Airway and cephalometric changes in adult orthodontic patients after premolar extractions

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ABSTRACT

Objective: To examine changes in the airway and cephalometric measurements associated with orthodontic treatment of adults with and without premolar extractions. The study investigated whether extractions had a direct or indirect effect on the airway and examined selected skeletal and dental features.

Materials and Methods: This retrospective study used pre- (T1) and posttreatment (T2) cone-beam computed tomography scans of 83 adult patients matched for age and sex. A total of 15 airway and 10 skeletal and dental measures were analyzed by means of repeated-measures analysis of variance.

Results: There were no results showing that extractions affected airway dimensions that could not be accounted for as reflections of measurement error. There was no evidence that extractions affected the airway indirectly through skeletal and dental changes. There were strong and consistent findings that patients with small airways showed larger ones after treatment and that patients with large airways showed smaller ones later. These effects were independent of whether or not extractions were part of treatment. The measurement phenomena of regression toward the mean and of differential unfolding of natural changes over time could have accounted for the results observed.

Conclusions: There was no evidence that extractions in nongrowing patients have negative consequences on the size of various airway measures in the nasopharynx, retropalatal, or retroglossal regions. (*Angle Orthod.* 2020;90:39–46.)

KEY WORDS: Airway change; Premolar extraction; Adults; CBCT; MCA; Incisor retraction

INTRODUCTION

Increased attention is being paid to airway capacity, promoted in part by more widespread use of cone-beam computed tomography (CBCT) and concerns regarding obstructive sleep apnea.[1–3] In addition, it seems there is a trend toward less frequent extraction and more arch expansion, especially in the mixed dentition.[4] These trends are sometimes conjoined and supported by the belief that extraction of premolars contributes to collapse of the airway. In a survey of 125 orthodontists presented with a mouth-breathing female and a CBCT minimal cross-sectional area (MCA) reading of 50 mm^2, 42% said they would modify their treatment approach based on that information. The most common modification chosen (69%) was to avoid extraction.[5]

Previous studies investigating the effect of extractions on the airway have found either a reduction in dimensions after extractions[6,7] or no significant changes.[8–10] It has been proposed[11] that the indication for extraction may be related to how the upper airway changes after treatment. For example, large retraction of the incisors to resolve bimaxillary protrusion after premolar extraction with maximum anchorage resulted in decreased upper airway volume,[7] whereas airway

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Table 1. Reasons for Exclusion and Number of Patients Excluded[a]

Reasons for Exclusion	No. of Excluded Patients (n = 77)
Craniofacial anomalies	3
Orthognathic surgery	32
Extraction of teeth other than premolars	7
Missing CBCT at T1 or T2	35

[a] CBCT indicates cone-beam computed tomography; T1, pretreatment; and T2, posttreatment.

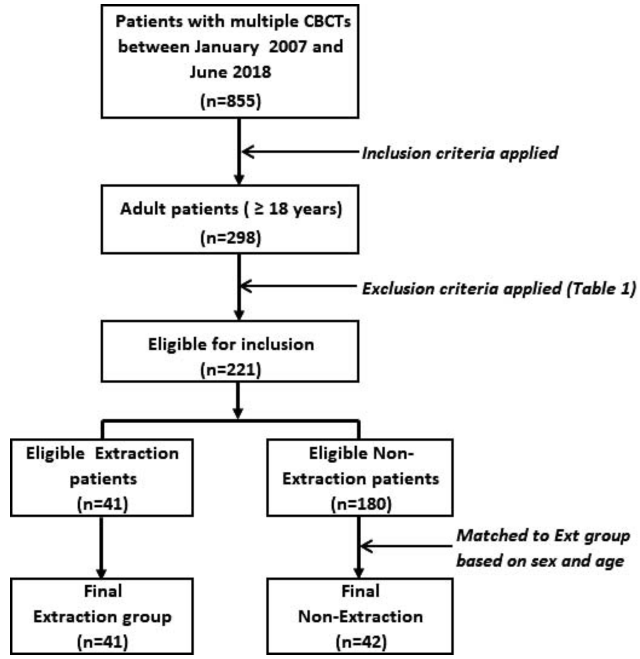

Figure 1. Sampling flow chart for patient selection, with exclusion criteria.

dimensions increased following extractions as a result of severe crowding with minimum anchorage space closure.[12]

Previous research has produced inconclusive findings. The purpose of this study was to investigate the relationship between extraction of premolars and changes in airway dimensions and possible associated skeletal and dental features in a sample of nongrowing patients. This research was undertaken to address four questions:

1. Is extraction as part of treatment associated with changes in airway dimensions?
2. Is extraction as part of treatment associated with selected skeletal and dental dimensions?
3. Do initial skeletal and dental dimensions interact with extraction to change airway dimensions?
4. Do measurement features of CBCT mask changes in airway, skeletal, and dental features?

MATERIALS AND METHODS

Sample selection began with identifying all patients who were treated between January 2007 and June 2018 in the Orthodontics Department at the University of the Pacific, Arthur A. Dugoni School of Dentistry, with appropriate CBCT images obtained as part of routine diagnostic records. Subjects met the following inclusion criteria: they were at least 18 years old at initiation of orthodontic treatment and there was availability of pre- (T1) and posttreatment (T2) CBCTs. After exclusion criteria were applied (Table 1), 221 patients were eligible to participate in this study (Figure 1). To be included in the extraction group, patients had to have had at least two premolars extracted. This condition was determined by the fact that shortening of the arch dimension by incisor retraction is primarily achieved by premolar extraction. Subjects in the nonextraction group were selected by matching for age and sex with subjects in the extraction group (Table 2). This sampling process resulted in 42 matched subjects for the extraction and nonextraction groups. One extraction subject was later excluded as a result of poor CBCT scan quality. Therefore, the final sample of 83 subjects included 41 subjects in the extraction group and 42 subjects in the nonextraction group. Within the extraction group, six subjects had only upper premolars extracted, and 35 subjects had four premolars extracted.

This study was approved by the institutional review board at the University of the Pacific (18-27).

Seventy-three CBCT scans were taken using the i-CAT Classic unit with 40-second exposure time (23 cm

Table 2. Sample Characteristics and Demographic Information by Treatment Group[a]

Variable	Extraction Group (n = 41)	Nonextraction Group (n = 42)
Sex		
Male	20	22
Female	21	20
Age, y		
<20	8	7
20–30	26	26
>30	7	9
Mean age at T1, y	26.1 ± 7.1	26 ± 8.0
T1-T2, y	3.5 ± 1.6	2.3 ± 0.9
Treatment type		
Fixed appliance	40	37
Clear aligner	1	5
Angle classification		
Class I	16	20
Class II	22	20
Class III	3	2
Initial crowding, mm		
Mild (≤3)	7	9
Moderate (4–6)	10	28
Severe (≥7)	24	5

[a] T1 indicates pretreatment; T2, posttreatment.

Table 3. Definitions of Skeletal and Dental Landmarks

Landmark	Symbol	Definition
Skeletal landmarks		
Nasion	N	The midpoint of the frontonasal suture
Basion	Ba	The most inferior and posterior point at the anterior margin of the foramen magnum
Sella	S	The midpoint of the cavity of sella turcica in all three planes
Orbitale[a]	Or	The most inferior point along the inferior margin of the orbital rim
Porion[a]	Po	The most superior and lateral point of the external auditory meatus
Anterior nasal spine	ANS	The most anterior point of the maxilla
Posterior nasal spine	PNS	The most posterior point of the palatine bone
Point A	A	The deepest point on the contour of the maxilla between the anterior nasal spline and the upper incisor
Point B	B	The innermost point on the contour of the mandible between the lower incisor and the bony chin
Menton	Me	The most inferior point along the middle of the mandibular symphysis
Gonion[a]	Go	The most inferior point of the angle of the mandible where the body of the mandible meets the ramus
Dental landmarks		
U1 incisal edge[a]	U1	The most mesial point along the maxillary central incisor incisal edge
U1 apex[a]	U1A	The maxillary central incisor root apex
L1 incisal edge[a]	L1	The most mesial point along the mandibular central incisor incisal edge
L1 apex[a]	L1A	The mandibular central incisor root apex
U6 MB cusp[a]	U6_MBC	The maxillary first molar mesiobuccal cusp tip
L6 MB cusp[a]	L6_MBC	The mandibular first molar mesiobuccal cusp tip

[a] Bilateral landmarks (right and left).

× 17 cm FOV, 0.3-mm voxel size), and 93 CBCT scans were taken using the i-CAT Next Generation unit with 8.9-second exposure time (23 cm × 17 cm FOV, 0.3-mm voxel size). While taking the scans, subjects were sitting upright and were instructed to bite into maximal intercuspation and remain stationary without swallowing. No instructions were given regarding the mode of breathing or tongue position. DICOM images were imported into Invivo software (version 6; Anatomage, San Jose, Calif) and deidentified for analysis. All scans were oriented as follows: (1) axial plane was adjusted by aligning the inferior border of the right and left orbits; (2) coronal plane was determined by the Frankfort horizontal plane (right porion and right orbitale); and (3) sagittal plane was adjusted by aligning the most anterior point on the lateral borders of the right and left orbital rims. Skeletal and dental landmarks were identified using the 3D Analysis function of Invivo software (Table 3).

For purposes of analysis, the airway was divided into three regions: nasopharynx (superior to the palatal plane), retropalatal region of the oropharynx (between the palatal plane and the base of the soft palate at the most anterior point), and retroglossal region of the oropharynx (between the base of the soft palate and the base of the epiglottis). Airway segmentation threshold values were adjusted to eliminate imaging artifacts and were held constant at about 400 relative Hounsfield units. The airway volume was then calculated in cubic centimeters, and the most constricted MCA of the airway was calculated in square millimeters for each of the three regions using the airway function of Invivo software. Additionally, in order to standardize measurements based on anatomical landmarks, the sagittal length (AP, in millimeters), lateral width (Lat, in millimeters), and cross-sectional area (XSec, in square millimeters) were measured at the level of the palatal plane, the base of the soft palate, and the base of the epiglottis (Figure 2; Table 4). In total, 15 airway and 10 cephalometric measurements were determined by averaging the measurements from two judges (Figures 2 and 3). Table 4 summarizes the variables used in this study.

Statistical Analysis

All airway measurements were performed by two judges. The average of their values was used for analysis, and the consistency of their reading of the CBCT images was gauged by Cronbach's alpha, a universal ICC measure. Descriptive statistics were calculated for 15 airway and 10 skeletal and dental variables at T1 and T2.

Independent *t*-tests were performed to determine whether groups were comparable at baseline. Repeated-measures analysis of variance (ANOVA) tests were performed to test for differences across time and across group (extraction vs nonextraction) and to identify interactions showing that extraction differentially affected airway, skeletal, or dental features. Repeated-measures tests were appropriate given that failure to consider within-subject variance typically overestimates the sensitivity of tests. Correlations between baseline scores and change in score, using Pearson correlation coefficients, were performed to identify potential confounding measurement sources of

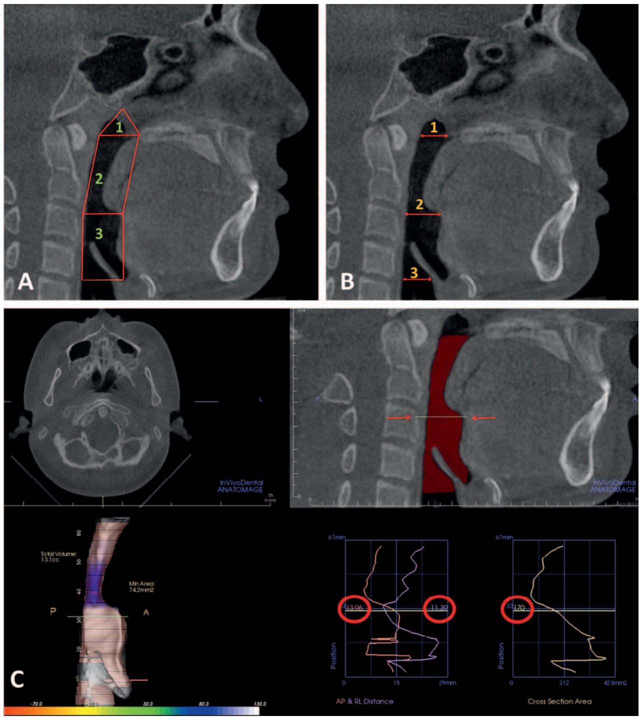

Figure 2. Regions of the airway and airway measurements. (A) 1, Nasopharynx; 2, Retropalatal; 3, Retroglossal; (B) (1) level of PNS; (2) level of base of soft palate; (3) level of base of epiglottis for cross sections parallel to Frankfort horizontal at standardized anatomical locations; (C) AP, Lat, and XSec at the level of the base of the soft palate.

variance. Sequential-entry multiple regression analysis was performed to control for potentially confounding effects. Exact test statistics are reported, as are exact *P*-values for all tests.

RESULTS

The average Cronbach alpha coefficient for consistency in airway readings for two judges was 0.981, with no coefficient below 0.954.

Table 4. Airway and Skeletal and Dental Cephalometric Measurements

Measurements	Definition
Airway analysis	
Anatomic defined measurements	
AP, mm	Sagittal linear dimension at the lowest border of each region of the airway
Lat, mm	Lateral linear dimension at the lowest border of each region of the airway
XSec, mm^2	Cross-sectional area on the axial plane at the lowest border of each region of the airway
Regional airway measurements	
Vol, cm^3	Total volume of each region of the airway
MCA, mm^2	The most constricted minimal cross-sectional area of each region of the airway
Cephalometric analysis	
Skeletal	
Sperp-A, mm	Horizontal distance from the perpendicular line through Sella to Point A
Sperp-B, mm	Horizontal distance from the perpendicular line through Sella to Point B
FMA, °	Mandibular plane angle; FH to mandibular plane (Go-Me)
Dental	
Sperp-U1, mm	Horizontal distance from the perpendicular line through Sella to U1
Sperp-L1, mm	Horizontal distance from the perpendicular line through Sella to L1
U1PPA, °	Angle between the long axis of the U1 and the palatal plane
IMPA, °	Angle between the long axis of the L1 and the mandibular plane (Go-Me)
IIA, °	Interincisal angle; angle between the long axis of the U1 and long axis of the L1
U6-6, mm	Maxillary intermolar width (UR6_MBC-UL6_MBC)
L6-6, mm	Mandibular intermolar width (LR6_MBC-LL6_MBC)

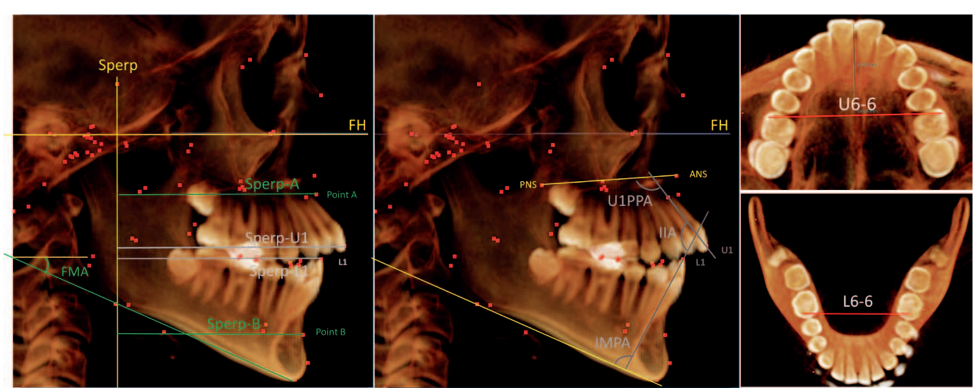

Figure 3. Three-dimensional cephalometric measurements.

Table 5. Airway Characteristics as a Function of Time and Extraction (EXT), Descriptive Means (Standard Deviations), and Tests of Hypothesis and *P*-Values Concerning Patterns in the Data[a]

	EXT Group (n = 41)		Non-EXT Group (n = 42)		Δ/Base	Significance			
	T1	T2	T1	T2	(Corr)	Base	Group	Time	Gr × T
Nasopharynx									
AP, mm	19.86	19.48	21.30	20.71	−.426***	1.950+	3.997*	1.875	0.084
	(3.32)	(3.57)	(3.40)	(3.49)	<.001	0.055	0.049	0.175	0.772
Lat, mm	26.31	26.33	26.42	26.21	−.283***	0.141	0.001	0.085	0.123
	(3.56)	(3.61)	(3.75)	(4.45)	0.01	0.888	0.995	0.77	0.727
Xsec, mm²	504.46	501.15	523.32	509.95	−.406***	0.68	0.275	0.482	0.189
	(125.0)	(131.3)	(126.9)	(133.7)	<.000	0.498	0.601	0.489	0.665
Vol, cm³	5.37	5.32	4.70	4.87	−.134	1.691+	1.968	0.259	0.851
	(1.81)	(2.06)	(1.80)	(1.92)	0.226	0.095	0.164	0.612	0.359
MCA, mm²	289.30	266.79	242.01	256.83	−.475***	2.869**	3.679+	0.307	7.212**
	(72.1)	(76.0)	(77.9)	(73.7)	<.001	0.005	0.059	0.581	0.009
Retropalatal region of oropharynx									
AP, mm	11.00	11.09	9.84	9.28	−.395***	1.66	5.521*	0.462	0.93
	(3.27)	(3.58)	(3.08)	(3.17)	<.001	0.101	0.021	0.499	0.338
Lat, mm	21.27	20.76	21.23	19.81	−.605***	0.02	0.111	1.241	0.282
	(6.09)	(8.18)	(10.20)	(6.22)	<.001	0.981	0.74	0.269	0.597
Xsec, mm²	230.18	238.27	188.98	175.80	−.425***	1.791+	6.357*	0.044	0.77
	(118.1)	(134.3)	(90.0)	(86.0)	<.001	0.077	0.014	0.834	0.383
Vol, cm³	8.43	8.34	7.79	7.58	−.299**	0.899	1.042	0.191	0.035
	(3.42)	(4.23)	(2.99)	(3.08)	0.006	0.371	0.31	0.663	0.851
MCA, mm²	182.55	167.52	149.60	139.99	−.312**	1.850+	0.038	1.724+	0.083
	(86.1)	(110.9)	(75.9)	(83.0)	0.004	0.068	0.193	0.085	0.774
Retroglossal region of oropharynx									
AP, mm	10.23	9.84	10.20	10.77	−.444***	0.108	0.561	0.068	1.951
	(2.97)	(3.49)	(2.93)	(2.74)	<.001	0.914	0.456	0.794	0.167
Lat, mm	28.14	27.84	26.29	26.50	−.330**	1.461	1.467	0.005	0.145
	(5.53)	(7.26)	(6.49)	(6.55)	0.003	0.148	0.23	0.943	0.704
Xsec, mm²	241.24	230.05	209.85	216.82	−.384***	1.831+	1.634	0.044	0.814
	(79.6)	(108.4)	(82.7)	(79.9)	0.001	0.071	0.205	0.835	0.37
Vol, cm³	6.99	7.15	6.15	6.08	−.293**	1.25	1.907	0.023	0.13
	(3.47)	(3.96)	(2.82)	(2.97)	0.009	0.215	0.171	0.879	0.72
MCA, mm²	172.04	174.49	134.03	126.04	−.474***	2.007*	6.934**	0.092	0.325
	(98.3)	(92.7)	(66.2)	(70.0)	<.001	0.048	0.01	0.763	0.57

[a] Airway features—AP indicates sagittal dimension measured at the inferior border of each region; Lat, transverse dimension measured at the inferior border of each region; XSec, area measured at the inferior border of each region; Vol, volume; and MCA, minimal cross-sectional area. Tests performed on data—Δ/Base indicates change in airway feature correlated with base value of that feature at pretreatment (T1) (*r*); Base, difference between average feature value at T1 for extraction and nonextraction cases (*t*); Group, difference between average extraction and nonextraction values combining T1 and posttreatment (T2) (*F*); Time, difference between values at T1 and T2 combining groups (*F* for repeated-measures analysis of variance [ANOVA]); and Gr × T, interaction of extraction or nonextraction over time (*F* for repeated-measure ANOVA). Report of tests: Test statistics (*r, t,* or *F*) reported on first line; *P*-value reported on second line.

+ $P < .10$; * $P < .05$; ** $P < .01$; *** $P < .001$.

The results for airway measures are shown in Table 5. The mean and standard deviation 2 × 2 crossed classification of scores for the five airway measures in the nasopharynx, retropalatal, and retroglossal regions are shown. Figure 4A is a graph of a representative result for retropalatal volume. This is typical of the findings by virtue of showing no change over time, a slight tendency for extraction cases to have larger measurements both initially and at the end of treatment, and no differential effects with extraction.

Although subjects were matched based on age and sex, for seven of the 15 airway features measured, the extraction group began the study with slightly larger airways (independent *t*-tests for differences between groups at baseline). In five of 15 cases, subjects in the extraction group showed larger airway values when combined across both T1 and T2 (main effect for group in repeated-measures ANOVA). There was only one feature (MCA in the retropalatal areas) for which that effect showed a marginally significant difference during treatment, regardless of extraction (main effect for time in repeated-measures ANOVA). It appeared that there was a differential effect of extraction in the single case of MCA in the nasopharynx region. That difference failed to reach significance at $P < .10$ when corrections are taken for measurement error.

The only consistent finding in these data was that changes in airway features were associated with their

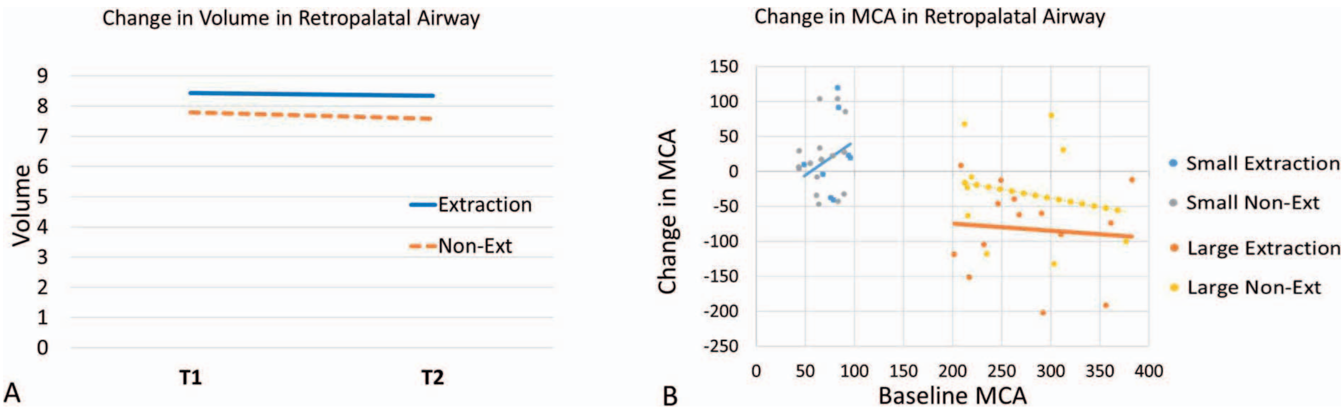

Figure 4. (A) Change in retropalatal volume in extraction and nonextraction groups; (B) Change in retropalatal MCA as a function of baseline values in extraction and nonextraction cases for subjects in whom baseline MCA was less than 100 mm^2 or greater than 200 mm^2.

baseline conditions. For all but one feature, the correlation between baseline score and change score was highly significant. The association was always negative, demonstrating that small airways grew in size and large airways decreased in size. This effect is diagrammed in Figure 4B for retropalatal MCA, showing that both extraction and nonextraction cases that were initially smaller than 100 mm^2 tended to increase and that both extraction and nonextraction cases that were larger than 200 mm^2 tended to decrease in size during treatment.

Table 6 is a parallel summary of the analysis of three skeletal and seven dental features as they were affected by extraction or nonextraction. The positions of both the maxillary and mandibular incisors were larger in the extraction group initially but decreased significantly in the extraction group and increased significantly in the nonextraction group. The same

Table 6. Skeletal and Dental Characteristics as a Function of Time and Extraction (EXT), Descriptive Means (Standard Deviations), and Tests of Hypothesis and *P*-Values Concerning Patterns in the Data[a]

	EXT Group (n = 41)		Non-EXT Group (n = 42)		Δ/Base	Significance			
	T1	T2	T1	T2	(corr)	Base	Group	Time	Group × T
Skeletal									
Sperp-A, mm	65.81	65.79	68.81	68.73	0.04	3.223**	10.033**	0.639	0.175
	(4.05)	(4.09)	(4.42)	(4.55)	0.74	0.008	0.002	0.43	0.68
Sperp-B, mm	59.57	59.45	63.54	63.41	−.114	2.816**	8.018**	0.438	0.001
	(3.56)	(3.61)	(3.75)	(4.45)	0.31	0.006	0.008	0.51	0.98
FMA, °	25.19	25.13	22.79	22.74	−0.175	1.631	2.73	0.122	0
	(7.19)	(7.17)	(6.18)	(5.97)	0.11	0.11	0.10	0.73	0.997
Dental									
Sperp-U1, mm	67.64	65.39	70.46	71.31	−0.11	2.367*	14.743***	7.657**	5.047***
	(5.58)	(5.05)	(5.26)	(5.36)	0.34	0.02	<.000	0.01	<.000
Sperp-L1, mm	70.97	68.37	73.58	73.99	−.168	2.144*	25.688***	13.574***	12.768***
	(6.05)	(5.21)	(5.00)	(5.38)	0.13	0.035	<.000	<.000	0.001
U1PPA, °	112.48	109.74	110.57	113.45	−.585***	2.367*	0.363	0.006	8.711**
	(8.98)	(8.33)	(7.64)	(7.22)	<.001	0.02	0.55	0.94	0.004
IMPA, °	99.39	100.30	99.69	100.77	−.430***	1.046	0.097	1.889	0.018
	(6.81)	(7.31)	(5.20)	(6.26)	<.001	0.30	0.75	0.17	0.89
IIA, °	126.28	130.59	130.21	123.47	−.712***	1.324	0.538	0.722	14.934***
	(14.16)	(9.06)	(12.82)	(10.69)	<.001	0.19	0.47	0.40	<.001
U6-6, mm	51.37	49.73	51.90	52.77	−.491**	0.732	8.584**	2.716	28.691***
	(3.39)	(2.09)	(3.23)	(3.02)	<.001	0.47	0.004	0.10	<.001
L6-6, mm	45.71	43.95	46.27	47.10	−.368***	0.742	7.338**	3.130+	24.172***
	(3.03)	(3.07)	(3.85)	(3.21)	0.001	0.46	0.008	0.08	<.001

[a] Tests performed on data—Δ/Base indicates change in airway feature correlated with base value of that feature at pretreatment (T1) (*r*); Base, difference between average feature value at T1 for extraction and nonextraction cases (*t*); Group, difference between average extraction and nonextraction values combining T1 and posttreatment (T2) (*F*); Time, difference between values at T1 and T2 combining groups (*F* for repeated-measures analysis of variance [ANOVA]); and Gr × T, interaction of extraction or nonextraction over time (*F* for repeated-measures ANOVA). Report of tests: Test statistics (*r, t,* or *F*) reported on first line; *P*-value reported on second line.
+ = $P < 0.10$; * $P < .05$; ** $P < .01$; *** $P < .001$.

significant interaction was observed for both the maxillary and mandibular intermolar widths. The opposite effect was seen with respect to interincisor angle, which indicates the impact of extraction on incisor inclination. Very large associations were observed between baseline and change measures for five of the dental features representing incisor inclination and intermolar width.

Correlation matrices were calculated relating changes in the 15 airway features with both baseline and change measures for the 10 skeletal and dental features. These calculations were performed for both the total sample and separately for only the extraction subjects. Of the 600 coefficient values calculated, only seven of them were statistically significant.

DISCUSSION

A retrospective analysis was conducted on 83 nongrowing, orthodontically treated patients, matched for sex and age, in which half received premolar extractions and half did not. Five features in each of the nasopharynx, retropalatal, and retroglossal airway regions and 10 skeletal and dental features were assessed at the beginning and end of treatment. Results were analyzed across time, across treatment type, and for interactions. Associations were also explored between airway and skeletal and dental measures.

The results supported the conclusion that extraction has an effect on dental features such as upper and lower incisor position and inclinations and intermolar width. However, there was no evidence that extraction changed sagittal and transverse distances or minimal cross-sectional area or volume in the nasopharyngeal, retropalatal, or retroglossal regions. In addition, there was no evidence that changes in the measured skeletal or dental features had an indirect effect on airway features. Strong evidence emerged that common measurement effects in repeated measures may obscure the types of conclusions drawn from similar clinical cases.

Two early studies[6,7] that reported a negative impact of extraction on airway did not use CBCT technology, so they could not report transverse dimensions, area, or volume. They reported correlations on changes rather than differences across groups and did not use a control group. Pliska et al.[10] reported results similar to those found in the current study. Their sample contained patients with larger initial airways and very large standard deviations,[10] but their results were similar in finding regression toward mean values. With respect to skeletal and dental features, the findings in the current study were similar to those reported previously in the literature.[9,12–14]

Averaging measurements across subjects masked conclusions about both individual and aggregate changes in airway features. This was the largest and most consistent finding in this research and an effect that applied equally to measures of airway and skeletal and dental features. In 19 of the 25 variables analyzed, this effect was significant at $P < .01$. The consistent negative associations between baseline score and change indicated that small values at T1 were more apt to grow in size by T2 and that initially large values consistently got smaller, which creates a chance for bias, especially if only large initial airways are studied. Such sampling restrictions are sometimes used on ethical grounds to mitigate supposed risk to patients with small airways or, in general, if adequately large airways dominate a sample.

Often, the difference between repeated measures of a feature can be attributed to treatment changes, but it is not always possible to isolate these effects from confounding factors such as measurement artifacts and natural growth. In most cases, the effects of measurement and growth are not random, and they interact with planned interventions.

Measurement error across repeated measures is known as "regression toward the mean."[15] Values far from the mean at T1 are seen to be closer to the mean at T2 because of the underlying nature of random sampling. It is unlikely that extreme values will become even more extreme. The more unreliable the measurement system, the larger the regression toward the mean. This effect can be approximated by looking for negative correlations between baseline score and change from T1 to T2 or by calculating the ICC with the difference between individual scores at baseline and baseline average as a covariate. This study showed an extremely high consistency in the reading of CBCT images of airway features but significant and consistent inconsistency in the taking of these images. Postural and functional fluctuations from one exposure to the next can vary depending on the type of feature being measured.

The conclusions of this study can only be generalized to nongrowing patients and are limited to conclusions measured by the variables chosen. A large number of zero-order correlations were calculated between skeletal and dental features and characteristics of the airway, and they were found to be insignificant. However, it remains possible that patterns of several skeletal and dental features might have an effect. Multiple regression and latent structure analyses may prove useful in clarifying this relationship. It was clear that factors such as planned therapeutic effects, natural growth, and the interaction of anatomical features are confounded with the variable timing of growth across individuals and the statistical complications of using measurement systems with significant potential for unreliability across repeated measures. Much work remains to be done to disentangle these sources of variation in order to prevent mistaking the reasons for observed changes or, in this case, the absence of changes, averaging across patients.

The assessment of airway dimensions utilizing CBCTs is subject to many limitations. For example, body mass index was not recorded, which might affect the airway dimensions. In addition, patient positioning and the process of breathing have been shown[16–19] to change upper airway volume, size, and shape. Patients with narrow upper airway cross sections can maintain airway patency by dilating their airway,[20] illustrating that the dimensions of the airway are dynamic and variable.

CONCLUSIONS

- Although the indications for extractions in orthodontics have been debated, the fact remains that some cases necessitate removal of teeth in order to achieve treatment and/or esthetic goals. As a result of the variability in airway dimensions, it is advised to consider additional diagnostic information, such as clinical examination, sleep questionnaires, and polysomnography, rather than relying solely on airway measurements from a CBCT scan, when making treatment decisions regarding airway concerns.
- Claims that extraction treatment is generally contraindicated because of airway considerations are too general to be useful. Extraction cases should be evaluated on a case-by-case basis, preferably with the aid of additional diagnostic evaluations, such as an obstructive sleep apnea screening. Characteristics of the airway at baseline must be taken into account, as must the possibility of wide variation due to the unreliability of CBCT imaging in evaluating certain features. Due partly to patient selection, natural growth, and measurement effects, small airway dimensions at baseline will appear to increase, and large airway dimensions will appear to decrease after treatment.

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