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Three-dimensional pharyngeal airway changes in orthodontic patients treated with and without extractions

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Structured Abstract

Objective – To evaluate and compare three-dimensional pharyngeal airway changes in orthodontic patients treated with and without extractions.

Material and Methods – Pharyngeal airway was analyzed for 31 subjects (15 males, 16 females) treated with extractions of four first premolars and 31 age- and gender-matched controls (15 males, 16 females) treated without extractions. The mean age of subjects was 12.97 ± 1.15 years at the beginning and 15.69 ± 1.28 years at the end of treatment. The mean age of controls was 12.86 ± 0.74 years at the beginning and 15.18 ± 0.86 years at the end of treatment. Nasopharyngeal (NP) and oropharyngeal (OP) volumes, area of maximum pharyngeal constriction (AMPC), and upper arch perimeter were measured on T0 and T1 cone beam computed tomography (CBCT) scans. Paired samples *t*-test was used for analyzing statistical significance of changes ($p \leq 0.05$).

Results – There were no statistically significant differences in the pharyngeal airway values between the extraction and non-extraction groups at neither T0 nor T1. The extraction group showed a statistically significant increase for NP and OP volumes and AMPC values. Such increase was also noted in the non-extraction group, without statistical significance for AMPC values.

Conclusions – The findings suggest that an extraction or non-extraction choice for orthodontic treatment would not affect the pharyngeal airway.

Key words: cone beam computed tomography; extraction treatment; orthodontics; pharyngeal airways

Introduction

Extractions of permanent teeth have long been a part of the orthodontic treatment. Most common indications for extractions in orthodontics are excessive crowding or anteroposterior changes, as in class II or class III dental camouflages. Depending on the diagnosis and treatment planning, two or four premolars are usually extracted.

Dental extractions have been a topic of discussion and a cause of clinical disagreement ever since they were introduced to orthodontics. The debate on permanent teeth extractions is ongoing, only now, it is not only the esthetics (1–5) and stability (6) that are discussed, but also temporomandibular joint problems (7) and upper airway volumes (8, 9). One of the main issues of the current dispute is the dilemma on whether extracting teeth, therefore reducing the length of the dental arch, would deprive tongue of its essential space (10) and affect the upper airways (11).

In most current studies, airway analysis has been performed on lateral cephalograms, but because the airway passage is a three-dimensional structure, this may not represent a thorough assessment (12–14). Although airways could be visualized and analyzed in three dimensions (3D) using traditional computed tomography (CT), the radiation dose and the expenses are substantially high (15). Magnetic resonance imaging (MRI) is another possible method for 3D upper airway visualization, but it is also a costly procedure and requires significantly longer examination time, when compared to conventional CT. This may result in decreased airway image quality due to motion artifacts (16). Another disadvantage of using CT or MRI is that they are usually only available in hospital settings, making their use less accessible to most clinicians. Cone beam computed tomography (CBCT), developed in the 1980s, and introduced into widespread use in craniofacial imaging in the past decade provides a relatively low dose and less expensive alternative for 3D imaging of upper airways (17). Aboudara et al. (18) who compared airway analysis on lateral cephalograms and CBCT images reported and later confirmed (17) moderate variability in the measurements of airways and inaccurate depiction of airway information on lateral cephalograms.

The purpose of this study was to evaluate and compare three-dimensional pharyngeal airway changes in orthodontic patients treated with and without extractions.

Materials and methods

Subjects

The sample of this retrospective study consisted of 31 subjects who underwent orthodontic treatment with extractions of all four first premolars (extraction group) and 31 controls treated orthodontically without extractions (non-extraction group) at the Department of Orthodontics, School of Dental Medicine, Case Western Reserve University in Cleveland, OH, USA. The Department has around 30 supervising faculty, which are assigned cases and treat them as if they were patients in their own office; therefore, the criteria for extraction or non-extraction were based on the instructor's personal treatment philosophy. The non-extraction group was used as control and was matched for age and gender (Table 1). None of the patients had any history of breathing disorders.

Radiographic method

All patients were treated with standard edgewise appliances and had CBCT scans taken before (T0) and after orthodontic treatment (T1) using a custom Hitachi CB MercuRay scanner (Hitachi Medical Systems America Inc., Twinsburg, OH, USA). This particular CB MercuRay has custom settings to provide the lowest radiation exposure possible while maintaining acceptable diagnostic image quality (19, 20). This modification was made to fully comply with ALARA (as low as reasonably achievable) standards. All of the images were taken at 2 mA, 120 kV, and a 12-inch field of view (F mode) setting. Each patient's image data consisted of 512 slices, with an isometric voxel size of 0.377 mm, a resolution of 1024×1024 pixels and 12 bits per pixel (4096

Table 1. **Differences in age, treatment time, skeletal variables, and gender between the extraction and the non-extraction groups[†]**

	Age (years)		Tx. time	FMA (°)		Classes			Gender	
	Mean ± SD									
	T0	T1	T0–T1	T0	T1	I	II	III	Male	Female
Extraction group n = 31	12.97 ± 1.15	15.69 ± 1.28	2.72 ± 0.45	26.55 ± 4.79	26.55 ± 4.98	13	15	3	15	16
Non-extraction group n = 31	12.86 ± 0.74	15.18 ± 0.86	2.32 ± 0.34	24.34 ± 3.49	24.54 ± 3.65	14	15	2	15	16
p value	0.688	0.117	0.001*	0.051	0.097	NS			NS	

*$p < 0.01$.
[†]FMA indicates mandibular plane angle; classes present sagittal jaw relationship classification according to the ANB angle to classes I, II, and III.

grayscale). The images were taken in the sitting position with patient's head in the natural head posture, teeth in maximum intercuspation and at the end of the exhalation period when the patient was not swallowing. The scan time was 9.6 s. The images used were preexisting and taken as part of orthodontic records. All patients have signed the informed consent form allowing the use of their records for research and publication purposes. The Human Research Ethics Committee of the Faculty of Stomatology University of Belgrade approved this research (resolution number 36/20 from December 14, 2009).

Cephalograms were generated from Digital Imaging and Communication in Medicine (DICOM) images, and analysis was performed using Dolphin Imaging software version 11 (Dolphin Imaging, Chatsworth, CA, USA). FMA (Frankfort-mandibular plane angle), formed by the intersection of the Frankfort horizontal and the mandibular plane, was measured to define the mandibular plane angle (normal range: 25° ± 5°). Sagittal jaw relationships were determined according to the ANB angle. Values between 1° and 3° were considered class I, values >3° class II, and <1° class III.

Digital Imaging and Communication in Medicine images were analyzed using the InVivo Dental Software (Anatomage Inc., San Jose, CA, USA). Images were oriented in the section view according to the axial, coronal, and sagittal slices using the patient orientation tool (Fig. 1). Midsagittal plane was determined using the *foramen incisivum* on the axial slice as a reference point (a). Palatal plane was adjusted on the sagittal slice to coincide with the true horizontal plane (b), and infraorbital points were aligned on the coronal slice (c). Image orientation was automatically transferred to the volume render view section, where the image was further processed (Fig. 2). It was put into the grayscale view (a), and reconstruction was set to maximum intensity (b). With the help of the patient orientation tool (c), the image was moved upward or downward if necessary, in order for the palatal plane to coincide with the central horizontal line of the grid. At this point, the slice view and the volume render view matched.

A positive airway was created, and volumes were calculated in the volume render view. The image was kept in the grayscale view, and the view point was changed to top view (Fig. 3A). After setting the reconstruction back to volume rendering, the image was inversed (Fig. 3B). Opacity was reduced until the internal structures were visible (Fig. 3C). Undesired parts were removed with the sculpting tool (Fig. 3D). The partly sculpted image (Fig. 3E) was then reoriented to right lateral view (Fig. 3F), and further sculpting was performed (Fig. 3G). After isolating the desired airway (Fig. 3H), opacity was increased and brightness and contrast were reset, which enabled obtaining a solid airway before calculating the final airway volume (Fig. 3I).

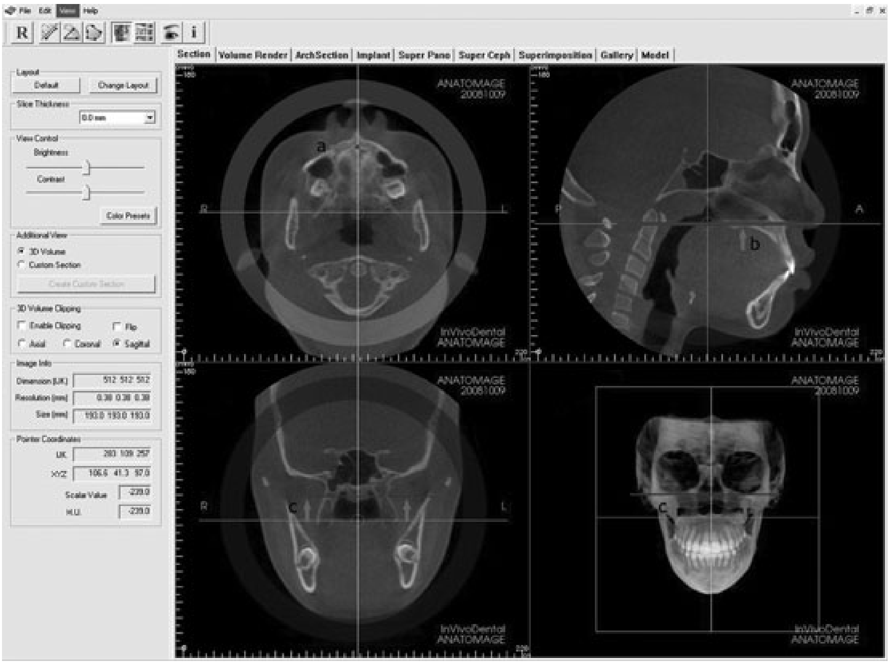

Fig. 1. Image orientation in the section view.

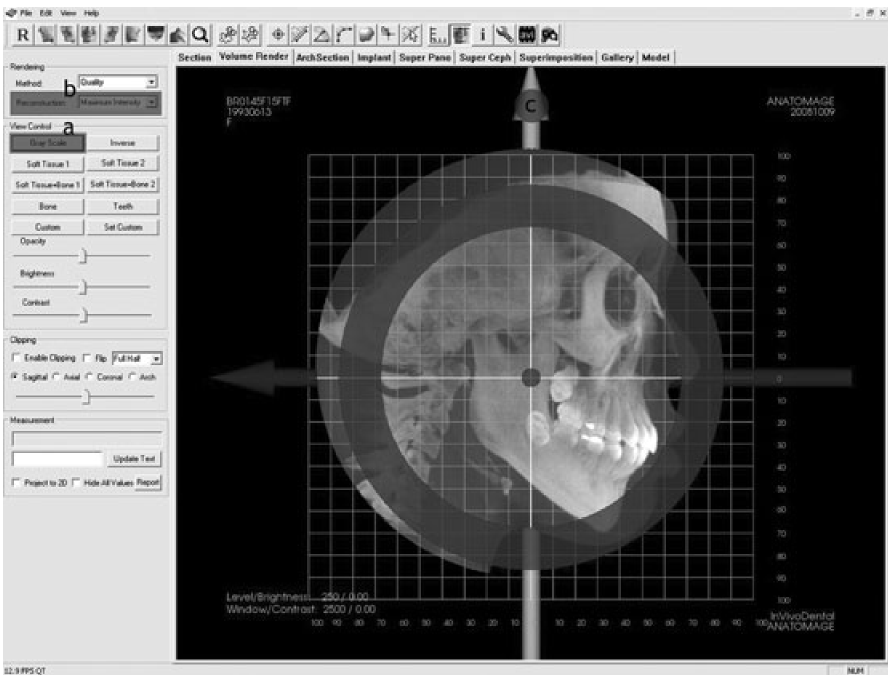

Fig. 2. Image orientation in the volume render view.

Nasal passages

For the Nasal passages (NP) airway volume calculation (Fig. 4), the horizontal line through the palatal plane was used as the inferior border of the NP (a). The superior border was defined in the section view by moving the axial reference plane on the sagittal slice until noting on the axial slice that it has reached the point where the nasal septum first fuses with the posterior wall of the pharynx (b). The distance between the superior and inferior borders was measured on the sagittal slice of the section view, using the distance measuring tool (c).

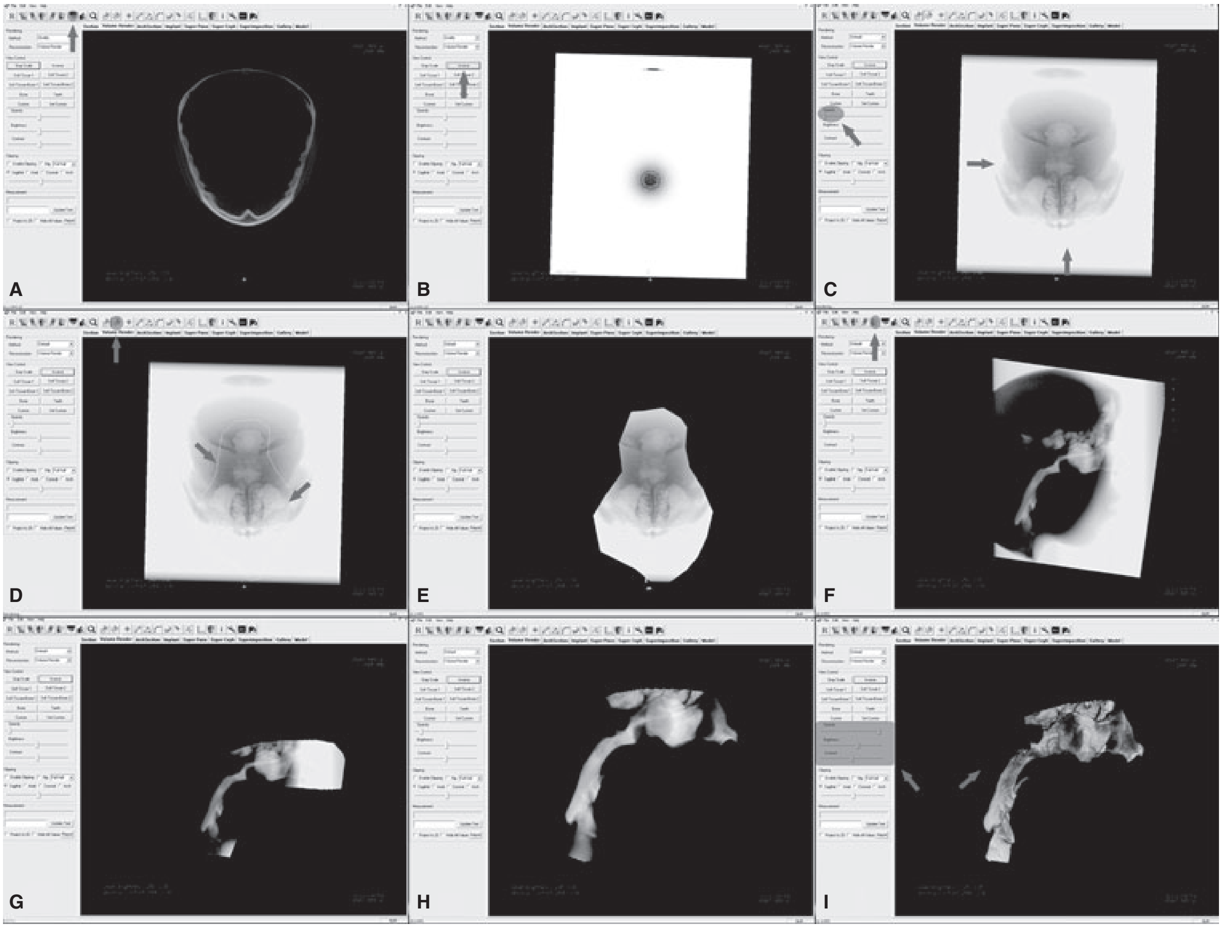

Fig. 3. Extracting the pharyngeal airway.

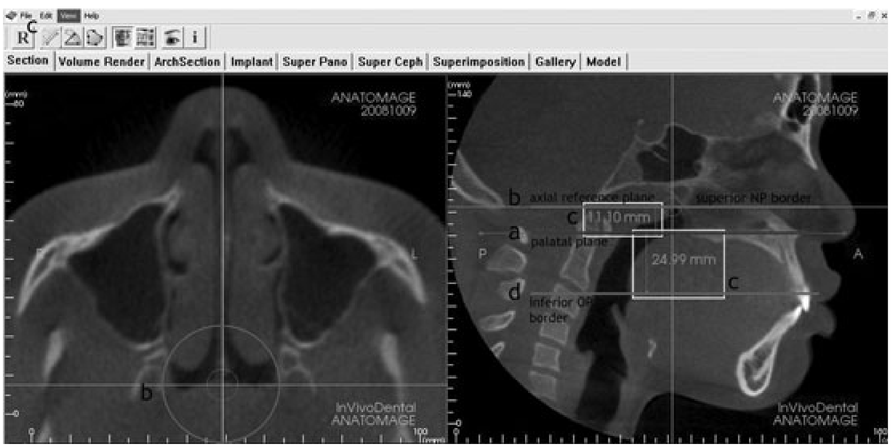

Fig. 4. Determining and measuring superior and inferior pharyngeal airway borders.

Airway volume was cut along the axial plane using the 3D volume clipping tool in the volume render view. By scrolling the mouse wheel, the clipping plane was moved, where needed, to coincide with the inferior NP border. The distance between the superior and

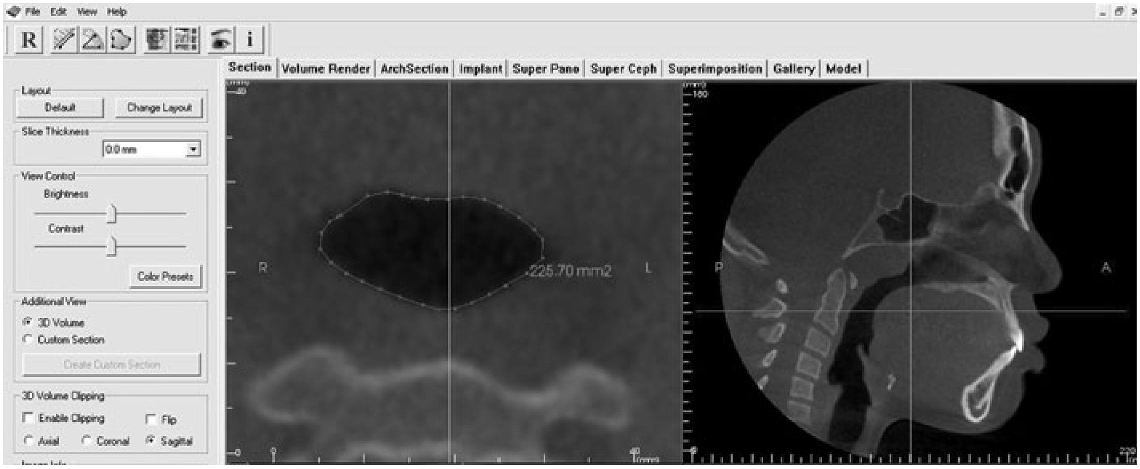

Fig. 5. Determining and measuring the area of maximum pharyngeal constriction.

inferior border, obtained earlier in the section view, was measured on the airway volume using the distance measuring tool, and the clipping tool was used to remove the airway volume above the superior NP border. The remaining volume was reoriented to the top view, and maxillary sinuses were sculpted out from the final NP volume.

The rest of the borders were determined by the software, as all volumes were calculated by automatic segmentation, using the volumetric measuring tool, which calculates and displays the desired volume measurement in mm^3 and cc.

Oropharyngeal airways

For the Oropharyngeal (OP) airway volume calculation (Fig. 4), the horizontal line through the palatal plane was used as the superior border (a) and the horizontal line through the most antero-inferior point of the second cervical vertebrae as the inferior border (d). The distance between the superior and inferior borders was measured on the sagittal slice of the section view, using the distance measuring tool (c).

The view of the airway volume that was cut for the NP volume calculation was flipped to the opposite side using the flip option of the 3D volume clipping tool, making the palatal plane the superior border. The distance between the superior and inferior border, previously measured in the section view, was transferred to the airway volume, and the airway volume below the inferior border was cut using the sculpting tool. Volume measuring tool was used for obtaining the OP volume value.

Area of maximum pharyngeal constriction

The area of maximum pharyngeal constriction (AMPC) was measured in the sectional view on the axial slices using the area measuring tool. The point of maximum constriction was determined by moving the axial reference plane on the sagittal slice and observing the airway area on the corresponding axial slice (Fig. 5).

Arch perimeter

Upper arch perimeter was measured on the axial slice, which was determined by moving the axial reference plane on the sagittal slice until it reached the middle of the upper teeth crowns. Axial slice was then enlarged, and the built-in option for linear measurements was used to measure distances between adjacent teeth from the distal surface of the upper right to the distal surface of the upper left first molar. Individual distances were added to obtain the upper arch perimeter.

A single operator (N.S.) was trained and calibrated by experienced experts (J.M.P. and H.E.), to perform all measurements collected. All measuring was repeated 2 weeks later for reliability testing.

Table 2. **Descriptive statistics and comparison of pharyngeal airway and arch perimeter measurements at T0 and T1 for the extraction and non-extraction groups†**

	T0				T1				
	Minimum	Maximum	Mean	SD	Minimum	Maximum	Mean	SD	*p* value
Extraction group									
n = 31									
NP volume (mm^3)	815	8377	3780.58	1968.49	1008	9049	4445.84	2002.49	0.002**
OP volume (mm^3)	606	17079	5063.45	2991.07	2263	19057	6732.32	3729.11	0.001**
AMPC (mm^2)	55.05	378.32	145.89	65.77	59.33	418.55	176.77	86.22	0.014*
Arch perimeter (mm)	84.40	109.19	95.99	5.90	78.80	95.30	87.56	4.58	0.000***
Non-extraction group									
n = 31									
NP volume (mm^3)	798	14408	4361.55	2572.64	2250	12092	5477.29	2652.78	0.007**
OP volume (mm^3)	1664	14665	6031.23	2946.24	2917	18665	7136.61	4014.98	0.038*
AMPC (mm^2)	19.57	348.16	153.23	83.09	60.46	387.44	172.57	87.56	0.082
Arch perimeter (mm)	84.19	105.31	97.23	4.88	87.98	106.33	98.02	4.57	0.274

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
†NP, nasal passage; OP, oropharyngeal; AMPC, area of maximal oropharyngeal constriction.

Statistical analysis

The collected data were organized, and descriptive statistics (means, standard deviations, and ranges for pretreatment (T0) and post-treatment (T1) records) was performed in Microsoft Office Excel 2003 (Microsoft Corporation, Redmond, WA, USA). Further statistical analysis was performed using the SPSS software (version 12, SPSS Inc., Chicago, IL, USA). Intraoperator reliability for each measurement was estimated using the intraclass correlation coefficient (ICC). The method used has been previously tested for accuracy and reliability (21). The Kolmogorov–Smirnov test was applied to determine the normality of distribution for all data. Due to the normal distribution of data, parametric tests were used. Paired samples *t*-test was employed for analyzing statistical significance of changes between T0 and T1. The level of significance was set at $p < 0.05$.

Results

The intraclass correlation coefficient for all measured parameters showed high reliability and reproducibility of measurements ($r > 0.95$).

Descriptive statistics and comparison of pharyngeal airway and arch perimeter measurements at T0 and T1 in both the extraction and non-extraction groups are presented in Table 2.

Both extraction and non-extraction groups showed an increase in NP and OP volumes, as well as the area of maximum pharyngeal constriction. The extraction group showed a statistically significant increase between T0 and T1 for all pharyngeal airway values. The non-extraction group expressed statistical significance for the OP and NP volume increase, while the increase in the AMPC showed no statistical significance. Arch perimeter decreased significantly in the extraction group, whereas no statistically significant change occurred in the non-extraction group (Table 2).

No significant pharyngeal airway differences were noted at either T0 or T1 between the extraction and the non-extraction groups. Arch perimeter values were significantly different between the groups at T1 (Table 3).

Discussion

This study was designed to assess the airway passage changes in growing orthodontic patients

Table 3. **Mean differences for pharyngeal airway and arch perimeter measurements between the extraction and non-extraction groups at T0 and T1**[†]

	T0			T1		
	Mean			Mean		
	Extraction n = 31	Non-extraction n = 31	*p* value	Extraction n = 31	Non-extraction n = 31	*p* value
NP volume (mm³)	3780.58 ± 1968.49	4361.55 ± 2572.64	0.324	4445.84 ± 2002.49	5477.29 ± 2652.78	0.063
OP volume (mm³)	5063.45 ± 2991.07	6031.23 ± 2946.24	0.172	6732.32 ± 3729.11	7136.61 ± 4014.98	0.699
AMPC (mm²)	145.89 ± 65.77	153.23 ± 83.09	0.721	176.77 ± 86.22	172.57 ± 87.67	0.857
Arch perimeter (mm)	95.99 ± 5.90	97.23 ± 4.88	0.248	87.56 ± 4.58	98.02 ± 4.57	0.000*

*$p < 0.001$.
[†]NP, nasal passage; OP, oropharyngeal; AMPC, area of maximal oropharyngeal constriction.

treated with and without extractions of permanent teeth. Introduction of the CBCT scanners enabled us to overcome some of the limitations of pharyngeal airway analysis on lateral cephalograms and analyze the airways of our patients in more detail and much easier than ever before (17, 18). Therefore, we could analyze the OP and NP airway volumes and the AMPC using the information from the DICOM images provided by a single CBCT scan.

The connection of the breathing function to the craniofacial complex development and the dental arch morphology (22, 23), as well as to the craniofacial complex and the occlusion (24, 25), has been reported in the literature. However, these authors examined the effect of impaired breathing on dental and craniofacial structures, while the present study attempted to see whether the change in arch size and morphology affected the upper airways. As expected, the dental arch perimeter in the extraction group in our research decreased significantly as a result of first premolar extractions, but this did not appear to have a negative effect on the pharyngeal airway dimensions. Results of this study show a statistically significant mean increase in the NP and OP airway volume and the AMPC for the extraction group. Germec-Cakan et al. (9) also reported a statistically significant increase in the superior and middle airway size in subjects treated with extractions and minimum anchorage, while Valiathan et al. (8) noticed a nonsignificant increase in the OP volume and area of maximum constriction in extraction subjects, but used a smaller sample size and restricted measurement to the oropharyngeal area.

The non-extraction group of our study showed similar results. A significant increase was noted in the NP and OP volume and a nonsignificant increase in the AMPC.

The potential explanation for the increase in the extraction and non-extraction group of our study could be growth, as Abramson et al. (26) explain that growth of the upper airways occurs predominantly during the primary (0–5 years) and permanent (12–16 years) stages of dentition, corresponding to periods of significant somatic growth. Baring in mind that the average age of patients in the extraction group of this study varied from 12.97 ± 1.15 years at T0 to 15.69 ± 1.28 years at T1 and from 12.86 ± 0.74 years at T0 to 15.18 ± 0.86 years at T1 in the non-extraction group, growth is the most likely explanation.

One of the concerns orthodontists might be facing nowadays is the potential link between pharyngeal airway dimensions and the sleep-induced breathing disturbances (27). The obstructive sleep apnea syndrome (OSAS) is one of the medical conditions with the raising occurrence in the general population (28). Attempts have been made to connect dentofacial characteristics and malocclusion with the

OSAS, but no correlations were found (29–31). They hypothesized that the occurrence of sleep problems is related to the size of the region enclosed by the mandible. This is in line with the findings of Zucconi et al. (32) that showed a significant decrease in sagittal dimensions of the mandibular bone in habitual snorer subjects.

Therefore, the increase in the pharyngeal airway measurements we found, especially the statistically significant increase in the NP and OP volume and the AMPC in subjects treated with extractions, is an encouraging result. However, one of the selection criteria for our sample was the absence of breathing disorders; hence, no correlations between sleep-induced breathing disturbances and orthodontic treatment with extractions of permanent teeth could be made.

The studies examining breathing disturbances were discussed to direct attention to the importance of pharyngeal airway dimensions assessment in orthodontic diagnosis and treatment planning. Further investigation on larger samples and non-growing patients is suggested to establish more potential correlations.

Conclusion

This study suggests that either an extraction or non-extraction choice for orthodontic treatment would not differently affect the pharyngeal airway. There were no statistically significant differences in the pharyngeal airway values at either T0 or T1 when comparing orthodontic treatment using extractions vs. no extractions.

Clinical relevance

There is little evidence as to if an extraction or non-extraction option for an orthodontic patient would influence the patient's airways. Differences in pharyngeal airway changes between extraction and non-extraction orthodontic patients were examined. Pharyngeal airway dimensions increased significantly in both groups, with the exception of AMPC values in the non-extraction group, which increased insignificantly. These findings suggest that an extraction or non-extraction choice for orthodontic treatment would not have a negative effect on the pharyngeal airway.

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