ORIGINAL ARTICLE

Long-term effects of rapid maxillary expansion: A posteroanterior cephalometric evaluation

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The aim of this study was to investigate long-term effects induced by rapid maxillary expansion (RME), followed by comprehensive orthodontic treatment, in a sample of 42 patients compared with normal growth changes in a sample of 20 subjects. Treated subjects underwent Haas-type RME with 2 turns a day (0.25 mm per turn) until the expansion screw reached 10.5 mm (about 21 days). The Haas expander was kept on the teeth as a passive retainer for an average of about 2 months. Immediately after the Haas expander was removed, fixed standard edgewise appliances were placed. Posteroanterior cephalograms were analyzed for each subject in both groups at T1 (pretreatment) and at T2 (long-term observation). The mean age at T1 was 11 years 10 months for both the treated and the control groups. The mean ages at T2 also were comparable (20 years 6 months for the treated group, and 17 years 8 months for the control group). The study included transverse measurements on dentoalveolar structures, maxillary and mandibular bony bases, and other craniofacial regions (nasal, zygomatic, orbital, and cranial). RME followed by edgewise appliance therapy appears to be an effective procedure to increase transverse facial dimensions in the long term, at both the skeletal and the dentoalveolar levels. Significant pretreatment deficiencies in maxillary width, maxillary incisor apex width, and maxillary first molar width remained corrected at a mean age of about 20 years. The initial deficiency in lateroorbitale width was also eliminated. (Am J Orthod Dentofacial Orthop 2002;121:129-35)

Interest in rapid maxillary expansion (RME) has increased markedly during the past 2 decades. The correction of transverse discrepancies and the gain in arch perimeter as a potential nonextraction technique appear to be the most important reasons underlying this increased interest. Although the major treatment effect is noticed clinically in the area of the dentition, transverse enlargement of the apical bone or the skeletal structures may be considered as additional contributions. Cephalometric studies on posteroanterior (PA) films therefore are needed to quantify possible changes induced by RME in the various regions of the facial skeleton.

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Currently, the number of scientific investigations conducted on frontal cephalograms is limited, and these studies have considered mostly the short-term changes associated with RME.[1-9] Furthermore, most studies incorporated no controls and failed to consider transverse modifications in facial skeletal structures far from the nasomaxillary complex.

There have been few well-designed investigations of the long-term craniofacial adaptations to RME therapy. A study that is representative of clinical studies without an untreated control group that considered the long-term effects of RME was performed by Haas.[10] The study presented long-term data from 10 subjects. After expansion, the average increases initially were 9 mm in apical base width and 4.5 mm in nasal cavity width. None of the 10 subjects underwent a loss in either dimension at the time of reevaluation (6-14 years postretention). In another long-term cephalometric study that incorporated metallic implants, Krebs[3] examined 23 patients with bilateral crossbites over a 7-year period after RME. He found that increments in both nasal and maxillary widths were relatively stable. The width of the dental arch was increased significantly by RME therapy, but the gain in many instances was not stable, with a steady decrease being recorded up to 4 or 5 years after the treatment.

The aim of the present study was to evaluate dental and skeletal changes induced by RME therapy in the long term. Particular features of this study were the use of an adequate untreated control group and the analysis of skeletal modifications in craniofacial structures other than the maxilla. The main focus of the investigation was to appraise the amount of residual correction of maxillary transverse deficiency at both the dentoalveolar and skeletal levels after the completion of growth.

MATERIAL AND METHODS

Subjects

Two groups of subjects were analyzed. The RME sample was derived from the long-term records of patients who had undergone Haas-type RME and nonextraction edgewise appliance therapy in a single orthodontic practice. The records obtained consisted of pretreatment (T1) and long-term posttreatment (T2) (minimum of 5 years) PA cephalograms. The PA cephalometric radiographs were taken according to a standardized technique similar to that used by Broadbent.[11] The patients originally were judged by the practitioner to have transverse maxillary deficiency as part of their overall orthodontic problem. These patients underwent Haas-type RME with 2 turns a day (0.25 mm per turn) until the expansion screw reached 10.5 mm (about 21 days). The Haas expander was kept on the teeth as a passive retainer for an average of 65 days (range, 42-75 days). Immediately after the Haas expander was removed, fixed standard edgewise appliances were applied.

Of the original 50 patients for whom long-term records were available, 7 had poor-quality radiographs caused by either poor exposure or excessive head rotation at the time of exposure. One patient had the RME appliance removed prematurely. Consequently, 8 patients were eliminated from the study. Of the remaining 42, 25 were female and 17 were male.

Twenty subjects (11 males and 9 females) who did not undergo orthodontic treatment were selected from the longitudinal records of the University of Michigan Elementary and Secondary School Growth Study to constitute the control group (CTRL).[12]

The RME and CTRL groups were well matched with regard to chronological age. The mean age at T1 was 11 years 10 months for both groups. The mean chronological ages at T2 also were comparable (20 years 6 months for the RME group, and 17 years 8 months for the CTRL group). Because no sex differences were found for all frontal cephalometric variables in previous studies,[5,13,14] the present sample was not separated according to sex. All persons in both groups were white.

Cephalometric analysis

PA cephalograms were analyzed for each patient at both T1 and T2. Serial PA cephalograms were hand traced with a 0.5-mm lead pencil on 0.003-mm matte acetate tracing paper. All tracings were performed by 1 investigator (C.G.C.) and subsequently verified by another investigator (J.A.M.). The traced PA cephalograms were analyzed by means of a digitizing tablet (Numonics, Landsdale Pa) and digitizing software (DFP Plus 2.02, Dentofacial Software, Toronto, Ontario, Canada).

Figures 1 and 2 show the skeletal and dental landmarks used in the PA tracings, respectively. The RME group had a magnification of 9.0%, and the CTRL group had a magnification of 12.92%. All linear cephalometric measures were converted to a 9.0% enlargement to standardize the data.

The following bilateral cephalometric landmarks and corresponding definitions were used:

Skeletal landmarks.

- Euryon (Eu)—the most lateral point of the cranial vault.
- Medioorbitale (Mo)—the most medial point of the orbital orifice.
- Lateroorbitale (Lo)—the intersection of the lateral wall of the orbit and the greater wing of the sphenoid (the oblique line).
- Zygomatic (Zyg)—the most lateral point of the zygomatic arch.
- Zygomandibulare (Zmd)—the intersection between the lower margin of the zygomatic bone and the lateral contour of the mandibular ramus.
- Condylar lateral (Cdl)—the point located at the lateral pole of the condylar head.
- Maxillomandibulare (Mmd)—the intersection between the lower margin of the maxilla and the medial contour of the mandibular ramus.
- Maxillare (Mx)—the point located at the depth of the concavity of the lateral maxillary contour, at the junction of the maxilla and the zygomatic buttress.
- Lateronasal (Ln)—the most lateral point of the nasal cavity.
- Gonion (Go)—the point located at the gonial angle of the mandible.
- Antegonion (Ag)—the point located at the antegonial notch.

Dental landmarks.

- Upper molar (Um)—the most prominent lateral point on the buccal surface of the upper first molar.
- Lower molar (Lm)—the most prominent lateral point on the buccal surface of the lower first molar.
- Upper incisor mesial (Uim)—the most mesial point of the upper central incisor crown.

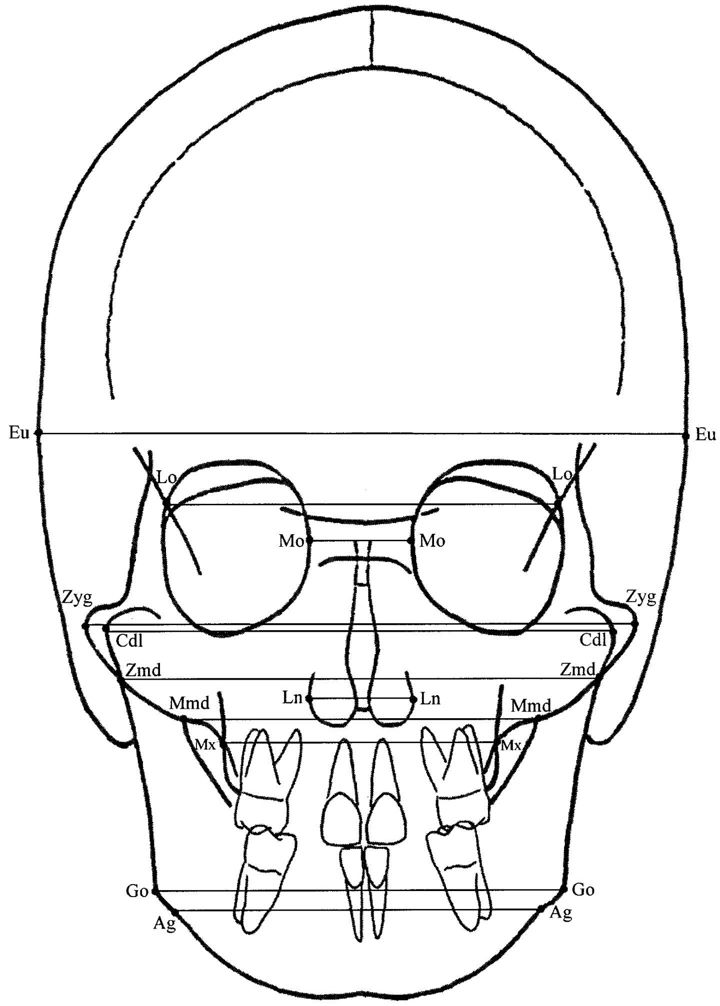

Fig 1. Cephalometric analysis on posteroanterior film: skeletal landmarks and measurements.

- Upper incisor apex (Uia)—the tip of the root apex of the upper central incisor.
- Upper incisor edge (Uie)—the point located on the incisal edge of the upper central incisor, centered mediolaterally.

From the digitized PA cephalograms, 15 width measurements (11 skeletal and 4 dental) were derived for each patient at each observation time by connecting bilateral cephalometric landmarks (Figs 1 and 2). The maxillary incisal angle was added to the previous transverse linear measurements (Fig 2).

Ten randomly selected PA cephalometric radiographs were retraced and redigitized to analyze the error of the method. A combined error of landmark location, tracing, and digitization was determined. The error standard deviation for each dimension was calculated from the double determinations with the aid of Dahlberg's formula.[15] For the measures used here, the mean value of the method error was 0.7 ± 0.3 mm.

Statistical analysis

Descriptive statistics were obtained for each cephalometric measurement at T1 and T2 for both the RME and the CTRL groups.

Independent sample *t* tests for the comparisons between the groups were used to evaluate the long-term effects of RME. Statistical computations were performed by means of computer software (SPSS for Windows, release 8.0.0, SPSS, Inc, Chicago, Ill). Statistical significance was tested at $P < .05$.

RESULTS

The RME and the CTRL groups had similar characteristics for 9 skeletal and 3 dental cephalometric measures at T1 (Table I). The RME group showed a defi-

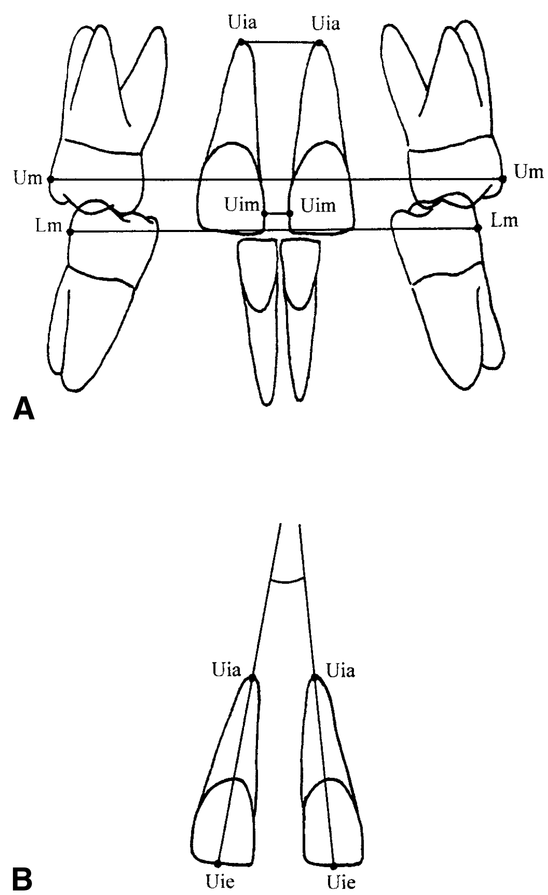

Fig 2. Cephalometric analysis on posteroanterior film: **A,** dental linear measurements; **B,** angular measurement for incisor inclination.

ciency in maxillary transverse measurements and in maxillary first molar width when compared with normal subjects, ie, the main indications for RME. Other significant differences included Lo width and maxillary incisor apex width, which were smaller in the RME group.

RME induced significant changes both in maxillary structures and in other craniofacial regions (Table II). The overall treatment effect (T2-T1) produced greater increments in the RME group in Lo width and maxillary width (at both the skeletal and the dental levels). Treatment also produced a greater increment in mandibular intermolar width when compared with the CTRL group. In addition, statistically significant increases were noted in Eu, Lo, Mmd, and Uia widths.

An analysis of the cephalometric values at T2 (Table III) allowed a comparison of the long-term observation in the RME group with the normal growth achieved in the CTRL group. The significant between-group differences identified at T1 for the most part had disappeared at T2. The 2 groups exhibited similar forms, with nasal width the only exception. The nasal width, in the long term, had a significantly greater value in the RME group than in the CTRL group.

DISCUSSION

The present study on PA cephalograms evaluated the long-term effects of RME therapy with the Haas expander. The objective was to appraise both dental and skeletal contributions to treatment-induced changes in facial transverse dimensions, after a period that incorporated active expansion and a postexpansion phase including fixed appliance therapy.

Long-term skeletal and dental modifications were calculated as changes from the time of suture opening (at a mean age of 11 years 10 months) to a posttreatment observation about 8 years later. These findings were compared with the changes that took place through normal growth. In the long term, several variables exhibited significantly larger incremental differences with respect to normal growth, including modifications in the transverse dimension of the cranial vault and of the orbital region (Table II).

Maxillary width in the RME group exceeded the expected growth increment of the CTRL group by 2.3 mm in the long term. This amount led to an almost complete correction of the initial deficiency in maxillary width in the RME group (-2.7 mm). Ln width exceeded expected growth by 2.6 mm in the long term. The initial transverse deficiency in Ln width in the RME group (-0.6 mm) therefore was overcorrected to about 2.0 mm more than the CTRL group at T2. The stability of the increase in nasal width after RME has been reported in previous studies.[2,3,5,7,16]

A major change during active RME therapy followed by edgewise therapy was in maxillary first molar width. The net overall change from T1 to T2 in the RME group was a net gain of 3.5 mm, which overcorrected the initial deficiency (-2.0 mm) by about 1.5 mm. The long-term net increase in mandibular intermolar width in the RME group was 1.4 mm. This revealed an overcorrection of the initial deficiency in mandibular intermolar width of 0.8 mm. Haas[2] reported an increase in width at the mandibular first molars from 0.5 to 2.0 mm in 10 patients 9 to 19 years of age.

A few issues must be considered with regard to the long-term treatment outcome in relation to the treatment protocol in the present study. Primarily, long-term increments in the dental transverse measurements must be interpreted as a combination of the outcomes of RME and fixed appliance therapy. To obtain proper

Table I. Comparison of starting forms

Variables		RME (n = 42)			CTRL (n = 20)					
		Mean	SD	SE	Mean	SD	SE	t value	P value	Significance RME-CTRL
Euryon width	mm	147.8	5.8	0.9	148.4	4.5	1.0	–0.38	.703	NS
Lateroorbitale width	mm	84.7	3.4	0.5	87.0	4.0	0.9	–2.34	.023	*
Medioorbitale width	mm	23.1	2.9	0.4	24.1	2.4	0.5	–1.43	.158	NS
Bizygomatic width	mm	122.2	5.3	0.8	122.0	5.2	1.2	0.11	.912	NS
Zygomandibulare width	mm	102.5	5.8	0.9	101.7	5.6	1.3	0.55	.584	NS
Maxillomandibulare width	mm	73.3	5.4	0.8	75.8	5.1	1.1	–1.74	.088	NS
Maxillary width	mm	59.5	2.8	0.4	62.2	5.0	1.1	–2.21	.037	*
Lateronasal width	mm	26.8	2.4	0.4	27.4	2.8	0.6	–0.98	.329	NS
Condylar width	mm	112.9	6.8	1.1	113.3	4.9	1.1	–0.23	.819	NS
Bigonial width	mm	92.8	5.4	0.8	90.5	6.1	1.4	1.51	.136	NS
Antegonial width	mm	82.8	4.6	0.7	81.2	5.7	1.3	1.18	.242	NS
Maxillary incisor apex width	mm	6.3	1.7	0.3	7.1	0.9	0.2	–2.54	.014	*
Maxillary incisor mesial width	mm	0.5	0.6	0.1	0.4	0.4	0.1	0.54	.588	NS
Maxillary first molar width	mm	56.5	2.7	0.4	58.5	4.3	1.0	–2.23	.029	*
Mandibular first molar width	mm	56.2	2.7	0.4	56.8	3.0	0.7	–0.76	.453	NS
Maxillary incisal angle	°	6.7	4.8	0.7	4.9	3.5	0.8	1.52	.135	NS

*$P < .05$.
NS, not significant.

Table II. Comparison of the overall treatment effects (treated group vs. control group from T1 to T2)

Variables		RME (n = 42)		CTRL (n = 20)				
		Mean	SD	Mean	SD	t value	P value	Significance RME-CTRL
Euryon width	mm	2.95	2.20	1.85	1.46	2.03	.047	*
Lateroorbitale width	mm	3.39	2.00	2.21	1.24	2.85	.006	**
Medioorbitale width	mm	1.55	2.84	1.72	2.27	–0.23	.818	NS
Bizygomatic width	mm	8.72	4.81	7.50	4.55	0.95	.347	NS
Zygomandibulare width	mm	6.68	4.16	7.35	3.34	–0.63	.533	NS
Maxillomandibulare width	mm	7.86	3.81	5.79	3.36	2.08	.042	*
Maxillary width	mm	3.38	2.27	1.11	1.24	5.09	.000	***
Lateronasal width	mm	4.16	1.83	1.52	1.13	5.93	.000	***
Condylar width	mm	6.90	4.97	5.45	4.28	1.12	.267	NS
Bigonial width	mm	6.52	4.56	5.76	3.65	0.65	.515	NS
Antegonial width	mm	4.19	3.36	3.86	3.46	0.35	.725	NS
Maxillary incisor apex width	mm	0.20	1.61	–0.59	0.99	2.01	.049	*
Maxillary incisor mesial width	mm	–0.35	0.61	–0.17	0.40	–1.21	.230	NS
Maxillary first molar width	mm	3.90	1.99	0.41	1.24	8.47	.000	***
Mandibular first molar width	mm	1.44	2.23	0.07	1.33	2.53	.014	*
Maxillary incisal angle	°	–0.63	4.49	–0.46	3.56	–0.15	.881	NS

*$P < .05$.
**$P < .01$.
***$P < .001$.
NS, not significant.

occlusal interdigitation and to correct inclinations of the posterior teeth, the maxillary molars usually undergo buccolingual uprighting during fixed appliance therapy after RME. Thus, the possible overexpansion of the maxillary dentition produced by standardized RME therapy (ie, the screw was expanded over 10 mm routinely) may be reduced by the fixed appliance, so that at the end of treatment a normal buccolingual relationship is established.

Second, it could be hypothesized that a greater increase in the long-term transverse dimension of the maxilla at the skeletal level might have occurred if a longer retention period had been implemented with the Haas appliance at the end of active expansion. In fact,

Table III. Comparison of treated group vs control group at T_2

		RME (n = 42)			CTRL (n = 20)					
Variables		*Mean*	*SD*	*SE*	*Mean*	*SD*	*SE*	*t value*	P *value*	*Significance RME-CTRL*
Euryon width	mm	150.8	6.5	1.0	150.3	4.9	1.1	0.33	.745	NS
Lateroorbitale width	mm	88.1	3.7	0.6	89.2	4.0	0.9	–1.08	.286	NS
Medioorbitale width	mm	24.6	3.4	0.5	25.8	3.0	0.7	–1.37	.177	NS
Bizygomatic width	mm	130.9	5.5	0.9	129.5	6.1	1.4	0.89	.380	NS
Zygomandibulare width	mm	109.2	6.8	1.0	109.0	6.1	1.4	0.11	.916	NS
Maxillomandibulare width	mm	81.2	3.4	0.5	81.6	5.9	1.3	–0.31	.761	NS
Maxillary width	mm	62.9	2.8	0.4	63.3	5.4	1.2	–0.30	.769	NS
Lateronasal width	mm	30.9	2.9	0.5	29.0	3.3	0.7	2.36	.021	*
Condylar width	mm	119.8	5.8	0.9	118.7	6.7	1.5	0.64	.524	NS
Bigonial width	mm	99.4	5.8	0.9	96.3	7.6	1.7	1.76	.084	NS
Antegonial width	mm	87.0	4.6	0.7	85.1	6.5	1.5	1.34	.185	NS
Maxillary incisor apex width	mm	6.5	1.4	0.2	6.5	1.4	0.3	–0.12	.904	NS
Maxillary incisor mesial width	mm	0.1	0.2	0.0	0.2	0.3	0.1	–1.65	.105	NS
Maxillary first molar width	mm	60.4	2.6	0.4	58.9	4.3	1.0	1.43	.164	NS
Mandibular first molar width	mm	57.7	2.8	0.4	56.9	3.4	0.8	0.97	.335	NS
Maxillary incisal angle	°	6.1	4.1	0.6	4.5	3.8	0.8	1.51	.137	NS

$^*P < .05$.
NS, not significant.

in the present study, the average duration of postexpansion stabilization with the Haas expander in situ as a retainer was about 2 months. Starnbach and Cleall[17] and Cleall et al[18] demonstrated that a normal radiographic appearance of the midpalatal suture is evident 3 months after expansion. An additional 3 months is necessary to reestablish a normal histologic appearance of the suture.

As for modifications in craniofacial structures far from the nasomaxillary area, overall changes in the RME group exceeded those in the CTRL group, with significant increases in Eu width (ie, the transverse cranial measurement), Lo width, and Mmd width. Long-term effects of RME, therefore, appear to involve an ample portion of the craniofacial complex, with enhanced transverse growth of the circummaxillary anatomical regions.

CONCLUSIONS

The findings of this investigation revealed that, in the long-term (about 8 years after expansion), the effects of RME with the Haas appliance followed by fixed appliance therapy can induce a normalization of both dental and skeletal components of the craniofacial complex. At the completion of active growth, initial deficiencies in the transverse measurements for maxillary width, maxillary incisor apex width, and maxillary first molar width are eliminated by means of this treatment protocol.

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