Rapid Maxillary Expansion Affects the Spheno-occipital Synchondrosis in Youngsters

A Study with Low-Dose Computed Tomography

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

ABSTRACT

Objective: To test the null hypothesis that the spheno-occipital synchondrosis does not show bony displacement in response to rapid maxillary expansion (RME) therapy in youngsters.

Materials and Methods: A total of 16 computed tomography (CT) records were taken from 8 growing patients (2 males and 6 females), before (T0) and after (T1) treatment with RME. All patients had been diagnosed originally with transverse maxillary deficiency. The mean chronological age of the patients was 9.8 $\pm$ 1.8 years (range, 8 to 11.4 years). High-resolution multislice multidetector CT was used to study quantitatively the extent of the opening of the spheno-occipital synchondrosis following RME. A low-dose CT scan protocol was used (80 kV, 10 mA) and the data file of each patient was transferred to a workstation where the anteroposterior width of the spheno-occipital synchondrosis was measured on axial images.

Results: Before treatment with RME (T0), the anteroposterior mean width of the spheno-occipital synchondrosis was 1.73 $\pm$ 0.46 mm immediately after the active phase of expansion (T1), and the width of the synchondrosis increased to 2.30 $\pm$ 0.47. This difference was statistically significant according to the Wilcoxon signed rank test ($P < .05$).

Conclusion: Rapid maxillary expansion leads to a small immediate widening of the spheno-occipital synchondrosis in youngsters. (*Angle Orthod.* 2010;80:106–110.)

KEY WORDS: Computed tomography; Rapid maxillary expansion; Spheno-occipital synchondrosis

INTRODUCTION

Rapid maxillary expansion (RME) is used frequently to correct maxillary posterior crossbite, to expand arch perimeters, and to alleviate dental crowding.[1] Patients with Class III malocclusion often are treated with RME because of an insufficient maxillary arch width.[2–4]

Although the RME force is concentrated on widening the maxilla, concomitant changes occur in circummaxillary sutures. Moreover, it has been claimed that the transverse forces generated during rapid maxillary expansion are transmitted, via the pterygomaxillary connection, to the unpaired sphenoid bone of the cranial base, where they lead to stress. The extent and effects of this have not yet been studied extensively, nor have they been well determined.[5]

Studies on the effects of RME on the spheno-occipital synchondrosis have dealt most often with experimental models based on finite element analyses (FEM).[5–11] Just two studies, one on an animal model[12] and the other on human subjects using a bone scintigraphic method, have demonstrated an opening of the spheno-occipital synchondrosis and a significant increase in metabolic activity in the area of the spheno-occipital synchondrosis following the application of RME.[13] Findings from these studies pointed out the involvement of the spheno-occipital synchondrosis following RME application. This notion, together with rising evidence that chondrocyte proliferation is modulated by mechanical stress, questions the solely genetic control of cranial base cartilage (CBC) growth. In fact, it has been speculated that the growth of CBC

[a] Associate Professor, Department of Orthodontics, University of Catania, Catania, Italy.

[b] Research Fellow, Department of Orthodontics, University of Catania, Catania, Italy

[c] Professor, Department of Orthodontics, University of Rome "La Sapienza", Rome, Italy.

Corresponding author: Dr Rosalia Leonardi, Department of Orthodontics, University of Catania, via S. Sofia n 78, Catania, Italy
(e-mail: rleonard@unict.it)

Accepted: March 2009. Submitted: January 2009.

 DOI: 10.2319/012709-56.1

also depends upon gradual enlargement of the growing brain, implying that chondral growth is encouraged by the continuous presence of tensile forces.[3,14]

In orthodontics, the cranial base (CB) has received attention because of the fact that its growth influences the maxillary-mandibular complex. Some authors in fact consider the cranial base as a guide rail[15] for development of the maxilla, midface, and lower facial complex. Among the synchondroses, the spheno-occipital synchondrosis (SOS) has received greater attention because it may be visible on lateral radiographs of the skull base through the period of adolescence. The intersphenoidal synchondrosis, on the other hand, is ossified immediately after birth, and the ethmoidal synchondrosis generally ossifies at the age of 7.[16]

Thanks to low-dose computed tomography (CT), it is now possible to acquire accurate radiographic images that allow clinicians and researchers to quantitatively evaluate bone changes with minimal distortion and lower radiation dosage.[1] Accordingly, the aims of this investigation were to test the hypothesis that spheno-occipital synchondrosis shows bony displacement in response to RME therapy and to study quantitatively the extent of spheno-occipital synchondrosis opening following RME by high-resolution multislice multidetector CT.

MATERIALS AND METHODS

The material for this prospective study consisted of lateral cephalometric radiographs and CT records taken from 8 growing patients (2 males and 6 females) treated with RME at the Department of Orthodontics, Faculty of Dentistry, Catania University, Italy. All patients had a bilateral posterior crossbite, transverse maxillary deficiency, a deep palatal vault, and dental crowding at the start of treatment. The mean chronological age of patients was 9.8 $\pm$ 1.8 years (range, 8 to 11.4 years).

Patient exclusion criteria included age younger than 8 or older than 11.4 years, absence of maxillary posterior permanent teeth, presence of metal restorations on the maxillary teeth, previous periodontal disease, and previous orthodontic treatment. All procedures were explained to the patients and their parents, and written consent was obtained from the parents. The study was approved by the ethical committee of Catania University, Italy.

An analysis of the lateral radiographs was performed, and cranial base measurements of the nasion-sella-basion angle (N-S-Na^) and the distance in millimeters of the sella-basion (S-Ba) were recorded according to the parameters suggested in the literature[15] (Table 1).

Table 1. Recordings for Each Patient[a]

SOS T0	SOS T1	Suture Opening at First Molar Level	N-S-Ba^	S-Ba, mm
0.214	0.271	1.95	138	42
0.240	0.299	1.88	135	46
0.134	0.184	1.74	128	50
0.120	0.187	2.05	131	48
0.119	0.181	1.80	124	42
0.211	0.272	2.01	132	46
0.184	0.250	1.89	127	41
0.168	0.197	1.76	135	44

[a] The anteroposterior width of the spheno-occipital synchondrosis (SOS), measured in millimeters before rapid palatal expansion (time T0) and at the end of the active expansion phase (T1). Midpalatal suture opening, in millimeters, at the level of the first maxillary molars, as recorded on frontal slices by computed tomography (CT). Cranial base measurements are recorded in lateral cephalometric x-rays. The nasion-sella-basion angle (N-S-Na^) and the distance in millimeters (sella-basion [S-Ba]) are provided.

Each patient was treated with a Hyrax palatal expander, and the activation protocol included three turns per day of the screw (0.25 mm per turn), for an average of 18 days, in all subjects. Expansion was considered adequate when the occlusal aspect of the maxillary lingual cusp of the permanent first molar contacted the occlusal aspect of the mandibular facial cusp of the permanent first molar. The appliance was left in place for approximately 6 months after active expansion.

Multislice CT scans were taken before rapid palatal expansion (time T0) and at the end of the active expansion phase (T1), without removing the expander. CT scans were carried out by a trained radiographer at the same scanner console to evaluate the buccal bone of the maxillary posterior teeth.[17] A low-dose CT scan protocol was used. This was similar to protocols already described in the literature,[18] but a lower kV and mA were used.

Briefly, patients were examined with a multidetector helical CT scanner (Lightspeed Ultra; GE Medical Systems, Giles, UK). Scanning parameters were 80 kV, 10 mA (low dose), 0.625-mm collimation, pitch 1, and gantry tilt 0 degrees. Multiplanar reformation and 3D post processing were performed on a workstation (Advantage Windows 4.1; GE Medical Systems). The patients were scanned in supine position, with chin and shoulder rests, and with the head positioned with Camper's plane perpendicular to the ground.[17]

Data on each patient were reconstructed with 0.5-mm slice thickness and were saved as DICOM (digital imaging and communications in medicine) files. Data then were transferred to a workstation (Mac Pro Quad 2.66GHz, APPLE; One Infinite Loop, Cupertino, Calif) and were measured by the computerized method. The

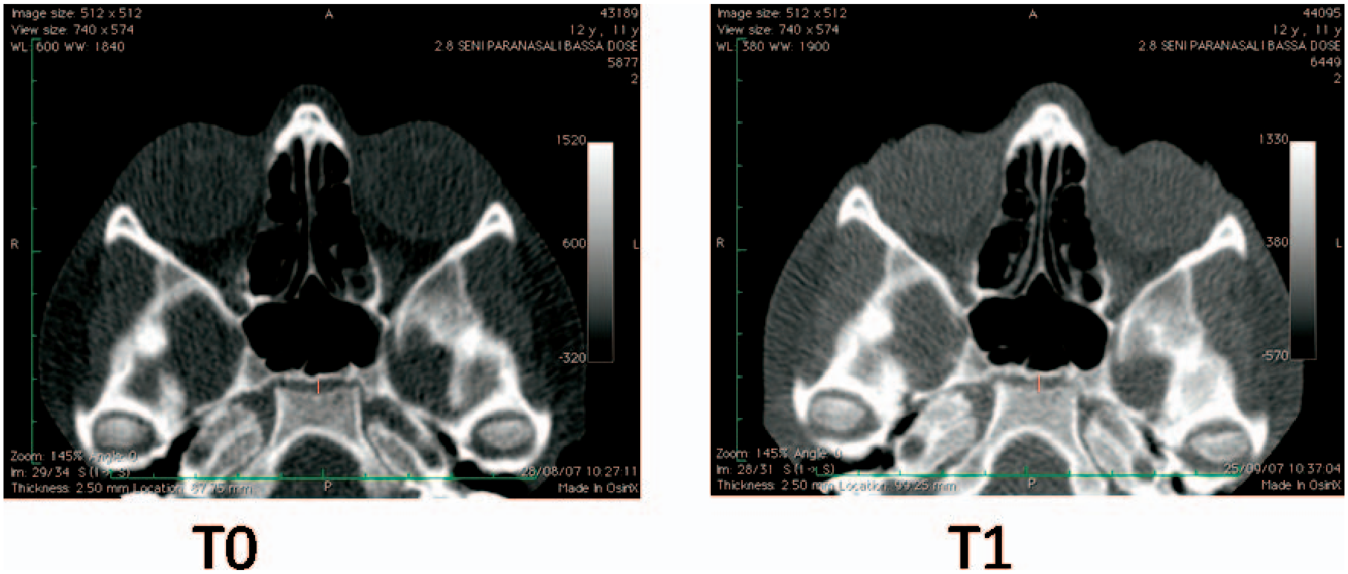

Figure 1. The anteroposterior width of the spheno-occipital synchondrosis measured on axial image in millimeters before rapid palatal expansion (time T0) and at the end of the active expansion phase (T1). The site of measurement appears in red.

OsiriX Medical Imaging software program (Open Source; OsiriX Medical Imaging Software, www.osirix-viewer.com) and Mimics, a 3D image processing and editing program based on scanner data software (Materialise NV Technologielaan, Leuven, Belgium), were used for this.

The anteroposterior width of the spheno-occipital synchondrosis was measured on axial images almost parallel to the orbitomeatal line, which was identified by lateral CT scans passing through the lower third of the synchondrosis.[19] This finally allowed us to visualize the axial slice. The widest measurement of the anteroposterior dimension of the synchondrosis on the midsagittal plane was recorded for each image.

Dimensional changes occurring in the midpalatal suture at the first molar level following RME also were evaluated. This sutural opening could be measured only on posttreatment scans. Before expansion, the suture could be defined anatomically, although no space between sutural surfaces could be measured. Frontal slices at the level of the first maxillary molars, showing their entire palatal root and crown, and midpalatal sutures were used to assess these changes. Measurements were carried out at the medial limit of the palatine processes, left and right respectively.[20] Linear measurements were made to the nearest 0.01 mm.

Statistical Analysis

All measurements were made twice with a 2-week interval by the same calibrated examiner.

Paired *t*-tests, at a significance level of 5%, were employed to evaluate the systematic error. Random error was calculated as previously described.[21] No systematic error was detected between duplicate measurements of the conventional variables. Differences between duplicate measurements ranged from 0.3 to 0.5 mm. The coefficient of reliability ranged from 95.6% to 97.3%. The random error (the square root of half of the variance of the difference between duplicate measurements) ranged from 0.11 to 0.19.

Descriptive statistics, including means and standard deviations, were calculated separately for each period. Means and standard deviations were calculated for each parameter. T0 and T1 data were compared by using the Wilcoxon signed rank test, with a probability level of .05 considered statistically significant. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) for Windows, version 16.0 (SPSS Inc, Chicago, Ill).

RESULTS

Before treatment with RME (T0), the mean anteroposterior width of the spheno-occipital synchondrosis was 1.73 ± 0.46 mm. Immediately after the active phase of expansion (T1), the width of the synchondrosis increased (Figure 1) in every patient, with a mean of 2.30 ± 0.47. This indicates a difference of 0.57 mm between T0 and T1. When changes between T0 and T1 were evaluated by using the Wilcoxon signed rank test, differences were found to be statistically significant ($P < .05$).

The average sutural opening at the molar level showed an average measurement of 1.885 ± 0.114mm (minimum, 1.74; maximum, 2.05).

The cranial base–related findings are given in Table

1. Both N-S-Ba^ (mean, 131.25 ± 4.713 degrees) and S-Ba distance (mean, 44.875 ± 3.182 mm) were within normal values.

DISCUSSION

Chondral growth of the cranial base, like that of the epiphyseal plates, relies on differentiation, proliferation, and maturation of chondrocytes, in addition to concurrent synthesis of extracellular matrices. The spheno-occipital synchondrosis is of particular importance, because of its late ossification in adolescent humans. The growth of the cranial base cartilage is considered controlled by predetermined cycles of mitosis and apoptosis, both of which are genetically coded in chondrocytes, even though a contribution from mechanical stimuli has been argued recently.

Closure of spheno-occipital synchondrosis has been studied morphologically, histologically, radiographically,[22–24] and by high-resolution CT.[19] Findings from some of these studies agree that the synchondrosis was completely ossified by the age of 16 to 17 years in girls, and about 2 years later in boys.[22,23] Other authors believe that no spheno-occipital synchondrosis persisted in any patient past the age of 13 years. Moreover, the initial ossification center within the synchondrosis is observed more frequently within the upper half and the middle portion of the synchondrosis.[19,24]

Findings from the study presented here demonstrate that the spheno-occipital synchondrosis is involved during RME therapy; for the first time in humans, it is known to widen in response to midpalatal suture expansion. Naturally, because a pattern of progressive ossification of the spheno-occipital synchondrosis has been identified, our findings cannot be true for adults.

Our results confirm most of the findings reported previously in the literature, which highlighted possible involvement of the spheno-occipital synchondrosis during RME therapy. Gardner and Kronman[12] described these effects on the cranial base in rhesus monkeys.[12] The AA reported an even 1.5-mm opening of the spheno-occipital synchondrosis in one animal during RME. According to bone scintigraphic records,[13] a significant increase in metabolic activity was noted in the area of the spheno-occipital synchondrosis, following nonsurgical RME in young adult females.

As far as the FEM studies are concerned, even though their limitations include not taking into account interindividual and intraindividual variation in bone tissue,[8] the results of most of the investigations,[6–8,25] except for one,[5] revealed an increase in stress levels at the skull base, at a degree ranging from relatively high to very high depending on the elements and their shape as used in the FEM analysis. This involvement finds its logical basis in the cumulative forces[26] of 100 N or more that can be achieved on repeated activation of the central expansion screw, which leads to stress on neighboring skull bones. In detail, the fixed pterygomaxillary connection, where spontaneous opening is not to be expected during a rapid palatal suture expansion,[27] allows the transmission of stress onto the skull base.

Involvement of the spheno-occipital synchondrosis has some important clinical and research implications, which could explain the beneficial effects of RME in favor of Class III corrections in young patients. Among these, the opening of the synchondrosis could account for the forward and downward displacement of the maxilla. It has been claimed by some but not all[28] authors that when the midpalatal suture opens, the maxilla always moves downward and forward, because of the disposition of the maxillocranial sutures. Palatal expansion causes disruption of these sutures, and an effect similar to immediate growth is manifested in downward and forward displacement of the maxilla.

On the other hand, stress on the synchondrosis could trigger biomolecular events, which, in turn, could lead to enhanced endochondral ossification.[29] Recently, it has been demonstrated in several organ cultures modeling the spheno-occipital synchondrosis[14,29–31] that tensile stress increases growth at this site. In fact, following the application of mechanical stress, chondrocyte proliferation and chondrocyte maturation are enhanced,[14,31] and thickening of the hypertrophic zone occurs.[30] Analysis of these data suggests that genetically coded chondral growth is upregulated by mechanical signals.[14] Thus enhancement of growth at the synchondrosis level seems to be expected following the application of a force.

However, one should bear in mind that these findings represent short-term observations,[28] requiring critical analysis of longitudinal studies. In this respect, CT diagnostic imaging studies are strongly encouraged because, contrary to FEM, it would be possible to demonstrate whether or not these effects on the spheno-occipital synchondrosis are long-lasting changes or are limited to the end of the active phase. Moreover, a comparison between subjects with a shortening of CB, who are supposed to have less growth potential at the SOS, compared with subjects with a normal CB is needed to evaluate whether such mechanical force is able in same way to affect the SOS. Future studies are required on a long-term basis.

CONCLUSION

- Rapid maxillary expansion leads to widening of the spheno-occipital synchondrosis on a short-term basis.

REFERENCES

1. 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.
2. Haas AJ. Rapid palatal expansion: a recommended prerequisite to Class III treatment. *Trans Eur Orthod Soc.* 1973; 311–318.
3. Wertz RA. Changes in nasal airflow incident to rapid maxillary expansion. *Angle Orthod.* 1968;38:1–11.
4. Wertz RA. Skeletal and dental changes accompanying rapid midpalatal suture opening. *Am J Orthod.* 1970;58:41–66.
5. 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.
6. Boryor A, Geiger M, Hohmann A, Wunderlich A, Sander C, Martin Sander F, et al. Stress distribution and displacement analysis during an intermaxillary disjunction—a three-dimensional FEM study of a human skull. *J Biomech.* 2008; 41:376–382.
7. Holberg C. Effects of rapid maxillary expansion on the cranial base—an FEM-analysis. *J Orofac Orthop.* 2005;66:54–66.
8. Holberg C, Rudzki-Janson I. Stresses at the cranial base induced by rapid maxillary expansion. *Angle Orthod.* 2006; 76:543–550.
9. 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.
10. 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.
11. 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.
12. Gardner GE, Kronman JH. Cranioskeletal displacements caused by rapid palatal expansion in the rhesus monkey. *Am J Orthod.* 1971;59:146–155.
13. 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.
14. Wang X, Mao JJ. Chondrocyte proliferation of the cranial base cartilage upon in vivo mechanical stresses. *J Dent Res.* 2002;81:701–705.
15. Proff P, Will F, Bokan I, Fanghanel J, Gedrange T. Cranial base features in skeletal Class III patients. *Angle Orthod.* 2008;78:433–439.
16. Sejrsen B, Jakobsen J, Skovgaard LT, Kjaer I. Growth in the external cranial base evaluated on human dry skulls, using nerve canal openings as references. *Acta Odontol Scand.* 1997;55:356–364.
17. 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.
18. 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.
19. Okamoto K, Ito J, Tokiguchi S, Furusawa T. High-resolution CT findings in the development of the spheno-occipital synchondrosis. *AJNR Am J Neuroradiol.* 1996;17:117–120.
20. Podesser B, Williams S, Crismani AG, Bantleon HP. 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.
21. Houston WJ. The analysis of errors in orthodontic measurements. *Am J Orthod.* 1983;83:382–390.
22. Ingervall B, Thilander B. The human spheno-occipital synchondrosis. I. The time of closure appraised macroscopically. *Acta Odontol Scand.* 1972;30:349–356.
23. Thilander B, Ingervall B. The human spheno-occipital synchondrosis. II. A histological and microradiographic study of its growth. *Acta Odontol Scand.* 1973;31:323–334.
24. Melsen B. Time of closure of the spheno-occipital synchondrosis determined on dry skulls: a radiographic craniometric study. *Acta Odontol Scand.* 1969;27:73–90.
25. Gautam P, Valiathan A, Adhikari R. Stress and displacement patterns in the craniofacial skeleton with rapid maxillary expansion: a finite element method study. *Am J Orthod Dentofacial Orthop.* 2007;132:5 e1–e11.
26. Zimring JF, Isaacson RJ. Forces produced by rapid maxillary expansion. 3. Forces present during retention. *Angle Orthod.* 1965;35:178–186.
27. Melsen B, Melsen F. The postnatal development of the palatomaxillary region studied on human autopsy material. *Am J Orthod.* 1982;82:329–342.
28. Garib DG, Henriques JF, Carvalho PE, Gomes SC. Longitudinal effects of rapid maxillary expansion. *Angle Orthod.* 2007;77:442–448.
29. Lei WY, Wong RW, Rabie AB. Factors regulating endochondral ossification in the spheno-occipital synchondrosis. *Angle Orthod.* 2008;78:215–220.
30. Rukkulchon BK, Wong RW. Effect of tensile force on expression of PTHrP and thickness of hypertrophic zone in organ-cultured mouse spheno-occipital synchondroses. *Arch Oral Biol.* 2008;53:690–699.
31. Wang X, Mao JJ. Accelerated chondrogenesis of the rabbit cranial base growth plate by oscillatory mechanical stimuli. *J Bone Miner Res.* 2002;17:1843–1850.