx between extraction and nonextraction treatments.

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