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Nasal cavity volume changes after rapid maxillary expansion in adolescents evaluated with 3-dimensional simulation and modeling programs

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Introduction: The purpose of this study was to evaluate the effects of rapid maxillary expansion on nasal cavity volume by using 3-dimensional simulation and modeling programs. **Methods:** The study group consisted of 15 patients (9 boys, 6 girls; mean age, 13.86 years) with maxillary constriction. Computed tomography scans were obtained before treatment and 6 months after the end of expansion. All computed tomography data were transferred to a computer, and the nasal cavity and maxillary teeth were segmented by using the Mimics and Simplant Ortho software programs (both, Materialise, Leuven, Belgium). Paired samples *t* tests were used to compare pretreatment and posttreatment nasal cavity volumes and maxillary areas. Data analysis was performed by using the software program SPSS for Windows (version 15.00; SPSS, Chicago, Ill). **Results:** Rapid maxillary expansion treatment induced significant increases in nasal cavity volume ($P \leq 0.001$) and maxillary transverse dimensions ($P \leq 0.001$). **Conclusions:** Both anterior-to-posterior and coronal-to-cranial expansions were observed after rapid maxillary expansion treatment, with the direction of expansion most likely affected by resistance from the cranial bones. (Am J Orthod Dentofacial Orthop 2011;140:633-40)

Posterior crossbite is a common malocclusion with a reported prevalence of 4% to 23%. Most posterior crossbites are unilateral and functional.[1-3]

Rapid maxillary expansion is frequently used to correct posterior crossbite, increase maxillary width, and expand the arch perimeters to alleviate dental crowding. First described by Angell[4] in 1860, rapid maxillary expansion was popularized by Haas[5,6] 100 years later. Now, a trend toward more conservative nonextraction treatment and the desire for broader, more esthetic smiles have led orthodontists to routinely use rapid maxillary expansion to relieve arch length discrepancies in patients with already adequate arch forms.[5-10]

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Rapid maxillary expansion appliances induce both skeletal and dental changes. Rigid, fixed rapid maxillary expansion appliances produce heavy forces that separate the maxillary suture, resulting in maximum skeletal or orthopedic expansion and minimum orthodontic tooth movement.[5-9] Orthopedic expansion via rapid maxillary expansion is achieved not only through the physical separation of the midpalatal suture, but also through rotational buccal force on the maxillary alveolar shelves,[8-10] when the maxillary bones swing transversely around the frontonasal suture at the approximate center of rotation.[5,7,11] Although rapid maxillary expansion forces are concentrated primarily on splitting the maxillary suture, the surrounding frontomaxillary, zygomaticomaxillary, zygomaticotemporal, and pterygopalatine sutures are also affected.[12] An increase in nasal cavity width is sometimes observed as well and can lead to decreased nasal resistance and improved airflow.[5,6,13,14]

The nasal cavity is designed specifically to humidify, adjust the temperature of, and remove infectious and impure particles from the air before it reaches the lungs. Nasal respiration contributes to the ideal development of the nasomaxillary complex. It has been hypothesized that, because the maxillary bones form half of the nasal cavity's anatomic structure, midpalatal disjunction will affect nasal cavity anatomy and physiology.[15,16] Changes in maxillary dental arch anatomy and nasal cavity anatomy and function from rapid maxillary expansion have been subjectively observed to improve nasal breathing and decrease nasal cavity resistance.[17,18] Wertz[19] confirmed the advantage of rapid maxillary expansion in improving nasal airflow in patients with stenosis of the nasal airway.

The skeletal and dental effects of rapid maxillary expansion appliances have been evaluated in numerous studies and with various techniques, ranging from manual measurement of dental casts[20,21] to plane film radiographic techniques with lateral[20,22,23] and posteroanterior cephalograms.[20,23,24] In human cadaver studies using computed tomography (CT), Montgomery et al[25] also showed that it was possible to obtain accurate volumetric measurements of the nasal airway from CT images. In recent years, newly developed 3-dimensional (3D) helical and multi-slice CT technologies have been accepted as noninvasive, time-efficient alternatives for reproducing 3D images.[26] In this study, we aimed to evaluate the effects of rapid maxillary expansion on nasal cavity volume using 3D simulation and modeling software.

MATERIAL AND METHODS

This prospective study was initiated after receiving institutional approval from the ethics committee of Gulhane Military Medical Academy in Ankara, Turkey; informed consent was obtained from all participants and their parents.

A total of 15 patients (9 boys, 6 girls) requiring treatment with rapid maxillary expansion were enrolled in the study. Their mean age was 13.86 ± 1.4 years (range, 12-16 years). All patients had maxillary constriction, bilateral posterior crossbite, and clinical crown length able to provide sufficient anchorage for the rapid maxillary expansion appliance. No patient had mandibular crowding or transverse deficiency (measured by calculating the difference between the distance of the distal or median cusp tips [if the mandibular molars had 2 buccal cusp tips, the measurement was made from the distal aspect; in case of 3 cusp tips, the measurement was made at the median] of the right and left mandibular molars and the distance between the median sulcus of the right and left maxillary molars). All patients were treated with bonded-type rapid maxillary expansion with posterior occlusal coverage. All appliances were fabricated in the same laboratory according to the method of Sarver and Johnston,[22] with maxillary occlusal coverage of 3-mm acrylic extending from the first premolars to the second molars (Fig 1). An expansion screw was centered in the

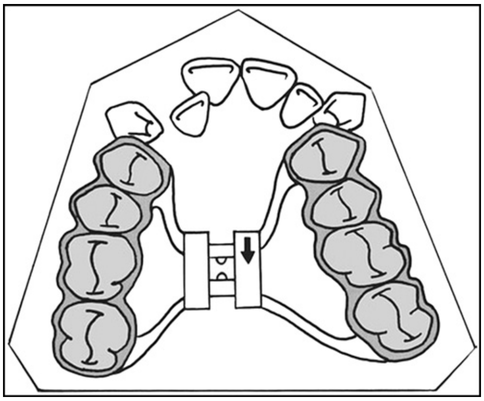

Fig 1. Bonded rapid maxillary expansion appliance.

maxillary arch, and the appliance was bonded to the teeth after the equilibration of the acrylic surface. The expansion screw and the frame were placed as close as possible to the roof of the palate without impinging on its surface. Patients underwent a standardized protocol of expansion (including a set amount of overtreatment) consisting of 2 turns per day (approximately 0.25 mm per turn) until the desired expansion was obtained.

All dental CT examinations were performed with a 16-detector CT scanner (MX 8000 IDT Multislice CT System-V 2.5; Philips Medical Systems, Best, the Netherlands) in the supine position. The following scan parameters were used: 16 × 0.75-mm detector collimation (pitch, 0.6); 1-mm slice thickness; 0.5-mm increments; 0.75-second rotation time; 120 kV; and 200 mAs.

All CT data were transferred to a computer, and the nasal cavity and the maxillary teeth were segmented by using the Mimics and Simplant Ortho software programs (both, Materialise, Leuven, Belgium). Nasal cavity segments were restricted to the ostium of the paranasal sinuses, the posterior airway, and the nostrils (Figs 2-5). Segmentation was performed by using the software's threshold feature on each slice or on the direct 3D virtual model to eliminate artefacts and unnecessary elements of the 3D models.

During the CT scans, the patients wore individual mandibular appliances to calibrate the magnification and confirm the appropriate section, which was used for linear measurements before treatment (T0) and 6 months after the end of expansion (T1) (Fig 6). The distances between the vertical shields of these appliances were controlled in sections; the distances, used for linear measurements, were identical at both times (T0 and T1). By this way, used sections were controlled. Linear measurements were made in the cross-section images comprising the entire image of the first premolar and the first

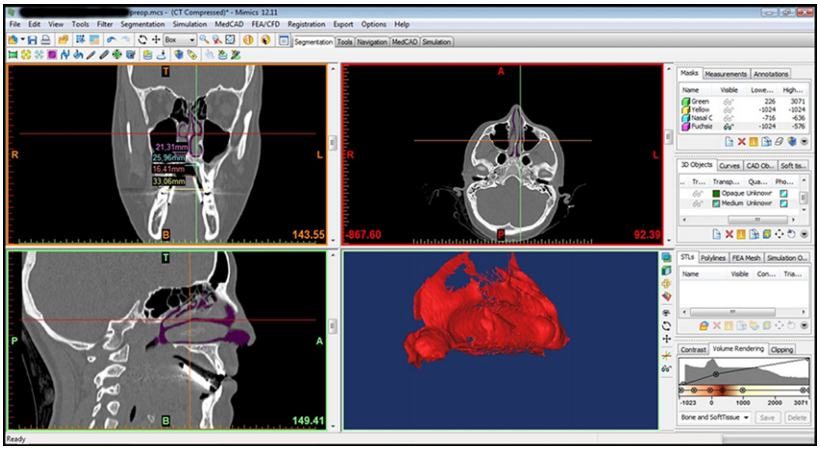

Fig 2. Segmentation of the nasal cavity with Mimics software.

molar. At the premolar level, the distance between buccal cusp tips, and the distance between the apices of the buccal roots (if the first premolar had 1 root), the nasal base widths were measured. Nasal base width was measured as the distance between the most inferior left and right points of the intersection between the maxillary sinus and the nasal cavity. At the molar level, the distance between the distobuccal cusp tips, and the distance between the apex of distobuccal root and the nasal base width were measured. The same measurements associated with these teeth were repeated on the segmented 3D models. In this way, all metric measurements associated with these teeth were proofed.

All images were traced by an author (S.G.). The landmarks, measurement points, and margins of the nasal cavity were verified by another investigator (H.O.), and the parameters were remeasured by the author. The mean values of the first and second measurements were calculated according to the methods of Gröndahl et al[27] and Ekestubbe and Gröndahl.[28] The points measured for the maxillary first molar and first premolars are shown in Figure 7. The same investigator remeasured the parameters 1 week later to evaluate measurement errors. Method error was determined by using Dahlberg's formula[29]: method error = $\Sigma d^2/2n$, where n is the number of subjects and d is the difference between the first and second measurements. The maximum method error for the linear measurements was 0.36 mm.

Statistical analysis

Analysis of data relating to nasal cavity volumes and maxillary areas before and after treatment was performed by using the software program SPSS for Windows (version 15.00; SPSS, Chicago, Ill). The Shapiro-Wilks analyses showed normal distributions for all parameters. Pretreatment and posttreatment measurements were compared by using paired samples t tests. To determine the sample size of this study, a statistical program (version 3.0.10; G* Power 1992-2008, Franz Faul, Universität Kiel, Kiel, Germany) was used. It was estimated that 15 subjects in each group must be included in the study for an effect size of 0.70, a power of 80, and error levels of $\alpha = 0.05$ and $\beta = 0.80$.

RESULTS

Mean values for all parameters measured at T0 and T1 are given in Table I, and the amounts and proportions of change between T0 and T1 are given in Table II. Significant increases were found in all variables ($P < 0.001$) (Table II).

Nasal cavity volume increased simultaneously with maxillary expansion in all subjects, with the amount of expansion tending to decrease toward the apical and posterior regions. The amount of expansion was approximately 8 mm at the appliance screw and tooth crowns, but 3.48 mm in the molar and 5.28 mm in the premolar apical regions. Measurement differences between the molar and premolar areas refer to more tipping of the molars than the premolars.

A 20% average increase was found at the coronal level, and a 12.1% increase was measured in nasal cavity volume.

DISCUSSION

We evaluated the effects of rapid maxillary expansion on nasal cavity volume using 3D simulation and modeling software. Previous studies have shown that bonded appliances result in less premolar and molar tipping than banded appliances[26]; therefore, to prevent tipping and achieve greater skeletal change, we used bonded

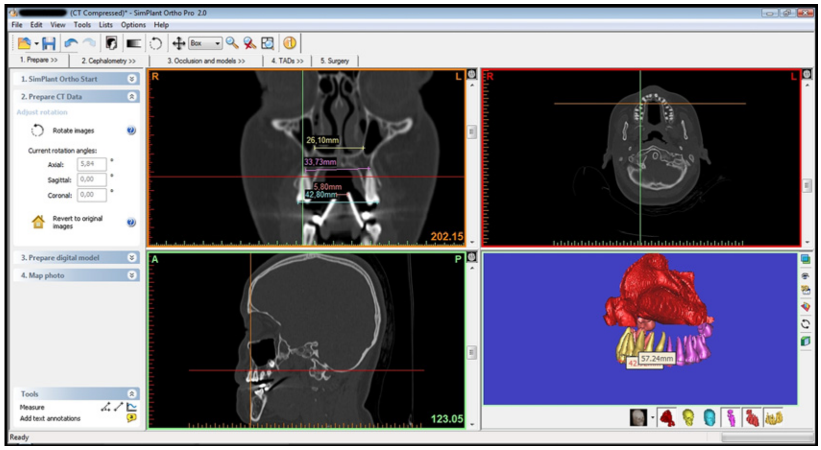

Fig 3. Segmentation of the teeth with Simplant Ortho software.

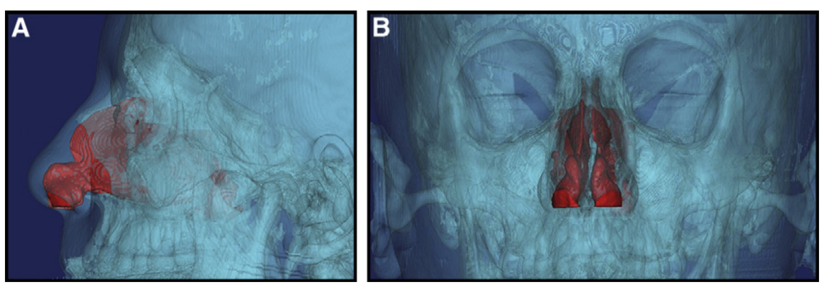

Fig 4. **A,** Three-dimensional representation of the segmented nasal cavity (lateral view); **B,** 3D representation of the segmented nasal cavity (frontal view).

appliances. Our findings showed greater tipping of the molars when compared with the premolars.

Some authors have suggested that the circummaxillary structures have the greatest resistance to rapid maxillary expansion, and it is reasonable to assume that resistance will increase the growth and maturation of these structures.[7,20] In our study, the measurement of the width of the nasal base showed greater expansion in the anterior portion of maxillary bone than in the posterior portion. The amount of increase was greatest at the coronal level and decreased toward the cranial level for all parameters measured. According to Garret et al,[30] skeletal expansion of the maxilla has a triangular pattern, with a wider base in the anterior region that accounts for 55% of the total expansion, compared with 6% from alveolar bending or tipping; rapid maxillary expansion produces a statistically significant increase in nasal width and a decrease in maxillary sinus width. Ballanti et al[31] examined the effects of rapid maxillary expansion on dental and periodontal tissues using low-dose CT images and found that rapid maxillary expansion induced a significant increase in the transverse dimension of the maxillary arch, with the amount of opening of the midpalatal suture during the active phase of expansion decreasing from the anterior to posterior regions. Garib et al[13] reported significant increases in all transverse linear dimensions as a result of rapid maxillary expansion, with a smaller increase from the dental arch to the basal bone. The amount of increase in the transverse dimension of the nasal floor corresponded to one-third of the amount of screw activation. The findings of this study are in line with those of the above-mentioned studies.

We found that nasal cavity volume increased in line with maxillary expansion in all subjects. The evaluation of the area measurements showed that the amounts of expansion had a tendency to decrease toward the apical and posterior areas. Cross and Mc Donald[24] reported that rapid maxillary expansion produced slight, but statistically significant, increases in maxillary width, maxillary and mandibular molar widths, width between the maxillary central incisor apices, and intranasal width. Basciftci et al[17] found increases in nasal floor width near the midpalatal suture and nasal cavity after rapid

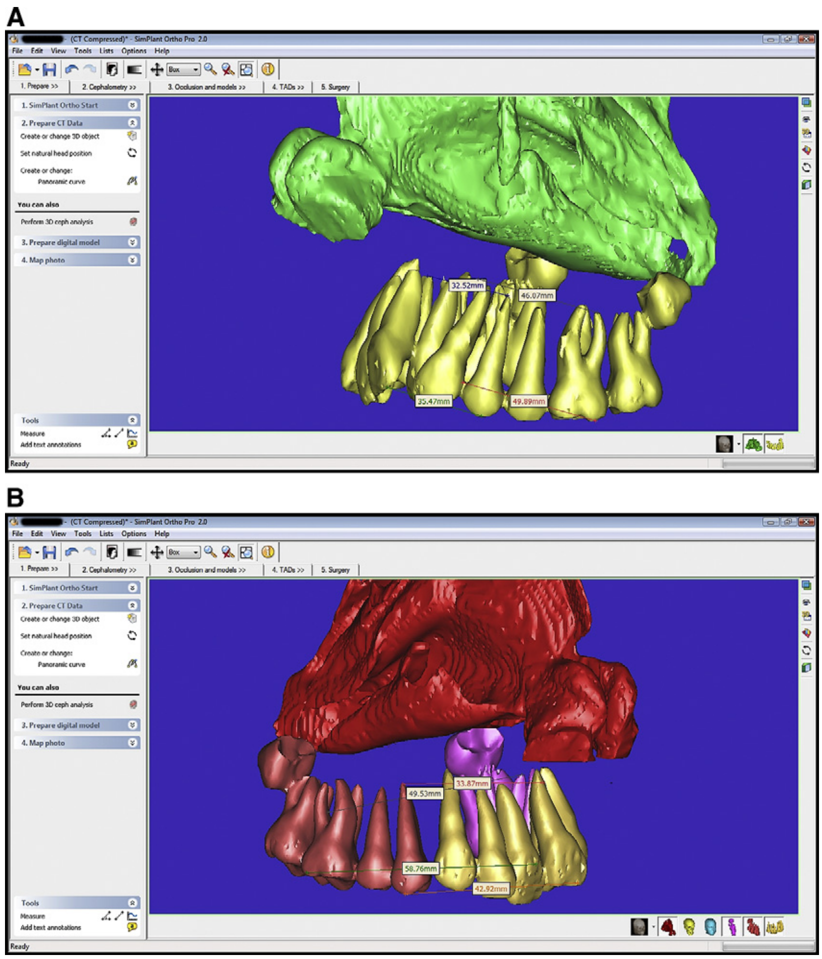

Fig 5. A, Three-dimensional representation of the segmented nasal cavity and teeth before treatment; **B,** 3D representation of the segmented nasal cavity and teeth after treatment.

maxillary expansion treatment. Lateral movement of the outer walls of the nasal cavity in line with the separation of the maxillary structures resulted in an increase in internasal volume. Nasal resistance decreased and respiratory area increased in subjects treated with rapid maxillary expansion. Doruk et al[32] also demonstrated a significant increase in nasal volume after rapid maxillary expansion using CT and acoustic rhinometry.

According to Baccetti et al,[33] patients treated with rapid maxillary expansion before the pubertal peak show significant and more effective long-term changes at the skeletal level in both maxillary and circummaxillary structures. If rapid maxillary expansion is performed after the pubertal growth spurt, maxillary adaptation to expansion therapy results in a shift from the skeletal to the dentoalveolar level. In this study, the mean age of the subjects was 13.86 years; although a significant amount of dental tipping occurred, marked changes in skeletal structures were also observed.

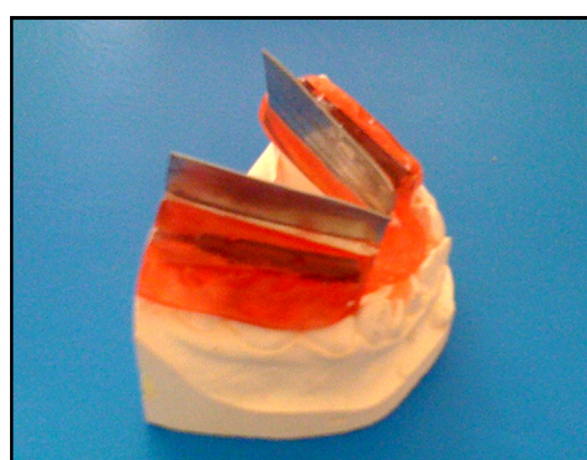

Fig 6. Mandibular control appliance used to calibrate the CT slices.

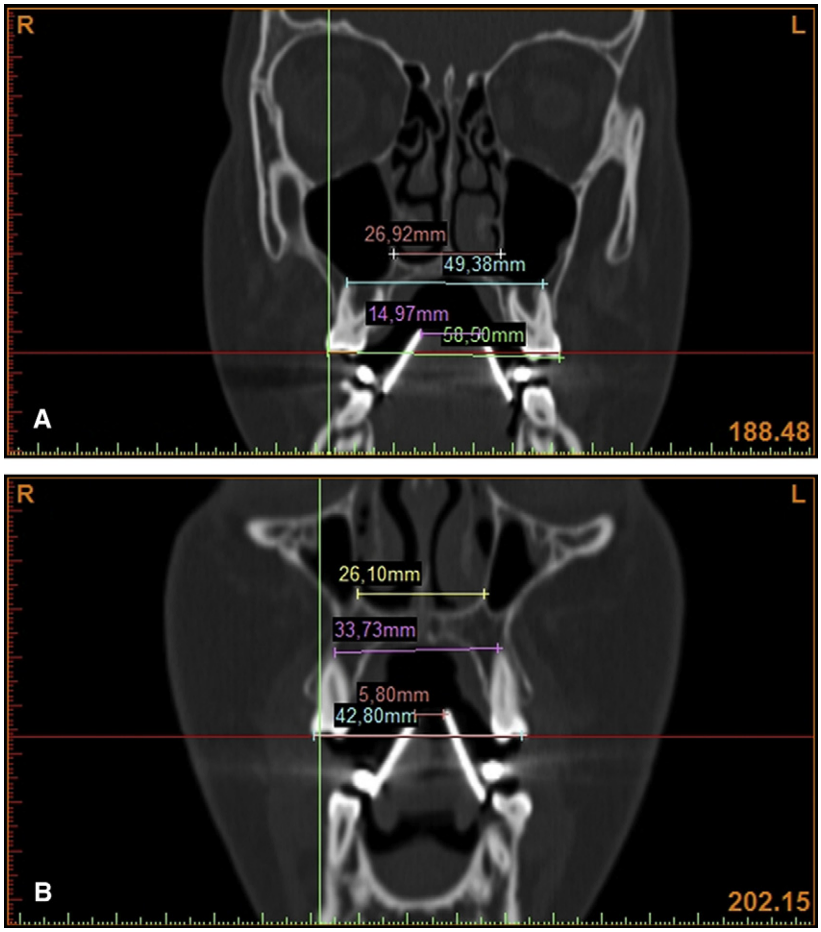

Fig 7. A, Linear measurements of the molar area; **B,** linear measurements of the premolar area.

Table I. Descriptive values of all measurements

	T0					*T1*				
			95% CI of the mean					*95% CI of the mean*		
	Mean	*SD*	*Upper bound*	*Lower bound*	*Median*	*Mean*	*SD*	*Upper bound*	*Lower bound*	*Median*
4-4 nasal base (mm)	20.93	2.06	22.06	19.75	20.36	25.59	2.58	27.02	24.16	25.48
4-4 apex width (mm)	29.25	4.53	31.75	26.73	30.08	35.74	4.18	38.05	33.41	36.50
4-4 crown width (mm)	31.75	4.46	34.21	29.28	32.14	39.70	3.99	41.90	37.48	40.16
6-6 nasal base (mm)	21.66	1.90	22.71	20.61	21.65	25.48	2.16	26.67	24.28	25.76
6-6 apex width (mm)	43.32	4.05	45.56	41.08	42.25	48.87	4.16	46.57	51.17	47.99
6-6 crown width (mm)	45.67	4.29	48.04	43.28	45.36	52.97	3.88	55.12	50.82	52.46
Nasal cavity volume (mm^3)	11693.27	1941.37	12768.36	10618.17	11674.00	13112.73	2026.29	14234.85	11990.61	12531.00

4-4, First premolar to first premolar; *6-6*, first molar to first molar.

Previous rapid maxillary expansion studies used lateral or posteroanterior cephalometric radiographs as well as study models.[17,20,23,24] In 1993, Zinreich and Kenneth[34] suggested that CT could be used successfully to examine paranasal sinuses and peripheral structures. Garib et al[13] used CT to compare the dentofacial effects of tooth-tissue and tooth-borne expanders, and Olmez et al[26] used CT to compare the effects of bonded and

Table II. Changes in all measurements between T0 and T1

	Mean	SD	95% CI of the difference Upper bound	95% CI of the difference Lower bound	t	Significance (P value)	Increase (%)
Measurement area							
4-4 nasal base (mm)	−4.67	1.49	−5.50	−3.84	−12.11	<0.001	22.31
4-4 apex width (mm)	−6.49	1.22	−7.16	−5.81	−20.64	<0.001	22.19
4-4 crown width (mm)	−7.95	1.32	−8.68	−7.21	−23.24	<0.001	25.02
6-6 nasal base (mm)	−3.82	1.47	−4.63	−3.01	−10.09	<0.001	17.63
6-6 apex width (mm)	−5.55	1.50	−6.38	−4.72	−14.35	<0.001	12.81
6-6 crown width (mm)	−7.31	1.41	−8.09	−6.53	−20.12	<0.001	16.00
Nasal cavity volume (mm^3)	−1419.47	647.69	−1778.14	−1060.79	−8.49	<0.001	12.14

4-4, First premolar to first premolar; *6-6*, first molar to first molar.

banded appliances. The use of CT images resulted in fewer projection magnification and distortion errors. Doruk et al[32] demonstrated reasonably good agreement between the results from acoustic rhinometry and CT.

Recently developed software has made it possible to create 3D models by using CT; in this study, CT imaging was used for both linear measurements and to create 3D models of the nasal cavity to measure its volume with the Mimics and Simplant Ortho software programs. Despite these great advantages, radiation exposure is still a great concern and the greatest disadvantage of CT imaging.

Using CT and Mimics software, Haralambidis et al[35] observed an average increase of 11.3% in the volume of the anterior nasal cavity volume after rapid maxillary expansion. In our study, the average increase after rapid maxillary expansion was 12.14%. The findings of these 2 studies are compatible; although Haralambidis et al limited volumetric investigations to the anterior portion of the nasal cavity, the amounts of increase that they observed might reflect an improvement in overall nasal cavity volume.

CONCLUSIONS

1. In spite of the radiation exposure during imaging sequencing, CT imaging can be considered a successful method for the observation of the nasomaxillary area.
2. Expansion of both the anteroposterior and coronal-cranial nasomaxillary structures occurs after rapid maxillary expansion. The direction of the expansion might be related to the resistance of the cranial bones.
3. In line with previous studies, we found rapid maxillary expansion to be a useful method for increasing the volume of the nasal cavity. Additionally, previously mentioned issues should be investigated to clarify the mechanisms affecting the surrounding structures.

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