Original Article

Early post-treatment changes of circumaxillary sutures in young patients treated with rapid maxillary expansion

Rosalia Leonardi[a]; Edoardo Sicurezza[b]; Alice Cutrera[c]; Ersilia Barbato[d]

ABSTRACT

Objective: To test the null hypothesis that circumaxillary sutures do not show bony displacement in response to rapid maxillary expansion (RME) therapy.

Materials and Methods: Subjects consisted of eight growing patients (two male and six female) with Angle Class I malocclusion, bilateral posterior crossbite, transverse maxillary deficiency, deep palatal vault, and dental crowding at the start of the treatment. A Hyrax palatal expander was used for each patient, and activation protocol required the screw to be turned three times per day (0.25 mm per turn) for an average of 18 days for all subjects. Multislice computed tomography (CT) scans were performed before rapid palatal expansion (time T0) and again at the end of the active expansion phase (time T1) without removing the expander. Measurements were carried out directly on the CT image using the OsiriX Imaging software program. Data were analyzed statistically by using the Wilcoxon signed rank test.

Results: All linear measurements showed an increase between T0 and T1 and RME determined a widening of suture; however, sutures far from the maxilla showed a smaller degree of disarticulation.

Conclusions: The hypothesis is rejected. Early treatment with RME produced a significant bony displacement by circumaxillary suture opening. The amount of changes of sutures depends on different factors relating to the subjects and varies between different sutures, showing that sutures that articulate directly with the maxilla face a greater influence by the RME compared with those located further away. (*Angle Orthod.* 2011;81:36–41.)

KEY WORDS: Rapid maxillary expansion; Computed tomography; Circumaxillary; Sutures

INTRODUCTION

Rapid maxillary expansion (RME) treatment has been used widely since the mid 1960s.[1] It is frequently used to correct maxillary width deficiency or posterior crossbite or to expand arch perimeters to alleviate dental crowding.[2] Although the major effect of this treatment is noticed clinically in the dentition and maxilla area, RME therapy appears to involve an ample portion of the craniofacial complex,[3] as the maxilla is associated with 10 bones in the face and head.[4–6] This involvement has been hypothesized following investigations based on histologic methods,[7,8] radiologic imaging, photoelastic models,[7,9] bone scintigraphy,[10] and finite element analysis.[11–18]

Histologic studies on animals demonstrated a sign of increased cellular activity at suture level and immature bony tissue depositing along the suture borders.[7,8] Scintigraphic investigation showed a statistically significant increase in metabolic activity around the maxillary, zygomatic, sphenoid, and nasal bones and midpalatal sutures.[10] Finite element analysis studies on the effect of RME associated, or not, with maxillary protraction[13–19] found signs of high stress around the circumaxillary sutures.

However, even though the above studies have been well designed, some issues may have affected their conclusions. In fact histologic findings are limited to experimental studies in animals. Moreover, accuracy

[a] Professor, Department of Orthodontics, School of Dentistry, University of Catania, Catania, Italy.
[b] Research Assistant, Department of Orthodontics, School of Dentistry, University of Catania, Catania, Italy.
[c] Research Fellow, Department of Orthodontics, School of Dentistry, University of Catania, Catania, Italy.
[d] Professor, Department of Orthodontics, School, of Dentistry, University La Sapienza of Rome, Rome, Italy.
Corresponding author: Dr Rosalia Leonardi, School of Dentistry, University of Catania, Catania, Italy
(e-mail: rleonard@unict.it)

Accepted: August 2010. Submitted: May 2010.

of the results of the finite element model (FEM) depends on the detailed geometry, material properties, and boundary conditions of the FEM.

Therefore, until now, there have been only speculations about whether RME can or cannot disarticulate these structures in humans. With advanced technology and the introduction of three-dimensional computed tomography (3D CT) imaging, this speculation can be verified. Therefore, to study the osseous effects of RME therapy on the midfacial complex, the use of 3D CT was considered in this investigation.

The aim of this investigation was to test the null hypothesis that circumaxillary sutures do not show bony displacement in response to RME therapy. This was done using high-resolution multislice multidetector computed tomography to evaluate quantitatively the early extent of these suture disarticulations in young orthodontic patients following treatment with RME.

MATERIALS AND METHODS

The materials for this prospective study consisted of good quality cephalometric radiographs and CT records taken from eight growing patients (two male and six female), with Angle Class I malocclusion, treated with RME at the Department of Orthodontics, Faculty of Dentistry, Catania University, Catania, Italy.

To be included in this study all patients had to have a bilateral posterior crossbite, transverse maxillary deficiency, deep palatal vault, and dental crowding at the start of the treatment. The mean chronologic age of the patients was 9.8 $\pm$ 1.8 years (range 8 to 11.4 years). Patients less than 8 and more than 11.4 years of age, and patients with missing maxillary posterior permanent teeth, presence of metal restorations on maxillary teeth, periodontal disease, previous orthodontic treatment, or craniofacial syndromes were not included in the study. All procedures were explained to the patients and their parents, and informed consent forms were signed by parents. This was the same patient population used in a previous investigation.[20] The study was approved by the ethical committee of Catania University, Italy.

A Hyrax palatal expander was used for each patient. The activation protocol required the screw to be turned three times per day (0.25 mm per turn) for an average of 18 days for all subjects. Expansion was considered adequate when the occlusal aspect of the maxillary lingual cusp of the permanent first molar came into contact with the occlusal aspect of the mandibular facial cusp of the permanent first molar. The average amount of screw expansion was 8.00 mm, the average total expansion at the molar crown (measured at the cusp tips of the mesiobuccal cusp on the maxillary first molars, left and right, respectively) was 3.20 mm, and the average sutural opening at the same level was 1.72 mm.

Multislice CT scans were performed before rapid palatal expansion (time T0) and again at the end of the active expansion phase (time T1) without removing the expander. The CT scans were carried out by a trained radiographer, using the same scanner console with the primary indication of evaluating buccal bone of maxillary posterior teeth.[21]

A low-dose CT scan protocol was used. This was similar to protocols already described in the literature,[22] but lower voltage and current were used. Briefly, patients were examined with a multidetector helical CT scanner (Lightspeed Ultra, GE Medical Systems, Giles, UK). The scanning parameters were 80 kV, 10 mA (low dose), 0.625 mm collimation, pitch 1, and gantry tilt 0°. Multiplanar reformation and 3D post processing were performed on a workstation (Advantage Windows 4.1, GE Medical Systems). The patients were scanned in the supine position, with chin and shoulder rests, having the head positioned with Camper's plane perpendicular to the ground.[21]

The data of each patient were reconstructed with 0.5-mm slice thickness and saved as DICOM (digital imaging and communications in medicine) files. The data were then transferred to a workstation (Mac Pro Quad, 2.66 GHz; Apple, Cupertino, Calif) and visualized by using the OsiriX Imaging software program which allowed us to take measurements (open source, OsiriX Imaging software, www.osirix-viewer.com). Prior to carrying out measurements, in order to minimize eventual measurement errors due to the absence of a cephalostat, the 3D images were reoriented according to two reference planes: NFZ (a frontal plane passing through the two frontozygomatic sutures at the inner rim of the orbit and nasion) and the Frankfort horizontal (FH) plane as described recently by Cho.[23] Six circumaxillary sutures were examined (five were bilateral sutures and one a single suture). They were classified into four groups according to the kind of articulation and their running pattern.[24] Thus, we had: (1) sutures running sagittally and articulating directly to maxilla (nasomaxillary sutures); (2) sutures running coronally and articulating directly to maxilla (frontomaxillary suture and zygomaticomaxillary suture); (3) sutures running sagittally and articulating indirectly to maxilla (internasal suture, zygomaticotemporal suture); and (4) sutures running coronally and articulating directly to maxilla (frontonasal suture) (Figure 1).

Measurements were carried out directly at the CT image slices either on axial section parallel to the FH plane or on sagittal section perpendicular to the NFZ plane. In order to ensure that the same point was used on the subsequent CT scans, ie, between T0 and T1, and because opening varied along the length and thickness of each suture,[24] the middle site of sutures was chosen as the recording point for each suture.

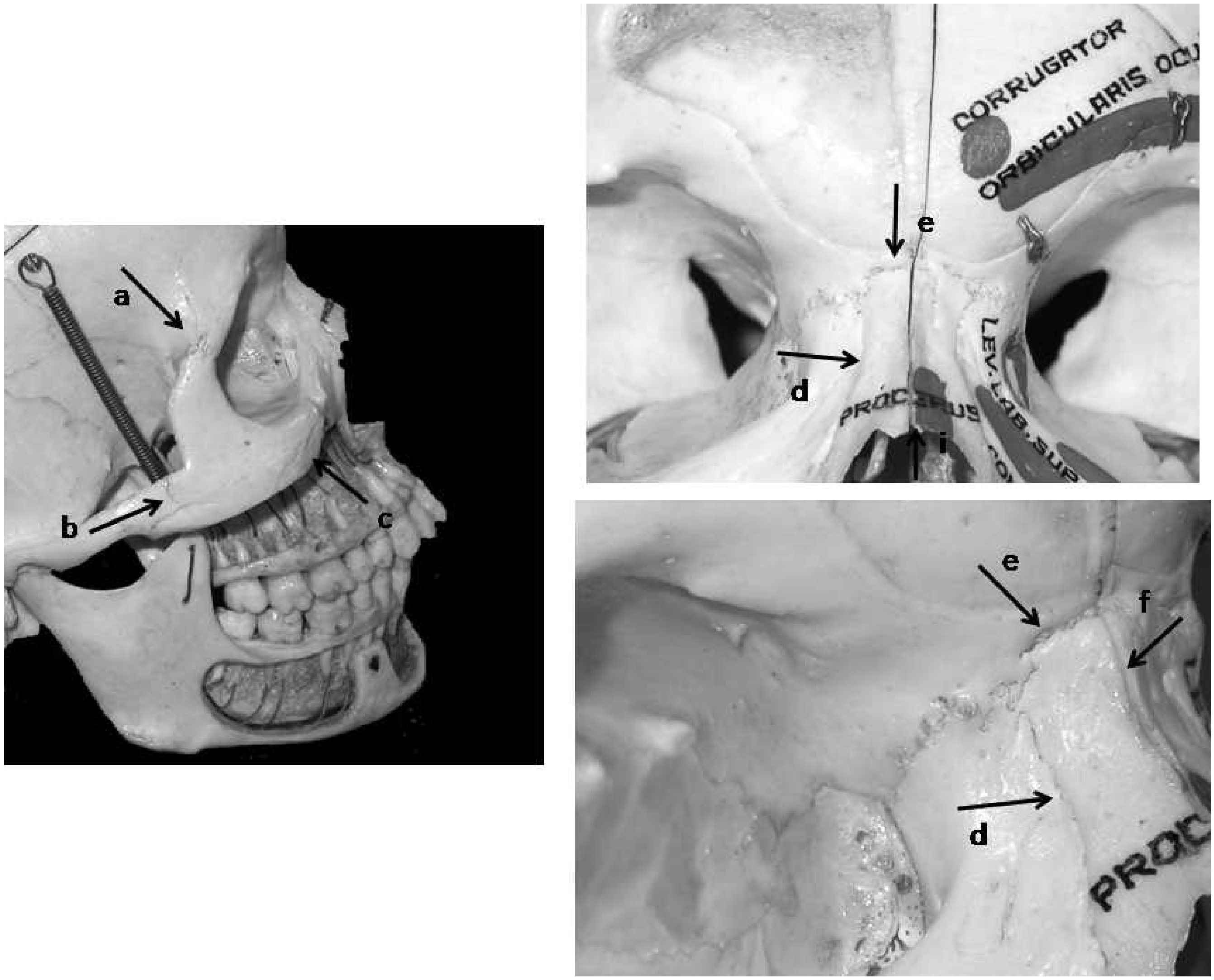

Figure 1. The arrows point out the circumaxillary sutures evaluated in this study. (a) Zygomaticofrontal suture. (b) Zygomaticotemporal suture. (c) Zygomaticomaxillary suture. (d) Nasomaxillary suture. (e) Frontonasal suture. (f) Internasal suture.

Briefly, the first the middle site of each suture was landmarked on the 3D images. Thereafter, the OsiriX Imaging software allowed to find the same point on CT slice, and at this site the suture width was recorded.

The suture width at T0 and T1 was assessed on the right and left side of the skull for bilateral sutures; the single sutures were measured alone. Linear measurements were taken to the nearest 0.01 mm. Figure 2 illustrates the linear variables obtained from the magnified image (4×) before and after expansion.

Statistical Analysis

All measurements were performed by the same observer, thus eliminating the interobserver error factor. Measurements for each single suture were made blinded twice, with a 2-week interval between the first and second readings. The average value of the first and second readings was used as recommended by Baumrind and Frantz.[25]

Descriptive statistics, including the means standard deviations and standard error, were calculated separately for each period (T0 and T1). To evaluate the normal distribution of sutures data, the Shapiro-Wilk test was carried out. This test showed normal distribution of the data. Therefore, the data for suture opening at T0 and T1 were compared using a Student's *t*-test. An AP value of .05 was considered statistically significant. Data were analyzed using SPSS for Windows, version 16.0 (SPSS Inc, Chicago, Ill).

RESULTS

Evaluating the changes between T0 and T1 (Table 1), all linear measurements showed an increase and RME determined a widening of the suture of about

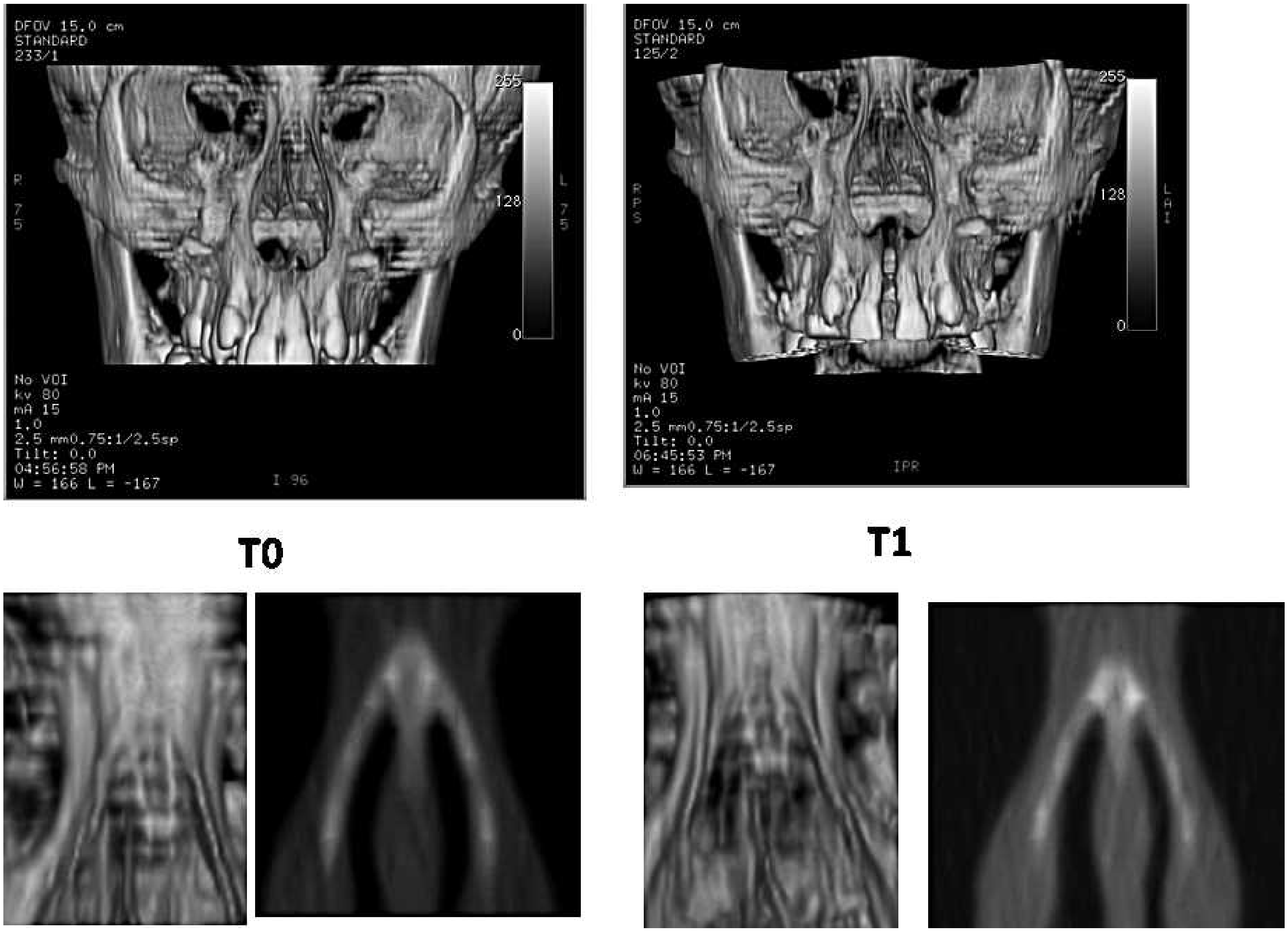

Figure 2. Rendering of the skull before (T0) and after expansion (T1). At the bottom the same magnified image (4×) at internasal suture level before and after expansion and the CT scan slices.

30% ± 12%. The quantity of suture opening at each right and left suture was not significantly different ($P >$ .05); therefore, right and left sutures were combined in order to compare differences between T0 and T1 (Figure 2). Although all values showed clear differences between T0 and T1, indicating that in all patients the appliance had a widening effect on circumaxillary suture, there were individual variations. Descriptive statistics at T0 and T1 are reported in Table 1. Differences between T1 and T0 and P values are shown in the same table.

The average amount of opening was generally higher in the sutures articulating directly to the maxilla (zygomaticomaxillary and frontomaxillary suture), and differences between T0 and T1 were highly significant. Among the sutures indirectly articulating to the maxilla, the internasal suture showed the highest degree of disarticulation, ie, it showed a mean widening of

Table 1. Changes in Circumaxillary Sutures Before Rapid Palatal Expansion (T0) and at the End of the Active Expansion Phase (T1)

Suture	T0, mm (Mean ± SD)	T1, mm (Mean ± SD)	T1–T0, mm	Paired *t*-test
Zygomaticomaxillary	1.198 ± 0.522	1.541 ± 0.638	0.343	<.0005*
Zygomaticotemporal	1.035 ± 0.178	1.248 ± 0.261	0.213	<.0001***
Nasomaxillary	1.224 ± 0.226	1.64 ± 0.432	0.460	<.0001***
Frontonasal	1.209 ± 0.398	1.498 ± 0.476	0.289	<.0005*
Zygomaticofrontal	0.781 ± 0.181	1.068 ± 0.290	0.287	<.0005*
Frontomaxillary	1.017 ± 0.187	1.326 ± 0.169	0.309	<.0001***
Internasal	0.786 ± 0.101	1.173 ± 0.173	0.387	<.0450*

Significance level of P value: * Statistically significant, *** Statistically highly significant.

0.386 mm, and differences between T0 and T1 were statistically significant. Sutures far from the maxilla showed also a certain degree of disarticulation.

DISCUSSION

Tomographic studies on RME have provided useful findings, even though they have been limited in precise evaluation of the biomechanical effect of orthopedic forces on midpalatal suture. In recent years, some experimental data concerning the effect of RME on circumaxillary sutures have been accumulated. In fact, although RME force is concentrated on splitting the maxillary suture, there are concomitant changes to the surrounding circumaxillary sutures.[26,27] Therefore, the purpose of this study was to demonstrate, through 3D CT imaging, the osseous effects on the orofacial skeleton induced by RME on circumaxillary sutures. seeing that it has still not been well explored quantitatively.

In fact, most investigations have been carried out on animals, or through FEM studies, few of which were validated with the use of posteroanterior x-rays, whose usefulness due to the low reliability of cephalometric points can be questioned.[28] Therefore, no clinical evidence is available on human beings. It has been stated that palatal expansion ''disarticulates'' the maxilla and initiates cellular responses at the circumaxillary sutures.[10,29] This leads to an increased anabolic rate of sutural cells and a modified activity of many genes and transcriptional factors and therefore enhances transverse growth of the circumaxillary anatomical regions.[30–32]

Findings from our investigation showed that circumaxillary sutures articulating directly to the maxilla were opened more extensively than those indirectly articulated. In fact, the distant structures of the craniofacial skeleton (zygomatic bone and temporal bone) were also affected by transverse orthopedic forces, although to a lesser extent. All in all, an increased width in circumaxillary sutures, with the highest amount of opening at the internasal suture (0.386 mm) and the lower at the zygomaticotemporal suture (0.213 mm) was observed. Our findings support the results from previous FEM studies that demonstrated higher stress levels in the zygomatic process, external walls of the orbit, the frontozygomatic suture, and the frontal process of the maxilla.[12,14–18]

For the sake of clarity, it should be emphasized that results from our CT study may have underestimated suture disarticulation as the evaluations were carried out only on a plane of the CT scan and at the middle portion of the suture, ie, in a point. As a matter of fact, due to the complexity of the facial skeleton and the topography of sutures, it is reasonable to assume that compression, shear, and tension forces may coexist in the same suture at different sites. Thus, experimental models like FEM would, apparently, seem to depict better what really happens on circumaxillary sutures following RME.

However, it should be pointed out that FEM studies have their own limitations. In fact, it is important to realize that results from FEM studies depend on the selections of nodes and elements valid for a specific human skull as the analytical model is generally developed from just one skull. Accordingly, one should be aware that the structural and spatial relationship of various craniofacial components varies among individuals.[17] Acquaintance with these initial mechanical reactions helps the orthodontist to understand better the final therapeutic effects and the way the orthodontic appliance actually acts on sutures of the craniofacial system.

An increased success rate for orthodontic treatment of Class III malocclusion using RME followed by facial mask therapy[33–35] is also rational and supported by our findings. From a biomechanical point of view, knowing the displacement and stress patterns in the craniofacial skeleton will help us to gain a better understanding of how the internal bony structures of the craniofacial skeleton respond to RME therapy.

CONCLUSIONS

- The null hypothesis that circumaxillary sutures do not show bony displacement in response to RME is rejected.
- The amount of widening after RME therapy is different among sutures and highly variable among subjects.
- Sutures articulating directly to the maxilla are more affected by the RME therapy.

REFERENCES

1. Lagravere MO, Heo G, Major PW, Flores-Mir C. Meta-analysis of immediate changes with rapid maxillary expansion treatment. *J Am Dent Assoc*. 2006;137:44–53.
2. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2008;134:8–9.
3. Cameron CG, Franchi L, Baccetti T, McNamara JA Jr. Long-term effects of rapid maxillary expansion: a posteroanterior cephalometric evaluation. *Am J Orthod Dentofacial Orthop*. 2002;121:129–135; quiz 93.
4. Bell RA, LeCompte EJ. The effects of maxillary expansion using a quad-helix appliance during the deciduous and mixed dentitions. *Am J Orthod*. 1981;79:152–161.
5. Bishara SE, Staley RN. Maxillary expansion: clinical implications. *Am J Orthod Dentofacial Orthop*. 1987;91:3–14.

6. Timms DJ. A study of basal movement with rapid maxillary expansion. *Am J Orthod*. 1980;77:500–507.
7. Chaconas SJ, Caputo AA. Observation of orthopedic force distribution produced by maxillary orthodontic appliances. *Am J Orthod*. 1982;82:492–501.
8. Gardner GE, Kronman JH. Cranioskeletal displacements caused by rapid palatal expansion in the rhesus monkey. *Am J Orthod*. 1971;59:146–155.
9. Itoh T, Chaconas SJ, Caputo AA, Matyas J. Photoelastic effects of maxillary protraction on the craniofacial complex. *Am J Orthod*. 1985;88:117–124.
10. Baydas B, Yavuz I, Uslu H, Dagsuyu IM, Ceylan I. Nonsurgical rapid maxillary expansion effects on craniofacial structures in young adult females. A bone scintigraphy study. *Angle Orthod*. 2006;76:759–767.
11. Lee H, Ting K, Nelson M, Sun N, Sung SJ. Maxillary expansion in customized finite element method models. *Am J Orthod Dentofacial Orthop*. 2009;136:367–374.
12. Provatidis CG, Georgiopoulos B, Kotinas A, McDonald JP. Evaluation of craniofacial effects during rapid maxillary expansion through combined in vivo/in vitro and finite element studies. *Eur J Orthod*. 2008;30:437–448.
13. Boryor A, Geiger M, Hohmann A, Wunderlich A, Sander C, Martin Sander F, Sander FG. Stress distribution and displacement analysis during an intermaxillary disjunction—a three-dimensional FEM study of a human skull. *J Biomech*. 2008;41:376–382.
14. Provatidis C, Georgiopoulos B, Kotinas A, McDonald JP. On the FEM modeling of craniofacial changes during rapid maxillary expansion. *Med Eng Phys*. 2007;29:566–579.
15. Yu HS, Baik HS, Sung SJ, Kim KD, Cho YS. Three-dimensional finite-element analysis of maxillary protraction with and without rapid palatal expansion. *Eur J Orthod*. 2007;29:118–125.
16. Holberg C. Effects of rapid maxillary expansion on the cranial base—an FEM-analysis. *J Orofac Orthop*. 2005;66:54–66.
17. Jafari A, Shetty KS, Kumar M. Study of stress distribution and displacement of various craniofacial structures following application of transverse orthopedic forces—a three-dimensional FEM study. *Angle Orthod*. 2003;73:12–20.
18. Iseri H, Tekkaya AE, Oztan O, Bilgic S. Biomechanical effects of rapid maxillary expansion on the craniofacial skeleton, studied by the finite element method. *Eur J Orthod*. 1998;20:347–356.
19. Bobak V, Christiansen RL, Hollister SJ, Kohn DH. Stress-related molar responses to the transpalatal arch: a finite element analysis. *Am J Orthod Dentofacial Orthop*. 1997;112:512–518.
20. Leonardi R, Cutrera A, Barbato E. Rapid maxillary expansion affects the spheno-occipital synchondrosis in youngsters. A study with low-dose computed tomography. *Angle Orthod*. 2010;80:106–110.
21. Garib DG, Henriques JF, Janson G, de Freitas MR, Fernandes AY. Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders: a computed tomography evaluation. *Am J Orthod Dentofacial Orthop*. 2006;129:749–758.
22. Lione R, Ballanti F, Franchi L, Baccetti T, Cozza P. Treatment and posttreatment skeletal effects of rapid maxillary expansion studied with low-dose computed tomography in growing subjects. *Am J Orthod Dentofacial Orthop*. 2008;134:389–392.
23. Cho HJ. A three-dimensional cephalometric analysis. *J Clin Orthod*. 2009;43:235–252. discussion 235; quiz 273.
24. Wang YC, Chang PM, Liou EJ. Opening of circumaxillary sutures by alternate rapid maxillary expansions and constrictions. *Angle Orthod*. 2009;79:230–234.
25. Baumrind S, Frantz RC. The reliability of head film measurements. 2. Conventional angular and linear measures. *Am J Orthod*. 1971;60:505–517.
26. Starnbach H, Bayne D, Cleall J, Subtelny JD. Facioskeletal and dental changes resulting from rapid maxillary expansion. *Angle Orthod*. 1966;36:152–164.
27. Ten Cate AR, Freeman E, Dickinson JB. Sutural development: structure and its response to rapid expansion. *Am J Orthod*. 1977;71:622–636.
28. Leonardi R, Annunziata A, Caltabiano M. Landmark identification error in posteroanterior cephalometric radiography. A systematic review. *Angle Orthod*. 2008;78:761–765.
29. Turley PK. Orthopedic correction of Class III malocclusion with palatal expansion and custom protraction headgear. *J Clin Orthod*. 1988;22:314–325.
30. Hong L, Mao JJ. Tissue-engineered rabbit cranial suture from autologous fibroblasts and BMP2. *J Dent Res*. 2004;83:751–756.
31. Kopher RA, Mao JJ. Suture growth modulated by the oscillatory component of micromechanical strain. *J Bone Miner Res*. 2003;18:521–528.
32. Mao JJ, Wang X, Mooney MP, Kopher RA, Nudera JA. Strain induced osteogenesis of the craniofacial suture upon controlled delivery of low-frequency cyclic forces. *Front Biosci*. 2003;8:a10–7.
33. Toffol LD, Pavoni C, Baccetti T, Franchi L, Cozza P. Orthopedic treatment outcomes in Class III malocclusion. A systematic review. *Angle Orthod*. 2008;78:561–573.
34. Baccetti T, Franchi L, McNamara JA Jr. Treatment and posttreatment craniofacial changes after rapid maxillary expansion and facemask therapy. *Am J Orthod Dentofacial Orthop*. 2000;118:404–413.
35. Westwood PV, McNamara JA Jr, Baccetti T, Franchi L, Sarver DM. Long-term effects of Class III treatment with rapid maxillary expansion and facemask therapy followed by fixed appliances. *Am J Orthod Dentofacial Orthop*. 2003;123:306–320.