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Skeletal and dental changes after rapid maxillary expansion: a computed tomography study

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Objectives: To investigate the skeletal and dental changes induced by rapid maxillary expansion, using computed tomography (CT) scans and three-dimensional (3-D) reconstructed images.
Methods: Twenty patients (Mean age: 12.3 ± 1.9 years) who required rapid maxillary expansion as a part of their comprehensive orthodontic treatment underwent pretreatment (T1) and post-treatment (T2) CT scans. The T2 – T1 differences between selected skeletal and dental measurements on the coronal CT and 3-D volumetric images were compared using the Wilcoxon signed ranks test.
Results: At T2 the Maxillary alveolar width (4.5 ± 3.5 mm) was greater than the Maxillary base width (1.7 ± 0.9 mm). The greatest transverse dental change was in the Intermolar width (6.3 ± 2.1 mm and 2.7 ± 1.9 mm at the crown and the apex, respectively). On the 3-D volume, significant increases occurred in the Bicondylar width (1.2 ± 1.3 mm), Bimaxillo-mandibular width (2.1 ± 2.3 mm) and the Maxillary width (2.5 ± 1.6 mm). The greatest change in the dental measurements was in the Maxillary first molar width (6.4 ± 0.1 mm). The Maxillary central incisor angle decreased significantly (-7.9 ± 8.4 mm), indicating an increase in the distance between the apices of the central incisors.
Conclusion: Volumetric 3-D CT scanning provides a useful method for assessing skeletal and dental changes after rapid maxillary expansion. Although significant increases occurred in most skeletal and dental measures, it appears that dental tipping explains most of the expansion.
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Introduction

Rapid maxillary expansion (RME) is a routine orthodontic procedure used to normalise a constricted maxillary dental arch. It increases the width of the maxillary dental arch by separating the maxillae at the midpalatal suture and allows the maxillary and mandibular dental arches to match transversely.[1,2] Traditionally, two-dimensional planar radiographic images have been used to identify specific anatomic landmarks from which vertical and anteroposterior skeletal and dental dimensions can be measured. Within the past few years, three-dimensional (3-D) radiographic images have been used for the same purposes with many advantages.

Computed tomography (CT) allows fast and precise acquisition of multiple thin slices and has the potential for multiplanar, 3-D reconstruction. These capabilities greatly increase the utility of CT as a diagnostic method. It also facilitates precise measurements to evaluate surgical and orthodontic outcomes,

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Figure 1. Hyrax appliance.

for example, following rapid maxillary expansion.[3,4] Diagnosis and treatment planning are more precise and predictable with the use of CT technology in combination with the available software. Clinicians can take advantage of 3-D planning for many applications.[5] For all these reasons, CT has become an acceptable, accurate and readily accessible tool for today's clinical practice.

Multislice CT is a powerful craniofacial measurement tool with several advantages: true volumetric 3-D representation of the hard and soft tissues of the skull; real-size (1:1 scale) and volumetric 3-D cephalometric analysis; and high accuracy and reliability with no superimposition of anatomic structures.[6] Therefore, the aim of this prospective, clinical study was to investigate the changes in the craniomaxillary complex and dental arches after rapid maxillary expansion using multislice CT scans and 3-D reconstructed images.

Material and methods

The study included 20 patients (Mean age: 12.3 ± 1.9 years; Age range: 8–15 years) with bilateral posterior crossbites who required RME prior to comprehensive orthodontic treatment. The exclusion criteria included: presence of a premature contact; previous orthodontic or orthopaedic treatment; systemic disease; congenital abnormality; TMJ disorder; carious, gingival and/or periodontal lesions; and a metallic restoration(s). The study was approved by the Ethical Committee of the Dental Faculty, Al-Azhar University, Cairo, Egypt, and the parents of each patient gave their informed consent.

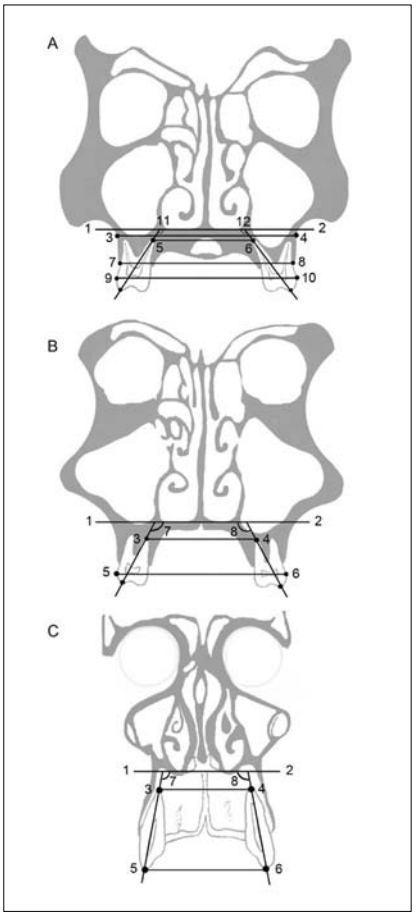


Figure 2. Coronal diagrams showing the landmarks and measurements. A, Molar level: 1-2, line tangent to the base of the nose; 3-4, Maxillary base width; 5-6, Intermolar width (apex); 7-8, Maxillary alveolar width; 9-10, Intermolar width (crown); 11 and 12, Right and Left molar angulations. B, Premolar level: 1-2, line tangent to the base of the nose; 3-4, Interpremolar width (apex); 5-6, Interpremolar width (crown); 7 and 8, Right and Left premolar angulations. C, Canine level: 1-2, line tangent to the base of the nose; 3-4, Intercanine width (apex); 5-6, Intercanine width (crown); 7 and 8, Right and Left canine angulations.

The Hyrax appliance design was used, which required banding either the maxillary first premolars or the maxillary first primary molars and the maxillary first permanent molars (Figure 1). The appliance screw was activated two quarter turns twice per day until the palatal cusps of the maxillary first molars contacted the buccal cusps of the mandibular first molars. The appliance was left in situ as a passive retainer for three months, after which it was removed.

The multiplanar spiral CT machine (X vision EX, General Electric 'GE' Corporation Medical Systems Company, NY, USA) was used to obtain pre-RME (T1) and post-RME (T2) CT images. The latter were taken the day after the Hyrax appliance was removed.

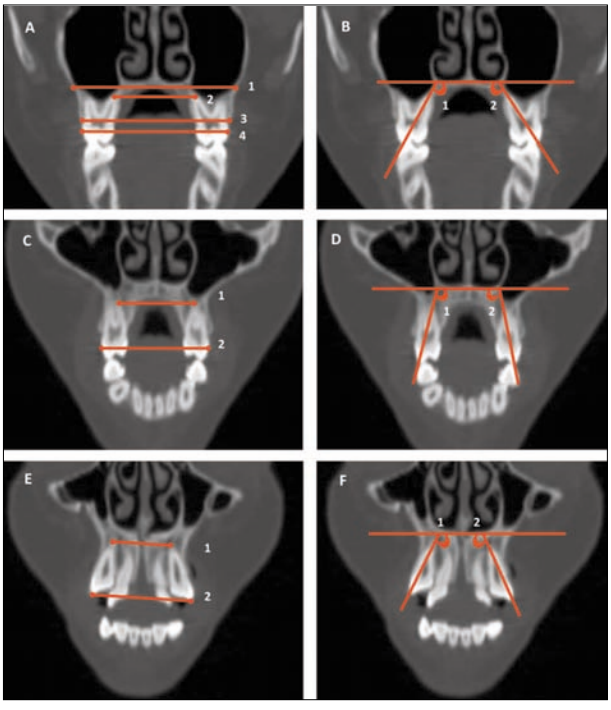


Figure 3. CT coronal images. A: 1, Maxillary base width; 2, Intermolar width (apex); 3, Maxillary alveolar width; 4, Intermolar width (crown). B: 1 and 2, Right and Left molar angulations; C: 1, Interpremolar width (apex); 2, Interpremolar width (crown); D: 1 and 2, Right and Left premolar angulations; E: 1, Intercanine width (apex); 2, Intercanine width (crown); F: Right and Left canine angulations.

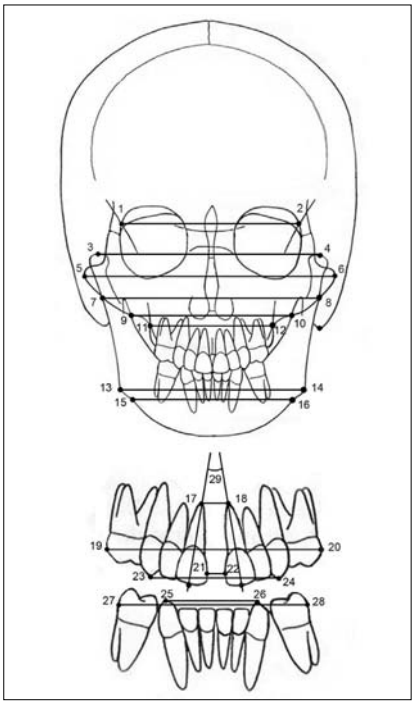


Figure 4. Frontal diagram showing the landmarks and measurements: 1-2, Bilatero-orbital width; 3-4, Bicondylar width; 5-6, Bizygomatic width; 7-8, Bizygomatico-mandibular width; 9-10, Bimaxillo-mandibular width; 11-12, Maxillary width; 13-14, Bigonial width; 15-16, Biantegonial width; 17-18, Maxillary central incisor apex width; 19-20, Maxillary first intermolar width; 21-22, Maxillary central incisor mesial width; 23-24, Maxillary intercanine width; 25-26, Mandibular intercanine width; 27-28, Mandibular first intermolar width; 29, Maxillary central incisor angle.

The CT scans were performed at 120 kV and 20 mA (low dose), with a scanning time of 2 s/section. The machine's perpendicular light beams were used to standardise the head position in all three planes, allowing comparison of the images before and after expansion. The scans were taken with the patients in the supine position and the palatal plane perpendicular to the floor. Each subject was positioned so that the longitudinal light beam passed through the centre of glabella and the philtrum, and the transverse light beam passed through the lateral canthi of the eyes. One-millimetre thick axial sections were made parallel to the palatal plane.

The digital images (Imaging and communications in medicine, DICOM) were assessed and measured using the InVivoDental Imaging software programme (Anatomage Incorporated, San Jose, CA, USA). Multiplaner reformatting and 3-D post-processing of the DICOM images were carried out with the software used to create the 3-D volumetric skull models. Linear and angular parameters were measured to the nearest 0.1 mm and 0.1 degree respectively, on both the coronal sections of the CT images and on the 3-D volumetric scans (Figures 2 to 6).[7,8]

The Maxillary base width (MBW) and Maxillary alveolar width (MAW) were measured on the coronal sections that included the furcations of the maxillary first permanent molars. The same procedure was repeated for the T2 measurements. The amounts of skeletal expansion at the Maxillary base and the Maxillary alveolar process and dental expansion at the Intermolar, Interpremolar and Intercanine widths at the crowns and root apices were the differences between the T1 and T2 widths (T2 minus T1). Positive values indicated expansion.

Dental angulations were measured on the coronal sections as the angles between the line tangent to the base of the nose (representing the lower limits of the nasal cavity on the right and left sides, respectively) and lines passing through the buccal cusps and the apices of the palatal roots of the maxillary first permanent molars, through the buccal cusps and apices

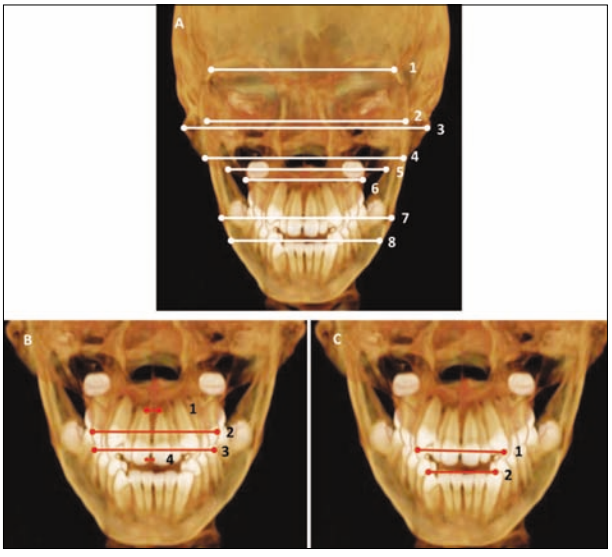


Figure 5. 3-D volume. A: 1, Bilatero-orbital width; 2, Bicondylar width; 3, Bizygomatic; 4, Bizygomatico-mandibular width; 5, Bimaxillo-mandibular width; 6, Maxillary width; 7, Bigonial width; 8, Biantegonial width. B: 1, Maxillary central incisor apex width; 2, Maxillary first intermolar width; 3, Mandibular first intermolar width; 4, Maxillary central incisor mesial width. C: 1, Maxillary intercanine width; 2, Mandibular intercanine width.

of the first premolars, and the cusp tips and apices of the canines. The same procedure was repeated for the T2 measurements. An increase in the value (T2 – T1) indicated buccal tipping of the maxillary dental arch.

From the 3-D volume of each patient, 14 distances and one angle were measured at T1 and T2. To improve the reliability and validity of the measurements of the 3-D volume, the selected skeletal and dental landmarks were defined on each model by two investigators. The following skeletal landmarks were used: Latero-orbitale point – the intersection of the lateral wall of the orbit and the greater wing of the sphenoid (the oblique line); Condylion – the superior point of the condyle; Zygomatic point – the most lateral point of the zygomatic arch; Zygomandibulare – intersection between the lower margin of the zygomatic bone and the lateral contour of the mandibular ramus; Maxillomandibulare – the intersection between the lower margin of the maxilla and the medial contour of the mandibular ramus; Maxillare – the depth of the concavity of the lateral maxillary contour, at the junction of the maxilla and the zygomatic buttress; Gonion – the gonial angle of the mandible; Antegonion – the antegonial notch.

The following dental landmarks were located on the 3-D volume: Maxillary first molar – the most prominent lateral point on the buccal surface of the maxillary first molar; Mandibular first molar – the most prominent lateral point on the buccal surface of the mandibular first molar; Maxillary central incisor mesial – the most mesial point of the maxillary central incisor crown; Maxillary central incisor apex – the tip of the root apex of the maxillary central incisor; Maxillary central incisor edge – the incisal edge of the maxillary central incisor, centred mediolaterally. The amount of dental expansion was determined as the difference between the T1 and T2 widths. For the Maxillary incisal angle, a positive value for T2 – T1 indicated flaring of the maxillary central incisors crowns, while a negative value indicated flaring of the maxillary central incisor apices. In addition, the buccal aspects of all involved teeth were scanned to determine if the roots fenestrated or dehisced the buccal cortical plate.

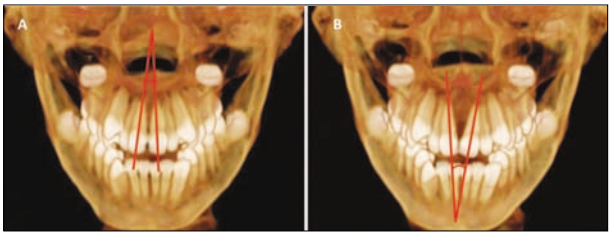


Figure 6. 3-D volume. The Maxillary central incisor angles before (A) and after (B) RME.

Statistical analyses

All parameters were measured twice by the same examiner with a fortnight between the measurements.[9] The errors were assessed by Dahlberg's method and the intra-examiner reliability was assessed with the intraclass correlation coefficient (ICC). Since the data were not normally distributed, the change in each variable was tested with the Wilcoxon signed rank test.

Results

We found no statistically significant differences between the first and second measurements and high intra-examiner reliability (ICC > .97). The Dahlberg values fell between 0.13 mm for the Maxillary central incisor width at T1 and 0.91 mm for the Maxillomandibular width at T2, and 0.38 and 0.88 degree for the Maxillary central incisor angle at T1 and T2, respectively. The majority of the ICC values were .98

Table I. Comparison of the T1 and T2 measurements on the coronal CT sections (N = 20).

	T1		T2		Change		*p*
	Mean	SD	Mean	SD	Mean	SD	
Maxillary base width (MBW, mm)	59.7	2.7	61.5	2.6	1.7	0.9	0.01
Maxillary alveolar width (MAW, mm)	52.8	4.0	57.3	4.1	4.5	3.5	0.01
Intermolar width (crown, mm)	50.3	3.4	56.6	3.6	6.3	2.1	0.01
Intermolar width (apex, mm)	29.3	2.2	32.0	2.8	2.7	1.9	0.01
Interpremolar width (crown, mm)	40.6	2.9	46.6	3.2	6.0	2.6	0.01
Interpremolar width (apex, mm)	26.5	3.3	29.2	3.6	2.8	1.7	0.01
Intercanine width (crown, mm)	31.4	5.0	34.5	4.4	3.1	2.0	0.01
Intercanine width (apex, mm)	23.5	3.3	25.9	3.0	2.4	1.4	0.01
Right molar angulation (degrees)	118.9	5.6	126.0	4.7	7.2	4.2	0.01
Left molar angulation (degrees)	119.5	7.5	125.9	6.6	6.3	4.7	0.01
Right premolar angulation (degrees)	107.6	5.1	114.1	5.2	6.5	3.4	0.01
Left premolar angulation (degrees)	110.0	6.5	115.5	6.4	5.5	4.2	0.01
Right canine angulation (degrees)	100.5	7.8	105.6	6.6	5.1	5.1	0.01
Left canine angulation (degrees)	100.7	9.2	104.1	6.8	3.5	4.3	0.01

Statistically significant at $p < 0.01$

and .99 and only four values (Maxillary alveolar width T1; Mandibular first molar width T1 and T2; Maxillary central incisor mesial width T1) had an ICC of .97, confirming the reliability of our method of measurement. The results are given in Tables I and II. The changes T2 minus T1 are the overall treatment effect.

All skeletal and dental measurements on the coronal CT sections increased significantly from T1 to T2, indicating that the appliance had expanded the maxillary dentition and upper facial skeleton (Table I). The increase in Maxillary alveolar width was 4.5 ± 3.5 mm, which was greater than that seen at the Maxillary base width (1.7 ± 0.9 mm).

Greater transverse changes occurred at the molar crowns than the molar apices (Intermolar crown width: 6.3 ± 2.1 mm: Intermolar apical width: 2.7 ± 1.9 mm). In addition, the right and left molars were tipped buccally 7.2 ± 4.2 degrees and 6.3 ± 4.7 degrees, respectively. Dental tipping was not identical on the right and left sides. The premolar and canine widths also increased and the premolars and canines tipped buccally, but to a lesser degree than the molars.

There were nine significant increases in 3-D volume between T1 and T2 (Table II). The Bicondylar width, Bimaxillo-mandibular width and the Maxillary width increased between 1.2 and 2.5 mm. The greatest increase in the linear measurements was seen in the Maxillary first intermolar width (6.4 ± 0.1 mm). The Maxillary intercanine width (3.3 ± 0.9 mm), Maxillary central incisor apex width (3.4 ± 0.4 mm), Mandibular first intermolar width (1.7 ± 1.8 mm) and Mandibular intercanine width (0.6 ± 0.9 mm) also increased significantly. The Maxillary central incisor angle reduced significantly from T1 to T2 (-7.9 ± 8.4 mm), indicating that the distance between the root apices increased (Figure 6).

Discussion

Rapid maxillary expansion appliances are used to obtain a normal transverse relationship between the maxilla and the mandible and to relieve crowding in mild cases. The magnitude of the expansion varied greatly in different individuals and at different parts of the craniomaxillary complex. We found the Maxillary alveolar width increased more than the Maxillary base width and that the amount of skeletal and dental tipping gradually increased from the anterior region to the molar region. Technical advances in CT have increased its utility as a diagnostic aid and as a method of evaluating the treatment outcome. Since CT can be used for multiplanar 3-D reconstructions and as it has few artifacts and superimposed structures (both of which can hinder measurement),

Table II. Comparison of T1 and T2 measurements on the 3-D volumes (N = 20).

	T1		T2		Change		t	p
	Mean	SD	Mean	SD	Mean	SD		
Bilatero-orbital width (mm)	85.0	4.2	85.1	4.2	0.1	0.1	1.96	0.06
Bicondylar width (mm)	91.8	6.8	92.9	6.6	1.2	1.3	4.20	**0.01**
Bizygomatic width (mm)	113.6	5.0	113.7	5.0	0.0	0.1	1.63	0.12
Bizygomatico-mandibular width (mm)	94.2	6.9	94.2	6.8	0.1	0.1	2.26	0.04
Bimaxillo-mandibular width (mm)	77.3	9.7	79.3	9.8	2.1	2.3	4.05	**0.01**
Maxillary width (mm)	56.2	4.2	58.7	3.7	2.5	1.6	7.16	**0.01**
Bigonial width (mm)	83.8	5.7	83.8	5.7	0.0	0.1	2.60	0.02
Biantegonial width (mm)	77.4	5.3	77.5	5.3	0.0	0.1	1.33	0.20
Maxillary central incisor apex width (mm)	5.5	1.7	8.9	4.1	3.4	0.4	3.82	**0.01**
Maxillary first intermolar width (mm)	49.7	3.5	56.1	3.6	6.4	0.1	29.59	**0.01**
Mandibular first intermolar width (mm)	51.0	2.6	52.7	2.7	1.7	1.8	4.41	**0.01**
Maxillary central incisor mesial width (mm)	0.5	0.8	0.9	1.3	0.4	1.5	1.32	0.20
Maxillary intercanine width (mm)	30.9	3.7	34.2	3.8	3.3	0.9	16.50	**0.01**
Mandibular intercanine width (mm)	26.6	1.9	27.2	2.2	0.6	0.9	2.89	**0.01**
Maxillary central incisors angle (degrees)	10.3	5.3	2.4	10.5	-7.9	8.4	4.20	**0.01**

Statistically significant at $p < 0.01$

evaluation of the skeletal and dental changes after rapid maxillary expansion is possible. In addition, the new software added to the CT workstation provides reproducible images over time, thereby increasing the possibility of a longitudinal investigation.[6]

In the present study, all linear and angular measurements on the coronal sections increased significantly, indicating that RME increased the transverse dimensions of the maxillae. The increase in the Maxillary base width, however, was considerably less than the increase in the Maxillary alveolar width. This finding is in agreement with previous studies conducted on frontal cephalograms,[10–15] with the use of implants,[16] and on CT scans.[17–20] Despite the heterogeneous sample regarding age, sex and amount of expansion, Krebs reported similar outcomes, with a mean increase in intermolar distance three times larger than expansion at the zygomatic processes.[16] Wertz and Dreskin reported a 2.5 mm widening of the maxillary base compared with a 6.5 mm increase in the intermolar distance.[10]

Our results also showed that the greatest increase in the width of the dental arch occurred opposite the first molars and the effect gradually decreased towards the canines, indicating that the posterior dentition underwent the greatest expansion as a result of RME therapy. This was further confirmed by our finding on the 3-D volume, that the greatest variation in the linear measurements was found in the Maxillary intermolar width. The increase in the Intermolar width reflects the total amount of dental and dento-alveolar expansion produced by the appliance.

In agreement with Garrett et al.,[19] we found that RME tipped the maxillary teeth buccally with the greatest effect at the first permanent molars, indicating increased alveolar bone bending posteriorly. In this regard, when tooth movement becomes the most significant response to expansion, care should be taken not to cause a fenestration or dehiscence in the cortical plate overlying the buccal roots of the first molars. We used the 3-D data to examine the cortical plates from the canines to the first molars, and we found no cases with alveolar fenestration.

The results from the coronal sections were confirmed by measurements of selected skeletal and dental parameters on the 3-D volumes. Skeletal parameters such as Bicondylar width, Bimaxillo-mandibular width and Bimaxillary width increased significantly, whereas the Bilatero-orbital width, Bizygomatic width, Bizygomatico-mandibular width, Bigonial width, and Biantegonial width did not change, presumably because the latter were located some

distance from the maxillae and not directly affected by the expansion. In addition, the Mandibular first intermolar and Mandibular intercanine widths increased significantly following RME although there was no appliance in the mandibular arch during this time, confirming that RME indirectly expands the mandibular dental arch.[2,8,13,21]

When we compared the radiographic and clinical findings we found that the median maxillary diastema closed at the end of active expansion as the central incisor crowns tipped mesially. This was accompanied by a significant reduction in the angle between the central incisors and an increase in the distance between the incisor apices, while the distance between the mesial surfaces of the central incisors did not change significantly.

Compared to current cephalometric methods, CT scans and 3-D reconstructed images provide a more comprehensive and accurate assessment of the dental and skeletal changes associated with RME. Furthermore, the use of CT scans for diagnosis and follow-up is becoming accepted by clinicians as a substitute for conventional cephalometry, but analysis of long-term data and a larger clinical series will be necessary to determine the application of this method in the clinical practice. Future studies will examine the long-term treatment effects of RME on this group of subjects.

Conclusions

RME produced a significant overall increase in maxillary transverse dimensions, with increasing magnitude from the base of the maxilla to the dental arch.

Although significant increases occurred in most skeletal and dental parameters, it appears that bone bending and tipping might explain most of the expansion. The amount of tipping gradually increased from the anterior region to the molar region.

Computed tomography is an effective and reliable method for evaluating the changes induced by RME. It also allows multiplanar and volumetric 3-D reconstruction of the image and a comprehensive evaluation of changes in the skeletal and dental structures. In addition, the volumetric images allow better examination of the treatment outcomes than conventional methods.

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References

1. McNamara JA. Maxillary transverse deficiency. Am J Orthod Dentofacial Orthop 2000;117:567–70.
2. Bishara S, Staley R. Maxilary expansion: clinical implications. Am J Orthod Dentofacial Orthop 1987;91:3–14.
3. Goldenberg D, Alonso N, Goldenberg F, Gebrin E, Amaral T, Scanavini M, Ferreira M. Using computed tomography to evaluate maxillary changes after surgically assisted rapid palatal expansion. J Craniofac Surg 2007;18:302–11.
4. Baumrind S, Carlson S, Beers A, Curry S, Norris K, Boyd R. Using three-dimensional imaging to assess treatment outcomes in orthodontics: a progress report from the University of the Pacific. Orthod Craniofac Res 2003;6:132–42.
5. Scarfe W, Farman A, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc 2006;72:75–80.
6. Swennen G, Schutyser F. Three-dimensional cephalometry: Spiral multi-slice vs cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2006;130:410–16.
7. Podesser B, Williams S, Bantleon H, Imhof H. Quantitation of transverse maxillary dimensions using computed tomography: a methodological and reproducibility study. Eur J Orthod 2004;26:209–15.
8. Baccetti T, Franchi L, Cameron C, McNamara JA. Treatment timing for rapid maxillary expansion. Angle Orthod 2001; 71:343–50.
9. Suomalainen A, Vehmas T, Kortesniemi M, Robinson S, Peltola J. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. Dentomaxillofac Radiol 2008;37:10–17.
10. Wertz R, Dreskin M. Midpalatal suture opening: A normative study. Am J Orthod 1977;71:367–81.
11. Frank S, Engel G. The effects of maxillary quad-helix appliance expansion on cephalometric measurements in growing orthodontic patients. Am J Orthod 1982;81:378–89.
12. da Silva Filho O, Montes L, Torelly L. Rapid maxillary expansion in the deciduous and mixed dentition evaluated through posteroanterior cephalometric analysis. Am J Orthod Dentofacial Orthop 1995;107:268–75.

13. Cameron C, Franchi L, Baccetti T, McNamara JA. Long term effects of rapid maxillary expansion: a posteroanterior cephalometric evaluation. Am J Orthod Dentofacial Orthop 2002;121:129–35.
14. Lamparski D, Rinchuse D, Close J, Sciote J. Comparison of skeletal and dental changes between 2-point and 4-point rapid palatal expanders. Am J Orthod Dentofacial Orthop 2003;123:321–8.
15. Davidovitch M, Efstathiou S, Sarne O, Vardimon A. Skeletal and dental response to rapid maxillary expansion with 2- versus 4-band appliances. Am J Orthod Dentofacial Orthop 2005;127:483–92.
16. Krebs A. Midpalatal suture expansion studies by the implant method over a 7-year period. Rep Congr Eur Orthod Soc 1964:40;131–42.
17. Garib D, Henriques J, Janson G, Freitas M, Coelho R. Rapid maxillary expansion-tooth tissue-borne versus tooth-borne expanders: a computed tomography evaluation of dentoskeletal-effects. Angle Orthod 2005;75:548–57.
18. Podesser B, Williams S, Crismani A, Bantleon H. Evaluation of the effects of rapid maxillary expansion in growing children using computer tomography scanning: a pilot study. Eur J Orthod 2007;29:37–44.
19. Garrett B, Caruso J, Rungcharassaeng K, Farrage J, Kim J, Taylor G. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2008;134:8e1–8.e11.
20. Ballanti F, Lione R, Fanucci E, Franchi L, Baccetti T, Cozza P. Immediate and post-retention effects of rapid maxillary expansion by computed tomography in growing patients. Angle Orthod 2009;79:24–9.
21. Adkins M, Nanda R, Currier G. Arch perimeter changes on rapid palatal expansion. Am J Orthod Dentofacial Orthop 1990;97:194–9.