ORIGINAL ARTICLE

A long-term evaluation of the mandibular Schwarz appliance and the acrylic splint expander in early mixed dentition patients

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Introduction: The aim of this prospective longitudinal clinical study was to evaluate the short-term and long-term changes in dental-arch dimensions in patients treated with either an acrylic splint rapid maxillary expander alone (RME-only) or a rapid maxillary expander combined with a mandibular removable Schwarz plate (RME-Sz) in the early mixed dentition, followed later by fixed appliances in the permanent dentition. **Methods:** The dental casts of 27 RME-only patients were compared with those of 23 RME-Sz patients and 16 untreated controls (CTRL) with constricted maxillary arches at 4 times: pretreatment (T1), after expansion but before fixed appliance therapy (T2), after fixed appliance therapy (T3), and at long-term observation (T4). The mean ages for the treated groups were approximately 9 years at T1, 12 years at T2, 14 years at T3, and 20 years at T4. Arch width, arch depth, arch perimeter, and molar angulation were assessed in all subjects at all observation times. T1-T2, T2-T3, T3-T4, and T1-T4 changes were compared statistically in the treated groups with respect to the CTRL. **Results:** Treatment with an RME-only or an RME-Sz followed by fixed appliances produced significant short-term and long-term increases in maxillary arch widths compared with the CTRL. The RME-Sz led to significantly more favorable results than the RME-only protocol: (1) significantly greater increases in the transverse width of the mandibular arch and mandibular arch perimeter in the long term, and (2) uprighting of the mandibular posterior teeth buccally, thus allowing for an amount of maxillary expansion that was clinically effective for the correction of moderate tooth size-arch size discrepancies. In the overall observation interval, the significant increases in maxillary and mandibular arch perimeters in the RME-Sz group were 3.8 and 3.7 mm, respectively, when compared with the CTRL. The RME-only protocol produced modest long-term increases in maxillary arch perimeter (2.6 mm); the average long-term increase in mandibular arch perimeter (2.0 mm) in the RME-only group was not statistically significant. **Conclusions:** The RME-Sz led to significantly more favorable results than the RME-only protocol. (Am J Orthod Dentofacial Orthop 2006;130:202-13)

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Extract or expand? Over the last 100 years, the intellectual pendulum has swung back and forth between nonextraction and extraction treatments in patients with tooth size-arch size discrepancies. For patients with mild (<3 mm) or severe (>6 mm) crowding, deciding whether to extract teeth to gain space is not difficult.[1] For patients with moderate crowding, however, the choice is less clear.

A typical appliance for the treatment of patients with borderline amounts of crowding and also needing expansion in both arches is the acrylic splint rapid maxillary expander.[1] An ongoing prospective clinical trial (Michigan Expansion Study [MES]) has the goal of evaluating the short-term and long-term effectiveness of rapid maxillary expansion (RME) with a bonded appliance in the mixed dentition followed by fixed appliances in the permanent dentition in correcting maxillary constriction and relieving tooth size-arch size discrepancies. An article by Spillane and McNamara[2] first described the treatment effects and the short-term stability produced by the acrylic splint

expander used in the early mixed dentition. Serial dental casts of 162 patients were analyzed to measure arch dimensions before expansion, immediately postexpansion, and yearly until the eruption of the first premolars. The average residual increase in transpalatal width was 5 to 6 mm. After the postexpansion observation period (2.4 years), 80% of the original expansion at the first permanent molars remained.

Brust and McNamara[3] examined a larger sample of patients from the same study group. Changes in arch width, arch perimeter, and molar angulation were evaluated immediately postexpansion, at the time of first premolar eruption, and before comprehensive orthodontic treatment. The changes were compared with those over a similar time interval in a control group of 22 untreated subjects from the University of Michigan Growth Study. A significant amount of stable expansion was achieved in the maxillary arch, whereas changes in the mandibular arch were less stable.

Recently, Geran et al[4] conducted an investigation to assess the long-term stability of dental-arch changes induced by the acrylic splint rapid maxillary expander in the early mixed dentition and followed later by comprehensive orthodontic treatment (phase II). No active expansion of the mandibular dental arch was undertaken in the mixed dentition. The final evaluation of the patients occurred at an average of 6 years after phase II, or approximately 10 years after the completion of RME. Serial dental casts of the maxillary and mandibular arches were compared with a control group of untreated subjects. According to the results of this study, therapy with an acrylic splint expander in the early mixed dentition followed by fixed appliances in the permanent dentition is an effective treatment approach to correct transverse deficiencies in both arches when evaluated in the long term. This treatment protocol also is an option to relieve modest tooth size-arch size discrepancies. Geran et al[4] reported that approximately 4 mm of long-term relative increase in maxillary arch perimeter and 2.5 mm additional maintenance of mandibular arch perimeter were observed in RME patients when compared with untreated subjects.

The only other long-term controlled study concerning the effects of RME on arch perimeter is that of McNamara et al,[5] who evaluated arch-dimension changes after Haas-type REM and fixed appliance therapy through the age of 20 years. Treatment with RME and fixed appliances induced stable favorable increases in the width of the dental arches and in arch depth. Approximately 6 mm of long-term increase in maxillary arch perimeter (80% of initial deficiency) and 4.5 mm in mandibular arch perimeter (full correction of initial deficiency) were observed in patients when compared with untreated subjects.

An alternative treatment protocol for patients with moderate crowding and also needing expansion in both arches is the combination of the acrylic splint rapid maxillary expander and the removable mandibular Schwarz expansion appliance (REM-Sz).[1] The protocol begins with an initial phase in which the Schwarz appliance is activated once a week for approximately 5 months. Mandibular expansion is followed immediately by RME. Dentoalveolar decompensation of the mandible with the Schwarz appliance establishes a "reference" mandibular arch width to which the maxillary teeth can be expanded.[6]

Wendling et al[7] compared cephalometrically the short-term skeletal and dentoalveolar effects in a group of patients from the MES who received either the RME-Sz or the RME-only protocol beginning in the mixed dentition. The mandibular Schwarz appliance appeared to prevent the mesial movement of the mandibular first molars, whereas the RME-only protocol led to a 0.6-mm mesial movement of these teeth. The Schwarz appliance, therefore, had a slight "space maintainer" effect on the mandibular arch.

The purpose of this study was to evaluate the long-term treatment effects of RME-only and RME-Sz therapy in the mixed dentition followed later by comprehensive orthodontic treatment. The treatment effects were compared with longitudinal records of an untreated control group (CTRL) with similar amounts of constriction of the dental arches and crowding at the initial observation. Of special interest is the long-term stability of these types of expansion and their effects on arch perimeter and the extraction or nonextraction decision.

PATIENTS AND METHODS

The patients examined were part of the MES, a prospective clinical investigation of mixed-dentition patients who had undergone RME. A focus of the MES was short-term and long-term treatment effects of RME with an acrylic splint expander in the mixed dentition followed by fixed appliances in the permanent dentition. This study compared the long-term effects of 2 treatments with 2 phases (RME-only and RME-Sz followed by comprehensive orthodontic treatment) with a well-matched untreated group.

The sample comprised consecutively treated patients from a private group faculty practice; all patients were treated jointly by the 3 practitioners. These clinicians intended to provide a short phase of phase I treatment (9-14 months, depending on the treatment protocol), followed by an interim period of simple

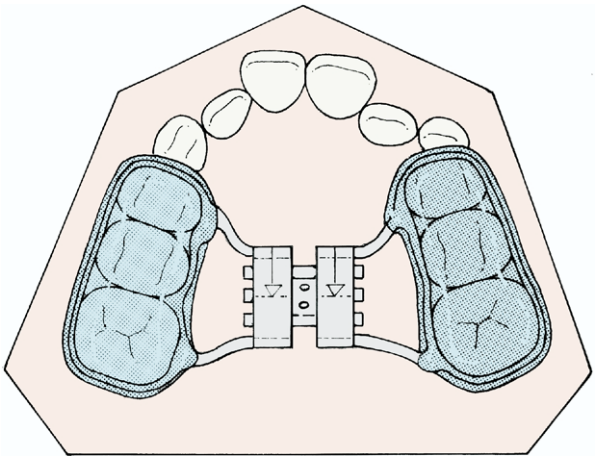

Fig 1. Acrylic splint rapid maxillary expander.

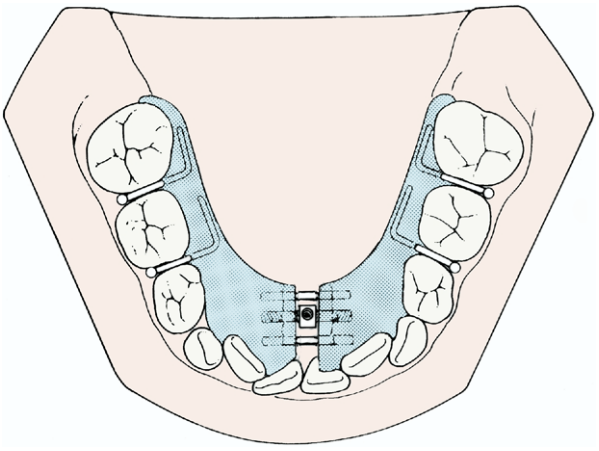

Fig 2. Removable mandibular Schwarz appliance.

retention until the eruption of the permanent teeth (excluding the second and third molars) was completed. A period of fixed appliance therapy then was used to finely detail the occlusion. The decision to use an expansion protocol was based on at least 1 of these preexisting criteria: crowding, lingual crossbite, esthetics, and tendency toward Class II malocclusion.[1]

Of the 50 patients included in this investigation (20 male, 30 female), 27 patients (11 male, 16 female) underwent RME-only treatment with bonded appliances (Fig 1) in the mixed dentition, and 23 patients (9 male, 14 female) had RME-Sz treatment (Fig 2) followed by a bonded maxillary expander.[1] Both groups were treated with the expansion protocol in the mixed dentition and were on average 6 years out of phase II treatment at the long-term observation. Additionally, the patients in both treatment groups had consistent characteristics. Before treatment, the following teeth were present: erupted maxillary and mandibular first permanent molars; erupted maxillary and mandibular permanent central incisors; and deciduous second molars. Dental casts were obtained for all patients at 4 times: before treatment (T1), after expansion and before phase II treatment (T2), after phase II treatment (T3), and at least 3 years after the T3 records (T4). The mean ages of the 2 treatment groups at the 4 times and the mean durations of observation intervals are given in Tables I-IV.

Serial dental casts of 16 untreated subjects (9 male, 7 female) were obtained from the longitudinal records of trhe University of Michigan Elementary and Secondary School Growth Study as the CTRL. The dental casts were selected to resemble the treated groups at each time that records were taken. The criteria for selection at T1 were based on dental development (early mixed dentition) and dental cast measurements (CTRL subjects had similar amounts of arch constriction as the treated patients), at T2 on dental development and homogeneity of observation interval, and at T3 and T4 on chronological age of 16 years 6 months or older, and a minimum interval between T3 and T4 of 3 years. The mean ages of the CTRL group at the different times and the mean durations of observation intervals are shown in Tables V and VI.

Treatment protocols

Twenty-seven patients (RME-only group) underwent RME with bonded acrylic splints (Fig 1) that covered the maxillary first and second deciduous molars as well as the maxillary permanent first molars.[1] The midline expansion screw was attached to the appliance with a heavy (.045 in) wire framework and was expanded routinely, once per day, until a buccal crossbite was approached. The transverse molar relationship obtained in most instances involved contact between the lingual cusps of the maxillary posterior teeth and the facial cusps of the mandibular posterior teeth.

After expansion (average, 7-8 mm), the bonded appliance usually remained in place for an additional 5 months, followed by stabilization with a simple palatal plate with ball clasps between the first and second deciduous molars and between the second deciduous and first permanent molars. The plate typically was worn full-time for at least 12 months and then only at night; in a few patients, however, the plate was discontinued after 1 year of retention. A transpalatal arch typically was placed before the loss of the second deciduous molars. In addition, over

Table I. Descriptive statistics for RME-only group at 4 time periods

	T1		T2		T3		T4	
RME-only group (n = 27)	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (y)	8.5	1.3	11.7	1.1	13.3	1.2	19.3	1.3
Measure (mm)								
Maxillary arch width (centroid)								
Intercanine	28.2	1.8	32.2	1.7	32.2	1.4	31.7	1.6
Interpremolar (first)	32.2	1.9	35.5	1.6	36.9	1.5	36.2	1.5
Interpremolar (second)	37.3	1.9	41.2	1.4	42.0	1.4	41.6	1.5
Intermolar (first)	42.0	2.1	47.2	2.3	45.9	2.0	46.1	2.0
Maxillary arch width (lingual)								
Intercanine	23.4	1.8	25.6	2.0	26.0	1.5	24.5	1.4
Interpremolar (first)	25.5	1.8	26.8	1.8	27.6	1.4	27.1	1.3
Interpremolar (second)	28.7	2.0	32.0	1.4	32.4	1.3	32.2	1.3
Intermolar (first)	32.5	2.1	37.8	2.5	35.0	2.0	34.8	2.0
Mandibular arch width (centroid)								
Intercanine	23.7	1.5	24.6	1.0	25.0	0.9	24.5	1.2
Interpremolar (first)	28.8	1.8	30.7	1.2	32.2	1.3	31.5	1.3
Interpremolar (second)	34.6	1.7	36.6	1.2	37.3	1.3	36.8	1.5
Intermolar (first)	40.0	1.8	41.9	1.7	41.5	1.7	42.0	1.9
Mandibular arch width (lingual)								
Intercanine	19.3	1.6	19.4	1.5	20.5	0.7	19.4	1.0
Interpremolar (first)	23.6	1.9	25.3	1.3	26.6	1.3	25.9	1.4
Interpremolar (second)	27.2	1.7	30.0	1.7	30.2	1.3	29.9	1.4
Intermolar (first)	31.2	1.9	33.3	2.2	32.3	1.8	32.8	2.0
Maxillary arch depth								
First molar	28.9	1.7	27.8	1.3	26.6	1.4	26.1	1.4
Mandibular arch depth								
First molar	24.1	1.3	23.2	1.6	22.2	1.3	21.5	1.4
Maxillary arch perimeter	75.6	4.1	78.2	2.9	76.8	3.2	75.8	3.1
Mandibular arch perimeter	67.8	3.1	66.6	2.9	65.5	2.5	64.2	2.8
Maxillary molar angulation (°)	177.3	9.8	181.1	8.8	184.0	7.2	182.8	6.7
Mandibular molar angulation (°)	206.7	12.3	199.0	9.1	198.9	7.7	202.5	7.5

half of the patients had their maxillary incisors bracketed for alignment. These so-called "temporary braces" were worn for approximately 6 months; the retainer used to stabilize the maxilla typically did not include a labial wire, so that the incisors were allowed to drift after bracket removal.

After eruption of the permanent teeth, the patients underwent comprehensive nonextraction orthodontic treatment with a preadjusted edgewise appliance (phase II). The transpalatal arch was left in place for the duration of treatment in most patients; in some patients, the palatal bar of the transpalatal arch was cut and removed toward the end of treatment. After phase II, a positioner usually was used to finely detail the dentition for 2 to 3 weeks. Then impressions for invisible retainers[1] typically were taken; the patients were instructed to wear the retainers full-time for a year. They also were advised to wear the invisible retainers at night for an additional year, after which they were encouraged to continue to wear them intermittently at night. Most patients were no longer wearing their retainers at the T4 records.

The first part of the treatment for the 23 patients in the RME-Sz group was the full-time wearing of a removable mandibular Schwarz appliance (Fig 2), which is a horseshoe-shaped acrylic appliance that fits along the lingual border of the mandibular dentition, extending to the distal aspect of the permanent first molars.[1] The inferior border of the acrylic was below the gingival margin and contacted the gingival tissues. The Schwarz applicance typically was used in patients who had mandibular incisor crowding or lingually inclined mandibular posterior teeth. Thus, the midline expansion screw was activated one-quarter turn per week (0.2 mm); this resulted in about 1 mm of expansion per month.

The Schwarz expander typically was activated for about 5 months, until the desired amount of expansion was achieved. The Schwarz appliance was used to upright the posterior segments (ie, dental decompensation), thereby providing a reference as to

Table II. Descriptive statistics for change scores in RME-only group at 4 time intervals

	T2-T1		T3-T2		T4-T3		T4-T1	
RME-only group (n = 27)	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (y)	3.2	−0.1	1.5	0.1	6.0	0.1	10.8	0.0
Measure (mm)								
Maxillary arch width (centroid)								
Intercanine	3.9	1.2	0.1	0.9	−0.5	0.7	3.5	1.7
Interpremolar (first)	3.8	1.8	1.2	1.3	−0.7	0.8	3.9	1.9
Interpremolar (second)	4.2	1.3	0.7	1.2	−0.4	0.8	4.3	1.9
Intermolar (first)	5.2	2.5	−1.3	1.2	0.1	1.0	4.0	2.1
Maxillary arch width (lingual)								
Intercanine	2.5	1.9	0.1	1.5	−1.6	1.0	1.0	1.7
Interpremolar (first)	1.7	2.0	0.6	1.2	−0.5	0.8	1.6	1.8
Interpremolar (second)	3.4	1.6	0.2	1.3	−0.2	1.0	3.5	2.1
Intermolar (first)	5.3	3.0	−2.7	2.1	−0.3	1.2	2.3	1.9
Mandibular arch width (centroid)								
Intercanine	1.0	1.6	0.4	0.7	−0.6	0.7	0.7	1.8
Interpremolar (first)	1.8	1.6	1.5	1.1	−0.7	1.0	2.7	1.9
Interpremolar (second)	1.6	1.1	1.0	0.7	−0.6	1.1	2.2	1.7
Intermolar (first)	1.9	1.4	−0.3	0.9	0.4	1.3	2.0	1.7
Mandibular arch width (lingual)								
Intercanine	0.1	1.8	1.1	1.2	−1.1	0.7	0.1	1.5
Interpremolar (first)	1.7	1.8	1.4	1.0	−0.7	1.0	2.4	2.1
Interpremolar (second)	2.5	1.9	0.4	1.2	−0.3	1.2	2.7	1.8
Intermolar (first)	2.1	1.8	−1.0	1.3	0.4	1.4	1.6	1.7
Maxillary arch depth								
First molar	−1.1	1.4	−1.2	1.4	−0.4	0.6	−2.7	1.8
Mandibular arch depth								
First molar	−0.8	1.1	−1.1	1.5	−0.6	0.9	−2.5	1.5
Maxillary arch perimeter	2.6	2.7	−1.4	2.7	−1.0	1.2	0.2	3.5
Mandibular arch perimeter	−1.2	2.2	−1.2	2.5	−1.3	1.4	−3.6	3.2
Maxillary molar angulation (°)	3.8	11.2	3.0	9.8	−1.2	7.5	5.5	9.0
Mandibular molar angulation (°)	−7.7	10.5	−0.1	9.0	3.5	6.8	−4.2	13.2

how far the clinicians could expand the maxillary arch.[6] Then a maxillary acrylic splint expander was bonded to widen the maxilla (8-10 mm of expansion), with the same protocol described previously for the RME-only group. At that point, the Schwarz appliance continued to be worn full-time as a passive retainer until the maxillary expander was removed. In addition, brackets were placed on the maxillary incisors in patients requiring derotation or space closure, as described above.

When the bonded expander was removed, a palatal plate was placed for retention in the maxillary arch, and the Schwarz appliance was discontinued in the mandibular arch. No retainer was worn in the mandibular arch after the placement of the maxillary stabilization plate to the beginning of phase II treatment. As with the RME group, most patients had transpalatal arches placed before the loss of the second deciduous molars. After phase II treatment, the same positioner and retention protocol was used for the RME-Sz group. Again, most patients were not wearing their retainers at the T4 records.

Data collection

The dental casts were measured with a digital imaging system (Bioscan OPTIMAS Imaging System, Seattle, Wash). This system was developed specifically for the acquisition, measurement, and storage of data obtained in an earlier study by Brust and McNamara.[3] Methods for image capture and landmark acquisition were described extensively in previous articles.[2-5,8]

Arch width was measured at the following teeth: deciduous or permanent canines, first deciduous molars or first premolars, second deciduous molars or second premolars, and first permanent molars. Arch width was measured from the lingual point of a given tooth to the like point on its antimere[3,4] and between the centroids of a tooth and its antimere, as described by Moyers et al [9] and Brust and McNamara.[3]

Arch depth was measured as the distance from a point midway between the facial surfaces of the central incisors to a line tangent to the mesial surfaces of the first molars.[3,4] Arch perimeter was determined by summing the segments between contact points from the

Table III. Descriptive statistics for RME-Sz group at 4 time periods

	T1		T2		T3		T4	
RME-Sz group (n = 23)	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (y)	9.1	0.9	12.5	1.1	14.4	1.2	21.0	1.6
Measure (mm)								
Maxillary arch width (centroid)								
Intercanine	28.0	1.4	31.7	1.3	32.5	1.5	32.0	1.5
Interpremolar (first)	31.8	1.3	35.8	2.2	37.5	1.6	36.5	1.6
Interpremolar (second)	36.9	1.0	41.5	2.3	42.6	1.9	41.8	1.8
Intermolar (first)	42.2	1.6	47.5	3.0	46.7	2.5	46.3	2.2
Maxillary arch width (lingual)								
Intercanine	23.2	1.4	24.6	1.9	25.6	1.5	24.7	1.5
Interpremolar (first)	24.8	1.1	26.8	2.0	28.2	1.4	27.4	1.5
Interpremolar (second)	28.3	0.9	32.3	2.4	32.8	1.7	32.5	1.7
Intermolar (first)	32.8	2.0	38.6	3.7	35.6	2.4	35.2	2.2
Mandibular arch width (centroid)								
Intercanine	22.4	1.2	24.8	1.3	25.3	1.2	24.2	1.3
Interpremolar (first)	27.5	1.2	31.0	2.1	32.4	1.3	31.4	1.4
Interpremolar (second)	33.6	1.5	36.6	2.1	37.9	1.6	36.8	1.6
Intermolar (first)	39.6	2.0	43.3	2.5	42.8	2.1	42.4	2.0
Mandibular arch width (lingual)								
Intercanine	18.3	1.3	19.9	1.4	20.4	1.0	19.1	1.0
Interpremolar (first)	22.3	1.2	25.9	2.3	26.7	1.1	25.9	1.4
Interpremolar (second)	26.4	1.4	29.9	3.1	30.7	1.4	30.0	1.6
Intermolar (first)	31.1	1.8	34.6	2.6	33.7	2.0	33.4	1.9
Maxillary arch depth								
First molar	27.8	2.0	27.2	2.3	26.4	1.8	25.9	1.9
Mandibular arch depth								
First molar	23.5	1.9	22.2	2.0	22.2	1.8	21.3	1.9
Maxillary arch perimeter	74.9	3.1	77.8	4.2	77.3	3.9	76.2	4.0
Mandibular arch perimeter	66.1	2.8	66.2	3.8	65.9	3.6	64.1	3.4
Maxillary molar angulation (°)	174.8	7.5	174.5	15.0	181.2	8.0	180.7	8.5
Mandibular molar angulation (°)	208.2	11.5	194.2	12.1	203.2	8.7	203.1	7.7

mesial surface of the first molar to the mesial surface of the opposite first molar.[4]

Molar angulation was calculated by measuring the angle of intersecting lines drawn tangent to the mesiofacial and mesiolingual cusp tips of the maxillary and mandibular right and left first molars.[3,4] Angulation less than 180° indicated that the molars were tipped facially; values over 180° implied that they were tipped lingually.

Error of the method

To verify the reliability of the data collected in this study, a double determination of dental casts was performed. Records of 10 subjects selected at random were redigitized for the various arch dimensions of interest. Two analyses were used to measure the reliability of the double determination data. First, an intraclass correlation coefficient was calculated for each arch parameter measured in both dental arches. Second, Dahlberg's formula[10] was used to report a standard error for each arch parameter.

Intraclass correlation coefficient values ranged from 0.895 for molar angulation to 0.997 for interpremolar (first) width in the maxilla, and from 0.932 for molar angulation to 0.995 for interpremolar (first) width in the mandible. The values of Dahlberg's formula ranged from 0.09 to 0.35 mm for linear measurements, whereas standard error was 3.36° for molar angulation.

Statistical analysis

Comparisons between the 2 treated groups (RME-only and RME-Sz) and the CTRL were performed with analysis of variance (ANOVA) with the Bonferroni post-hoc test ($P < .016$). The following statistical comparisons were performed:

- Comparison of starting forms: RME-only at T1 v RME-Sz at T1 v CTRL at T1.
- Evaluation of the effects of expansion: T2-T1 changes in RME-only v RME-Sz v CTRL.

Table IV. Descriptive statistics for change scores in RME-Sz group at 4 intervals

	T2-T1		T3-T2		T4-T3		T4-T1	
RME-Sz group	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (y)	3.5	0.2	1.9	0.1	6.6	0.4	12.0	0.7
Measure (mm)								
Maxillary arch width (centroid)								
Intercanine	3.4	2.0	0.5	1.6	−0.5	0.6	4.0	1.5
Interpremolar (first)	3.8	1.7	1.8	1.7	−1.0	0.7	4.6	1.3
Interpremolar (second)	4.5	1.9	1.0	1.7	−0.8	0.6	4.9	1.5
Intermolar (first)	5.3	2.5	−0.8	2.0	−0.4	0.7	4.1	1.5
Maxillary arch width (lingual)								
Intercanine	1.3	2.7	0.4	1.6	−0.9	0.8	1.5	1.7
Interpremolar (first)	2.0	1.6	1.3	1.6	−0.7	0.7	2.6	1.3
Interpremolar (second)	4.0	2.1	0.5	1.8	−0.3	0.8	4.3	1.7
Intermolar (first)	5.8	3.3	−3.0	2.7	−0.4	0.7	2.3	1.8
Mandibular arch width (centroid)								
Intercanine	2.3	1.3	0.5	1.1	−1.1	0.7	1.8	1.4
Interpremolar (first)	3.4	1.4	1.3	1.7	−1.1	0.8	3.9	1.3
Interpremolar (second)	2.6	1.6	0.9	1.3	−1.2	0.8	3.2	1.6
Intermolar (first)	3.7	2.0	−0.5	1.8	−0.4	0.8	2.8	1.7
Mandibular arch width (lingual)								
Intercanine	1.5	1.7	0.6	1.4	−1.3	0.8	0.8	1.5
Interpremolar (first)	3.5	1.6	0.7	1.9	−0.8	0.9	3.6	1.4
Interpremolar (second)	3.2	2.7	0.4	2.2	−0.7	0.9	3.6	1.8
Intermolar (first)	3.5	2.1	−0.9	2.1	−0.3	0.9	2.3	1.4
Maxillary arch depth								
First molar	−0.6	1.6	−0.8	1.5	−0.5	0.7	−1.9	1.8
Mandibular arch depth								
First molar	−1.3	1.0	0.0	1.2	−0.9	0.7	−2.2	1.5
Maxillary arch perimeter	2.9	2.8	−0.5	2.7	−1.1	1.1	1.3	3.2
Mandibular arch perimeter	0.0	2.4	−0.3	2.4	−1.7	1.2	−2.0	2.5
Maxillary molar angulation (°)	−0.3	13.4	6.7	14.1	−0.6	8.2	5.8	6.2
Mandibular molar angulation (°)	−14.0	14.9	9.0	10.4	−0.1	5.9	−5.1	12.7

- Evaluation of the effects of fixed appliances: T3-T2 changes in RME-only v RME-Sz v CTRL.
- Evaluation of posttreatment changes: T4-T3 changes in RME-only v RME-Sz v CTRL.
- Evaluation of overall changes: T4-T1 changes in RME-only v RME-Sz v CTRL.

RESULTS

Descriptive statistics for the CTRL and 2 treatment groups are given in Tables I to VI.

At T1, the starting ages of the 3 groups were similar (RME-only, 8.5 years; RME-Sz, 9.1 years; CTRL, 8.0 years). The pretreatment casts for the 3 groups were statistically similar in dental-cast measurements as a result of the ANOVA test.

Treatment with RME-only produced significant increments in all variables for maxillary arch widths (Tables II, VI, and VII), as measured at the centroids when compared with the CTRL (eg, 4.1 mm for maxillary intermolar width). Maxillary arch perimeter exhibited significant increases in the RME-only group when compared with the CTRL (2.3 mm). No significant increases were recorded for any other measurement during RME-only treatment with respect to the CTRL.

Adding a mandibular Schwarz appliance to RME treatment induced significant increments in both maxillary (4.3 mm for intermolar width) and mandibular (3.1 mm for intermolar width) arch widths when compared with the CTRL (Tables IV, VI, and VII). The increases in both maxillary and mandibular arch perimeters (2.7 and 2.8 mm, respectively) were significant as well. The RME-Sz group also showed significant uprighting of the mandibular first molars (11.0°) when compared with the CTRL. The comparison between the RME-Sz and RME-only groups showed that increases in mandibular arch widths were significantly greater in the former group.

Phase II treatment with fixed appliances induced a significant decrease in maxillary intermolar width (−1.7 mm) in the RME-only group when compared with the CTRL (Tables II, VI, and VII). No other significant difference was found for any measurement

Table V. Descriptive statistics for CTRL group at 4 time periods

	T1		T2		T3		T4	
CTRL group (n = 16)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (y)	8.0	0.8	12.3	1.1	13.4	1.1	19.0	2.5
Measure (mm)								
Maxillary arch width (centroid)								
Intercanine	28.6	1.6	30.0	1.8	30.1	1.5	29.8	1.6
Interpremolar (first)	32.5	1.6	33.5	1.5	33.7	1.5	33.5	1.7
Interpremolar (second)	37.5	1.5	38.4	1.2	38.6	1.4	38.2	1.8
Intermolar (first)	42.5	1.8	43.6	1.7	44.0	1.7	43.9	1.9
Maxillary arch width (lingual)								
Intercanine	23.9	1.6	22.6	1.5	22.8	1.5	22.2	1.6
Interpremolar (first)	25.7	1.6	25.0	1.4	25.1	1.1	25.2	1.4
Interpremolar (second)	28.8	1.4	29.8	1.2	30.0	1.3	29.9	1.6
Intermolar (first)	32.6	1.7	33.1	1.4	33.3	1.3	33.3	1.4
Mandibular arch width (centroid)								
Intercanine	22.7	1.4	23.5	1.2	23.3	1.2	23.1	1.5
Interpremolar (first)	28.2	1.5	30.2	1.8	30.1	1.7	30.1	1.8
Interpremolar (second)	34.0	1.9	35.5	2.1	34.7	2.1	34.4	2.3
Intermolar (first)	39.9	2.1	40.4	2.1	40.5	2.0	40.4	2.3
Mandibular arch width (lingual)								
Intercanine	18.6	1.6	18.7	1.4	18.0	1.4	17.5	1.6
Interpremolar (first)	23.0	1.6	24.7	2.0	24.8	1.7	24.7	1.8
Interpremolar (second)	26.7	2.1	29.2	2.7	28.4	2.3	28.1	2.6
Intermolar (first)	31.4	1.9	31.7	2.1	31.6	1.9	31.5	2.2
Maxillary arch depth								
First molar	28.3	2.1	28.0	2.3	26.9	2.4	26.3	2.2
Mandibular arch depth								
First molar	24.4	1.8	23.0	2.2	21.9	2.1	21.1	2.1
Maxillary arch perimeter	76.1	3.9	76.3	3.9	74.8	3.7	73.6	3.8
Mandibular arch perimeter	67.4	2.2	64.7	3.4	63.1	2.9	61.8	3.3
Maxillary molar angulation (°)	180.3	9.3	188.9	9.2	187.4	9.8	192.5	8.9
Mandibular molar angulation (°)	210.7	11.8	207.7	10.3	206.7	8.0	208.0	8.5

or between-group comparisons, except a significant lingual inclination of the mandibular molars in the RME-Sz group when compared with both the CTRL and the RME-only group (10.1° and 9.1°, respectively; Tables II, IV, VI, and VII).

No significant difference was found for any measurement or any between-group comparisons during the posttreatment phase after fixed appliances (Tables II, IV, VI, and VII).

When overall changes were considered, treatment with RME-only produced significant increments in all variables for maxillary arch widths as measured at centroid when compared with the CTRL (2.7 mm for maxillary intermolar width) (Tables II, VI, and VII). Maxillary arch perimeter exhibited significant increases in the RME-only group when compared with the CTRL (2.6 mm). No significant increases were recorded for any other measurement during RME-only treatment with respect to the CTRL, except the significant increase in mandibular arch width measured between the second premolars (1.8 mm).

RME-Sz treatment induced significant overall increments in both maxillary (2.8 mm for intermolar width) and mandibular (2.3 mm for intermolar width) arch widths when compared with the CTRL (Tables IV, VI, and VII). The increases in both maxillary and mandibular arch perimeters (3.8 and 3.7 mm, respectively) were significant. No significant differences were recorded for the comparison between the RME-Sz and RME-only groups.

DISCUSSION

The purpose of this long-term prospective clinical investigation in a private practice setting was to compare the modifications in arch dimensions in patients who were treated with 2 early expansion protocols (RME-only and RME-Sz) followed later by fixed appliances with those observed in an untreated CTRL group.

A unique aspect of this study was the nature of the CTRL. The untreated group used for comparison was unusual in that it matched the 2 treatment groups not only for chronologic age at all time intervals and

Table VI. Descriptive statistics for change scores in CTRL group at 4 time intervals

	T2-T1		*T3-T2*		*T4-T3*		*T4-T1*	
CTRL group (n = 16)	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (y)	4.4	0.3	1.1	0.1	5.5	1.3	11.0	1.7
Measure (mm)								
Maxillary arch width (centroid)								
Intercanine	1.4	1.0	0.1	0.4	−0.2	0.5	1.2	2.0
Interpremolar (first)	1.0	0.9	0.2	0.4	−0.2	0.9	1.0	1.7
Interpremolar (second)	0.8	0.9	0.2	0.5	−0.3	0.8	0.8	1.8
Intermolar (first)	1.1	1.1	0.4	0.7	−0.2	0.6	1.3	1.9
Maxillary arch width (lingual)								
Intercanine	−1.1	1.5	−0.3	0.8	−0.5	0.8	−1.7	2.2
Interpremolar (first)	−0.7	1.0	0.1	0.5	0.1	0.9	−0.6	1.6
Interpremolar (second)	0.9	0.9	0.3	0.7	−0.1	0.7	1.1	1.6
Intermolar (first)	0.5	1.2	0.2	0.7	0.0	0.4	0.7	1.9
Mandibular arch width (centroid)								
Intercanine	0.9	1.0	−0.1	0.4	−0.3	0.4	0.4	1.2
Interpremolar (first)	1.8	0.9	0.1	0.7	−0.1	0.6	1.9	1.1
Interpremolar (second)	0.8	1.1	−0.1	0.4	−0.3	0.6	0.4	1.5
Intermolar (first)	0.6	0.8	0.0	0.5	−0.1	0.6	0.5	1.5
Mandibular arch width (lingual)								
Intercanine	0.2	1.5	−0.6	0.9	−0.5	0.8	−1.1	1.9
Interpremolar (first)	1.5	1.1	0.1	0.6	−0.1	0.7	1.7	1.2
Interpremolar (second)	1.7	1.6	−0.2	0.6	−0.4	0.8	1.3	1.7
Intermolar (first)	0.3	0.8	−0.1	0.5	−0.1	0.6	0.1	1.3
Maxillary arch depth								
First molar	−0.4	1.1	−1.1	1.0	−0.6	0.6	−2.0	1.7
Mandibular arch depth								
First molar	−1.5	1.3	−1.1	1.1	−0.8	0.4	−3.3	1.6
Maxillary arch perimeter	0.2	2.3	−1.5	1.3	−1.2	0.7	−2.5	3.1
Mandibular arch perimeter	−2.8	2.1	−1.6	1.6	−1.3	1.3	−5.7	2.3
Maxillary molar angulation (°)	8.6	9.0	−1.5	5.8	5.1	10.9	12.2	9.8
Mandibular molar angulation (°)	−3.0	10.8	−1.1	7.8	1.3	9.0	−2.7	10.4

durations of observation intervals, but also for occlusal characteristics at T1. To date, no investigation concerning the effects of RME has incorporated a long-term observation of the occlusal changes in untreated subjects with initial constriction of the dental arches. The nature of our CTRL had an important effect on the interpretation of some numerical values reported below.

The evaluation of the active treatment effects after RME-only therapy showed significant increases in several maxillary arch dimensions when compared with the CTRL. From T1 to T2, maxillary intermolar and intercanine widths demonstrated average residual increases of 4.1 and 2.4 mm, respectively, whereas the increase in maxillary arch perimeter was 2.3 mm more than in the CTRL (Table VII). These values do not reflect the original amount of maxillary expansion but, rather, the amount of expansion remaining at the beginning of the fixed appliance phase of treatment. Retention after RME removal consisted only of a removable palatal plate without a labial wire worn full-time for at least 1 year. In most instances, a transpalatal arch also was placed before the loss of the maxillary second deciduous molars. The interval between T1 and T2 on average lasted 3 years 2 months. During the period with fixed appliances (T2-T3), which averaged 18 months in duration, a significant decrease (−1.7 mm) in maxillary intermolar width was recorded. The width between the maxillary second premolars decreased by only 0.5 mm during the same time period. No other significant changes occurred during either phase II treatment or the posttreatment period (T3-T4). In the overall observation interval (T1-T4), the RME-only group still showed significant increases in maxillary arch widths (2.7 and 2.2 mm at intermolar and intercanine widths, respectively) along with a significant increase in maxillary arch perimeter (2.6 mm) with respect to the CTRL. The nonsignificant increase in mandibular arch perimeter over the CTRL in the overall observation period was 2.0 mm. This lack of statistical significance, however, apparently was related to the nature of the controls rather than to the response of the treatment group, as will be discussed later.

Table VII. Statistical comparisons between groups by ANOVA and Bonferroni post-hoc test (between-group differences in change scores with their significance)

	RME-only v CTRL				*RME-Sz v CTRL*				*RME-Sz v RME-only*			
Measure (mm)	*T2–T1*	*T3–T2*	*T4–T3*	*T4–T1*	*T2–T1*	*T3–T2*	*T4–T3*	*T4–T1*	*T2–T1*	*T3–T2*	*T4–T3*	*T4–T1*
Maxillary arch width (centroid)												
Intermolar	4.1*	–1.7*	0.3	2.8*	4.2*	–1.2	–0.2	2.8*	0.1	–0.5	0.5	0.1
Interpremolar (second)	3.3*	0.5	–0.1	3.5*	3.7*	0.8	–0.4	4.1*	0.4	0.3	–0.3	0.6
Interpremolar (first)	2.9*	1.1	–0.5	2.8*	2.9*	1.6	–0.8	3.6*	0.0	0.5	–0.3	0.8
Intercanine	2.4*	0.0	–0.3	2.2*	2.0*	0.4	–0.3	2.8*	–0.4	0.4	0.0	0.6
Mandibular arch width (centroid)												
Intermolar	1.4	–0.3	0.5	1.5	3.1*	–0.5	–0.3	2.3*	1.7*	–0.2	–0.8	0.8
Interpremolar (second)	0.9	1.1	–0.3	1.8*	1.9*	1.1	–0.9	2.7*	1.0*	0.0	–0.6	0.9
Interpremolar (first)	0.0	1.4	–0.6	0.8	1.6*	1.2	–1.0	2.0*	1.6*	–0.2	–0.4	1.2
Intercanine	0.0	0.5	–0.3	0.3	1.4*	0.6	–0.8	1.4*	1.4*	0.1	–0.5	1.1
Maxillary arch depth												
First molar	–0.8	–0.1	0.2	–0.7	–0.2	0.2	0.1	0.1	0.6	0.3	–0.1	0.8
Mandibular arch depth												
First molar	0.6	0.0	0.1	0.8	0.2	1.0	–0.1	1.1	–0.4	1.0	–0.2	0.3
Maxillary arch perimeter	2.3*	0.1	0.2	2.6*	2.7*	1.0	0.0	3.8*	0.4	1.1	–0.2	1.2
Mandibular arch perimeter	1.6	0.5	0.0	2.0	2.8*	1.3	–0.5	3.7*	1.2	0.8	–0.5	1.7
Maxillary molar angulation (°)	–5.2	4.5	–6.3	–6.7	–8.9	–5.7	8.2	–6.4	–4.1	3.7	0.6	0.3
Mandibular molar angulation (°)	–4.7	1.0	2.2	–1.5	–11.0*	10.1*	–1.4	–2.4	–6.3	9.1*	–3.6	–0.9

*Significant comparison.

The addition of a removable lower Schwarz appliance to the bonded expander protocol produced significant increases in all maxillary and mandibular arch dimensions when compared with the CTRL, except arch depth and maxillary molar angulation (Table VII). From T1 to T2, maxillary intermolar and intercanine widths demonstrated significant residual increases of 4.2 and 2.0 mm, respectively, compared with the CTRL. Mandibular intermolar and intercanine widths had significant increases over the CTRL of 3.1 and 1.4 mm, respectively. The significant increases in maxillary and mandibular arch perimeters were 2.7 and 2.8 mm more than in the CTRL, respectively. Patients treated with the RME-Sz protocol showed a significant buccal inclination of the mandibular molars during active treatment compared with the CTRL (−11.0°). This amount of buccal tipping rebounded almost completely during the period with fixed appliances (10.1°). No other significant change was assessed during either this period or the posttreatment period. From T1 to T4, the RME-Sz group still showed significant residual increases in maxillary arch widths (both intermolar and intercanine widths increased 2.8 mm) and mandibular arch widths (2.3 and 1.4 mm at intermolar and intercanine widths, respectively) with respect to the CTRL. Residual increases in the premolar regions were similar. From T1 to T4, the significant increase of the RME-Sz group over the CTRL was 3.8 mm in maxillary arch perimeter and 3.7 mm in mandibular arch perimeter.

When analyzing the comparison between the 2 treated groups (Table VII), significantly greater increases in all mandibular arch widths were recorded in the RME-Sz group when compared with the RME-only group (differences ranged from 1.0 to 1.7 mm). A significant lingual inclination of the mandibular molars was observed during the phase with fixed appliances in the RME-Sz group (9.1°).

Our results confirm data from our earlier study[9] about the physiologic decrease in arch perimeters in untreated growing subjects observed from the early mixed dentition, also as described by Geran et al.[4] In contrast with this previous investigation, however, our CTRL subjects had constricted arches at T1. The overall decrease in maxillary arch perimeter in our study was smaller than that reported by Geran et al[4] (−2.4 and −3.8 mm, respectively), whereas the amounts of decrease in mandibular arch perimeter in the 2 studies were similar (−5.7 and −6.2 mm, respectively).

A direct comparison of our outcomes can be made with the results of 2 previous longitudinal controlled studies: Geran et al[4] and McNamara et al.[5] However, the investigation by McNamara et al[5] described the treatment effects of a protocol that included a tooth/tissue-borne device for RME (the Haas expander), whereas this study and that of Geran et al[4] used an acrylic splint expander bonded to the teeth.[1] Another difference is that both our study and that of Geran et al[4]

analyzed long-term treatment outcomes produced by RME in the early mixed dentition, whereas, in the study by McNamara et al, [5] the patients received expansion in the late mixed and early permanent dentitions. The advantages of the earlier orthopedic expansion of the maxilla performed in the MES include greater skeletal changes,[11] the possibility for spontaneous improvement of Class II occlusal relationships,[1,7] and an effective correction of posterior crossbites.[12-14] The nature of the CTRL also was different in our study (subjects with transverse deficiency of the dental arches) than in the previous investigations[4,5] in which untreated subjects generally with more normal occlusions were followed longitudinally.

In the studies by Geran et al[4] and McNamara et al,[5] the treated group showed mean overall residual increases in maxillary intermolar width of 3.5 and 4.0 mm, respectively—values that are slightly greater than the 2.8-mm increase in our study for both the RME-only and RME-Sz groups (Table VII). The residual increases in maxillary intercanine width in both previous studies were similar to the increase reported here (about 2.5 mm).[4,5] RME followed by fixed appliances appears to be an effective treatment option to increase the width of the maxillary arch.

Interestingly, the slightly less favorable results of this study compared with previous ones[4,5] in terms of long-term increase in maxillary intermolar width can be ascribed to the different behavior of our CTRL. Untreated subjects with constricted dental arches showed improvement in maxillary intermolar width of about 1.5 mm in the overall observation period, whereas the controls in the other investigations had improvements of only 0.4 to 0.8 mm.[4,5]

Mandibular intermolar width showed similar overall increases in the treatment groups over the controls in all 3 studies, ranging from 1.5 mm (our RME-only group) to 2.5 mm (McNamara et al[5]). In our study, the increase over the CTRL in mandibular intermolar width was significant in the RME-Sz group (2.3 mm), but not in the RME-only group (1.5 mm). All 3 studies agreed on the approximately 1.5-mm increase in mandibular intercanine width in the long term, except our RME-only group, which showed an increase of only 0.3 mm over the CTRL. The 2.3-mm increase in mandibular arch width in the RME-Sz group, however, can be interpreted as a favorable result because of the actual value shown by the CTRL for the long-term change in this measurement (0.8 mm more than the controls in the study by Geran et al[4] and 1.7 mm more than the controls in the study by McNamara et al[5]).

As for the measurement of maxillary arch perimeter, in this study, the overall increase in the RME-only group over the TRL was 2.6 mm, a smaller value than recorded in the RME-Sz group (3.8 mm) in the studies by Geran et al[4] (3.8 mm) and McNamara et al[5] (6.0 mm). The relatively smaller amount of increase over the CTRL in maxillary arch perimeter observed in our RME-only group with respect to the study by Geran et al[4] is explained by the different nature of the controls in the 2 studies. Although the untreated subjects in the study by Geran et al[4] had an overall decrease in maxillary arch perimeter of −3.8 mm, our CTRL group showed a decrease of only −2.4 mm. The RME-Sz improved the amount of increase over the CTRL in maxillary arch perimeter by 1.2 mm on average, with a final overall increase over the CTRL of 3.8 mm.

The greater amount of maxillary expansion in the RME-Sz patients occurred presumably because the mandibular appliance created a "new reference" for the width of the maxillary dental arch after uprighting the mandibular posterior teeth.[1,6] The amounts of actual activation of the RME screw were 7 to 8 mm for the RME-only group and 8 to 10 mm for the RME-Sz group because of the buccal inclination of 11.0° induced by the Schwarz appliance at the mandibular molars. Nevertheless, the increase over the CTRL in maxillary arch perimeter in the RME-Sz group (3.8 mm), although identical to that reported by Geran et al,[4] still was considerably smaller when compared with the 6.0-mm increase described by McNamara et al.[5] In this regard, the specifics of phase II treatment with fixed appliances in the different studies could have played an important role in maintaining or even improving the gain in arch perimeter from phase I treatment with RME. A specific aim of fixed appliance therapy in the treatment group of the study by McNamara et al[5] was the control of the sagittal position of the maxillary first molars in the expanded dental arch. This is evidenced by the considerably greater amount of long-term increase over the controls in maxillary arch depth in the treated sample described by McNamara et al[5] (3.0 mm) when compared with the RME-Sz sample of our study (0.1 mm). The increased maxillary arch depth can account for the supplementary increase of about 2.0 mm in maxillary arch perimeter during the overall treatment period in the treated sample described by McNamara et al[5] with respect to the RME-Sz group reported here, thus producing an increase over the CTRL in maxillary arch perimeter of 6.0 mm.

Mandibular arch perimeter exhibited consistent decreases throughout the treatment and posttreatment periods; this resulted in decreases in the overall observation period of −3.6 mm in the RME-only group and −2.0 mm in the RME-Sz group. In reality, the amount of decrease in mandibular arch perimeter in the un-

treated group of this study during the overall observation period (−5.7 mm) was much greater than that of the control group in the study by McNamara et al[5] (−3.0 mm). This differential decrease produced increases over the CTRL of 2.0 mm for the RME-only group and, more significantly, 3.7 mm in the RME-Sz group—a value that is similar to that reported by McNamara et al[5] (4.5 mm). The different values for the overall decrease in mandibular arch perimeter in the untreated groups were related to the time of first observation, which was before the exfoliation of the mandibular second deciduous molars (mean age, 8-9 years) in this study, and during the late mixed dentition (mean age, 11 years 6 months) in the study by McNamara et al.[5]

A useful clinical implication that can be derived from the various studies comprising the MES and the previous study by McNamara et al[5] is that, regardless of transverse occlusal relationships in each subject, an activation of the RME screw of at least 10 mm can be recommended in most instances. Smaller amounts of screw activation (7-8 mm) appear to produce only modest long-term increases in maxillary arch perimeter. The use of the RME-Sz can create a more adequate reference for the amount of expansion needed in the maxillary arch. The Schwarz-induced buccal inclination of the mandibular molars (11.0°) during the active treatment period allows the clinician to reach easily the 10 mm activation of the screw during expansion of the maxilla. Moreover, the use of the mandibular Schwarz appliance has the advantage of avoiding a complete buccal crossbite at the end of aggressive expansion of the maxilla.

CONCLUSIONS

- The RME-Sz protocol is as effective as the RME-only protocol in increasing the width of the maxillary arch, whereas it can induce a significantly more favorable increase in the transverse width of the mandibular arch.
- The mandibular Schwarz plate can decompensate the mandibular posterior teeth buccally; this allows for an amount of maxillary expansion (at least 10 mm of activation of the expansion screw) that is clinically favorable for the increase in arch perimeter.
- The long-term increase in maxillary and mandibular arch perimeters by using the RME-Sz protocol (3.8 mm) enables the correction of moderate tooth size-arch size discrepancies; the RME-only protocol produces smaller long-term increases in arch perimeter for the correction of more modest (<3 mm) tooth size-arch size discrepancies.

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