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Rapid Maxillary Expansion Followed by Fixed Appliances: A Long-term Evaluation of Changes in Arch Dimensions

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ABSTRACT

The purpose of this longitudinal study was to evaluate the short- and long-term changes in dental arch dimensions in patients treated with rapid maxillary expansion (RME) followed by fixed edgewise appliances. The records of 112 patients in the treated group (TG) were compared with those of 41 untreated controls. Serial dental casts were available at three different intervals: pretreatment (T_1), after expansion and fixed appliance therapy (T_2), and at long-term observation (T_3). The mean duration of the T_1-T_2 and T_2-T_3 periods for the TG group was three years two months ± five months and six years one month ± one year two months, respectively. Treatment by RME followed by fixed appliances produced significantly favorable short- and long-term changes in almost all the maxillary and mandibular arch measurements. In comparison with controls, a net gain of six mm was achieved in the maxillary arch perimeter, whereas a net gain of 4.5 mm was found for the mandibular arch perimeter of treated subjects in the long term. The duration of retention with a fixed lower appliance in the posttreatment period did not appear to affect the long-term outcomes of the treatment protocol significantly. The amount of correction in both maxillary and mandibular intermolar widths equaled two-thirds of the initial discrepancy, whereas treatment eliminated the initial deficiency in maxillary and mandibular intercanine widths. The amount of correction for the deficiency in maxillary arch perimeter was about 80%, whereas in the mandible a full correction was achieved.

KEY WORDS: Orthodontic treatment, Rapid maxillary expansion, Haas expander, Edgewise therapy, Tooth-size/arch-size discrepancies, Arch perimeter, Dental casts.

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INTRODUCTION Return to TOC

The present appeal of nonextraction treatment to correct discrepancies between tooth size and arch dimensions has created a renewed interest in alternative methods of increasing arch perimeter. Rapid maxillary expansion (RME) is a viable option to create additional space in the dental arches.[1–3] For example, Adkins et al[1] have demonstrated that every millimeter of transpalatal width increase in the premolar region produces a 0.7 mm increase in available maxillary arch perimeter.

When the aim of RME is to relieve crowding in the dental arches, long-term appraisal of residual gain in arch perimeter is mandatory to assess the potential effectiveness of this therapeutic approach in reducing the need for the extraction of permanent teeth. Unfortunately, there are few well-designed, long-term studies that address the stability of RME. The literature reports a range of the percent relapse after retention from 0 to 45%.[4–9] Furthermore, comparisons among different investigations are made difficult because the clinical studies vary widely regarding the sample size, age range of the sample, amount of expansion achieved, and method of retention used.

Furthermore, most investigations have not included the analysis of dental arch changes in a group of untreated subjects. One exception to this statement is the investigation of Brust and McNamara,[10] who compared arch dimensional and molar angulation changes three years after expansion in the early mixed dentition with the physiologic changes that occurred in an untreated control group (CG) studied at the same time intervals. The results revealed both a moderate increase in the arch perimeter of treated subjects and a net decrease in the same measurement in untreated controls.

One of the proposed procedures to treat tooth-size/tooth-arch discrepancies by an expansion protocol consists of RME followed by a phase of comprehensive fixed appliance therapy. Moussa et al[11] analyzed the long-term stability of RME and edgewise therapy and found that final values for both maxillary and mandibular intermolar widths were significantly greater than pretreatment values. They also demonstrated a slight increase in maxillary arch perimeter (+1.6 mm) in the long term. No control group was evaluated, however.

The aim of the present longitudinal study is to evaluate the short- and long-term changes in maxillary and mandibular dental arch measurements in patients who were treated with RME followed by edgewise appliances compared with the arch changes observed in a CG of untreated individuals.

SUBJECTS AND METHODS Return to TOC

Subjects

Treated group. The treated sample analyzed in this study (112 subjects, 61 females and 51 males) was part of a long-term prospective study on consecutively treated patients who had undergone Haas-type RME and nonextraction edgewise appliance therapy in a single orthodontic practice. All patients presented with a variable degree of crowding associated with narrow dental arches; none of the treated subjects exhibited posterior crossbites.

The patients underwent a standardized protocol of Haas-type RME with two 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). After expansion, all patients received full maxillary and mandibular fixed standard edgewise appliances and predominantly stainless steel wires. No further active expansion was obtained during the fixed appliance phase. The retention protocol after active orthodontic treatment consisted of a fixed lower retainer, with the exception of 24 patients who had the retention appliance removed after approximately one to two years after the end of treatment.

Dental casts were obtained at three observation times: pretreatment (T_1), after expansion and fixed appliance therapy (T_2), and at long-term recall (T_3). The mean age for treated group (TG) at T_1 was 12 years 2 months ± 1 year 4 months, 14 years 6 months ± 1 year 4 months at T_2, 20 years 5 months ± 1 year 7 months at T_3. The mean duration of the T_1-T_2 and T_2-T_3 periods for the TG group was 3 years 2 months ± 5 months and 6 years 1 month ± 1 year 2 months, respectively.

Control group. The dental casts of 41 untreated subjects (24 males and 17 females) were evaluated. The records were derived from both the University of Michigan Elementary and Secondary School Growth Study[12] and the University of Groningen Growth Study. The control sample matched the treated sample as to mean age at T_1, T_2, and T_3, sex distribution, and mean duration of observation periods. The subjects in the control sample presented with normal occlusions.

The mean age at T_1 for CG was 11 years 6 months ± 1 year, 13 years 11 months ± 1 year 5 months at T_2, 19 years 7 months ± 1 year 8 months at T_3. The mean duration of the T_1-T_2 and T_2-T_3 periods for CG was 3 years 1 month ± 1 year 2 months and 5 years 8 months ± 1 year 8 months, respectively.

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 earlier studies conducted by Brust[13] and by Brust and McNamara.[10] The imaging component of the system consisted of a digital camera mounted on a copy stand with attached tungsten lighting. Dental casts were mounted on a specially designed holder that allowed for precise positioning of the cast at a standardized distance from the camera lens. The dental cast holder also could be rotated 90° to permit the third dimension to be measured. This rotation allowed for the determination of the tipping and bodily movement of the maxillary and mandibular molars during the study period.

Once the dental cast was placed in the holder, the holder was raised to a removable Plexiglas plate located a fixed distance from the lens. The lens was calibrated to the nearest 0.2 mm at a set distance from the lens to a point located directly below the inferior surface of the Plexiglas plate. The Plexiglas then was moved out of the line of the camera, and the lighting intensity was adjusted to allow for optimal contrast as viewed on an adjacent video monitor. The dental cast, as viewed on the monitor, was magnified to approximately three times its normal size. With the aid of the OPTIMAS software program, the image was recorded and stored on an optical disk. The cast then was removed, and the second part of the process, landmark acquisition, was initiated.

Landmark acquisition

Landmarks were identified on the magnified image of the study model on the video monitor by a mouse. A point was placed on the distal, facial, mesial, and lingual surfaces of each tooth from the right first permanent molar to the left first permanent molar in the same arch (Figure 1). These points were selected in accordance with the guidelines established by Moyers et al[12] and Brust and McNamara[10] to determine the geometric center of each tooth, the tooth centroid (Figure 2). This point provides a more valid measurement of arch width because it removes the effect of tooth rotation.[12]

After cast rotation, the facial and lingual cusp tips of the first molars were selected to record molar angulation (Figure 3). Landmarks were not recorded if the teeth were in the process of exfoliation, ectopically erupted, or in the process of eruption before the height of contours of the four outer surfaces (ie, mesial, distal, facial, and lingual) were visible.

Measurements

Arch width (Figure 4) was measured at the following teeth: primary canines/permanent canines, first primary molars/first premolars, second primary molars/second premolars, and the first permanent molars. Arch width was evaluated by two sets of measurements: from the lingual point of a given tooth to the like point on its antimere and between the centroid of a tooth (Figure 2) and its antimere, as described by Moyers et al[12] and Brust and McNamara.[10]

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 permanent molars (Figure 5). Arch perimeter was determined by summing the segments between contact points from the mesial surface of the first permanent molar to the mesial surface of the opposite first permanent molar (Figure 4).

Molar angulation was calculated by measuring the angle of intersecting lines drawn tangent to the mesiofacial and mesiolingual cusp tips of the right and left maxillary and mandibular first permanent molars (Figure 5). Angulation of less than 180° indicated that the molars were tipped buccally, whereas values above 180° indicated that these teeth were tipped lingually.

Error of the method

The error of the method of the digital imaging system has been described previously.[10,14] The error standard deviation of the measures of arch width, arch depth, and arch perimeter ranged from 0.002 to 0.06 mm and for molar angulation, 0.3°.

Statistical analysis

Comparisons between TGs and corresponding CGs were performed by Student's *t*-test for independent samples.

The following statistical comparisons were performed. Comparison of starting forms: TG at T_1 vs CG at T_1. Evaluation of treatment effect: T_2-T_1 changes in TG vs T_2-T_1 changes in CG. Evaluation of posttreatment changes: T_3-T_2 changes in TG vs T_3-T_2 changes in CG. Evaluation of overall changes: T_3-T_1 changes in TG vs T_3-T_1 changes in CG. Comparison of final forms: TG at T_3 vs CG at T_3.

Additionally, a comparison of the T_3-T_2 changes in the group of patients who had the fixed lower retainer removed one to two years after T_2 (n = 24) with the changes in the same time interval in the group of patients who had the retainer removed at T_3 (n = 88) was performed to test the influence of the extended period of retention on the long-term outcomes of the treatment protocol.

RESULTS Return to TOC

Descriptive statistics for the values of the measurements at T_1, and for the changes T_2-T_1, T_3-T_2, and T_3-T_1 in all the examined groups along with statistical comparisons are reported in the Tables 1 through 4.

Comparison of starting forms (TG at T_1 vs CG at T_1) (Table 1)

Both the maxillary and mandibular dental arches of the patients in TG were significantly narrower than the corresponding dental arches of the subjects with normal occlusion. All measurements for maxillary and mandibular arch width, depth, and perimeter were significantly smaller in the TGs when compared with the CG. The maxillary molars also had a significantly greater buccal angulation in TG when compared with controls, whereas there was no significant difference in mandibular molar angulation.

Evaluation of treatment effects (T_2-T_1 changes in TG vs T_2-T_1 changes in CG) (Table 2)

Treatment by RME followed by fixed appliances produced significantly greater increments in all the variables for maxillary and mandibular arch widths (Figure 4) when compared with the controls. The most clinically relevant findings in this study were related to increases in arch perimeter (Figure 6). A clinically significant increase in maxillary and mandibular arch perimeters was found in the TG when compared with controls. For example, maxillary arch perimeter increased 6.3 mm in the treated patients but decreased 0.9 mm in the CG. Similarly, mandibular arch perimeter increased 3.9 mm in the patients and decreased (−0.8 mm) in the controls. As for the changes in molar angulation (Figure 3), maxillary first permanent molars showed a significant tendency to a more lingual inclination and mandibular first permanent molars presented with a significant tendency to a more buccal inclination in the TG.

Evaluation of posttreatment changes (T_3-T_2 changes in TG vs T_3-T_2 changes in CG) (Table 2)

In the TG, no significant differences in the posttreatment changes were found for controls, with the exceptions of maxillary intercanine widths, which showed significantly greater decreases in TG, and of the mandibular intermolar arch width (measured both at the centroid and lingually), which presented with greater increases in TG. The mandibular arch width as measured at the second premolar (centroid) showed significantly smaller decreases in TG when compared with CG.

No significant difference was recorded in the TG regarding changes in maxillary arch depth, whereas TG presented with significantly greater increments in mandibular arch depth when compared with CG. In the TG, significantly greater decreases in maxillary arch perimeter changes for controls were assessed during the posttreatment period. No significant difference was found for the mandibular perimeter. In the TG, maxillary molars showed a significant tendency to a less buccal angulation than CG. On the contrary, the TGs exhibited a significant tendency to a more buccal angulation of the mandibular molars.

Evaluation of overall changes (T_3-T_1 changes in TG vs T_3-T_1 changes in CG) (Table 2)

The statistical comparison of the changes in the overall observation period from T_1 to T_3 in the TG with the CG replicated for the most part the results of the analysis of active treatment changes (from T_1 to T_2). For example, the residual increase in maxillary arch perimeter in the treated patients was 2.8 mm, whereas the same measurement decreases in the corresponding CG (−3.0 mm), a difference of 5.8 mm. In the mandibular arch, the arch perimeter increased 1.5 mm in the patient group and decreased (−2.9 mm) in the matched CG, a difference of 4.4 mm.

No significant difference was found for any of the dental cast measurements in the posttreatment interval between those subjects who had the fixed lower retainer removed shortly after the end of fixed appliance therapy and those subjects who were retained until the completion of the overall observation period.

Comparison of final forms (TG at T_3 vs CG at T_3) (Table 3)

The transverse arch measurements in the TG at the completion of the observation period were slightly smaller than the untreated CG. Both maxillary and mandibular arch depths were significantly larger in the TG. Maxillary arch perimeter in TG was slightly smaller than CG, whereas no difference was found for mandibular arch perimeter. In the final forms, TG showed significantly more buccal inclination of the maxillary molars and more lingual inclination of the mandibular molars.

DISCUSSION Return to TOC

The present longitudinal study assessed changes in arch dimensions that occurred in patients who were treated with RME followed by edgewise appliances compared with those observed in an untreated CG. Before treatment, all subjects in the TG presented with significant constriction of both maxillary and mandibular arches associated with a variable degree of crowding for controls. The treated sample required a phase of RME to improve the transverse arch dimension before fixed appliance treatment. None of the examined subjects in either the treated and untreated groups exhibited posterior crossbites.

In the short term, after RME and fixed appliance therapy, the TG presented with significant changes in all arch dimensions when compared with normal controls (Table 2). Both maxillary and mandibular arch widths and depths showed significant increases in the treated sample. During active treatment, the maxillary arch width at both intermolar and intercanine measures demonstrated an average increment of about four mm, whereas the increases in mandibular arch widths range between one and two mm. With regard to the gain in arch perimeters, 6.5 mm of increase in the maxillary arch was associated with four mm of increase in the mandibular arch.

During the posttreatment period, very slight changes occurred in the arch width measurements both in the maxilla and mandible of the treated subjects (Table 2). On the contrary, a rather substantial tendency to relapse occurred in the arch perimeters (−3.5 mm in the maxillary arch and −2.5 mm in the mandibular arch) after active treatment. In the overall observation period, the increase for maxillary intermolar width was 4.5 mm and one mm for mandibular intermolar width. The increase in maxillary arch perimeter was three mm, whereas the increase in mandibular arch perimeter was 1.5 mm. These increments may appear limited in amount and clinical significance. However, the findings need to be interpreted by taking into consideration the actual changes that occur in a sample of untreated subjects in the long term. In a time period of about eight years that covers approximately the late mixed and early permanent dentitions, an average decrease of three mm is observed in untreated subjects in both maxillary and mandibular arch perimeters. The results of the present study confirm previous data by Brust and McNamara[10] in this regard.

The loss in arch perimeter, as revealed by the untreated controls, has to be ascribed mainly to the exfoliation of the second deciduous molars in both arches and to their replacement with the smaller-sized second premolars. These modifications have a direct effect on arch depth as well. In the present study, the initial deficiency in the depth of both arches (Table 1) in the TG was overcorrected at the end of the overall observation period (Table 3). The role of the fixed appliances in maintaining the sagittal position of the first molars within the dental arches has to be acknowledged because it contributes substantially to the final gain in arch perimeter (about one third of the total gain).

When the values and the changes in the untreated sample are considered (Table 4), in subjects treated with RME and edgewise appliances, maxillary arch perimeter shows increases of 7.5 mm because of the active treatment phase, followed by an “actual” relapse of −1.5 mm, resulting in an overall net gain of six mm. As for mandibular arch perimeter, the initial increase of five mm in the treated patients undergoes a relapse of only −0.5 mm in the posttreatment period, leading to an overall net gain of 4.5 mm.

In the long term, therefore, the treatment protocol investigated in this study is able to withstand the physiological tendency of both arches for a loss in arch perimeter (−3 mm) and to induce a supplementary gain of additional three mm in the maxilla and 1.5 mm in the mandible (Table 4). In the transverse dimension, the net changes in the TG when compared with controls in the long term replicate the favorable increases produced by active treatment, with the exception of maxillary intercanine width that shows a decrease of −1.5 mm during the posttreatment period (Table 4).

At the final long-term observation (T_3; Table 3), when all the subjects in both treated and untreated samples have ended the active growth period, the initial deficiencies in arch width, depth, and perimeter shown by the treated subjects for the controls were almost completely corrected. From a clinical standpoint, the amount of correction in both maxillary and mandibular intermolar widths equaled two-thirds of the initial discrepancy, whereas treatment eliminated the initial deficiency in maxillary and mandibular intercanine widths. The amount of correction for the deficiency in maxillary arch perimeter was about 80%, whereas a full correction was achieved in the mandible.

When analyzing the literature, a direct comparison of the outcomes of this study can be performed appropriately only with the results reported by Moussa et al.[11] These authors used a treatment protocol that was very similar to the one evaluated in the present investigation. In both studies, a tissue-borne device for RME (the Haas expander) was applied to the maxillary arch in association with a subsequent phase with standard edgewise appliances. The retention phase was very similar as well.

In the study by Moussa et al,[11] the TG showed a mean increase of 6.7 mm in maxillary intermolar width due to active treatment, a value that is greater than the value found in the present study for the same measurement (4.4 mm; Table 2). The increase in maxillary intercanine width was similar to the increase reported in this study (about four mm). As for the mandibular arch, Moussa et al[11] found an increase of about two mm for both the posterior and anterior arch widths in their treated sample in the short term. The amount of increase in the mandibular arch in the treated patients of the present study was similar for the intercanine measurement, whereas it was half for the intermolar measurement (one mm). The greater amount of maxillary intermolar expansion in the short term reported by Moussa et al[11] may be related to the greater amount of total activation of the screw in the RME appliance (11 to 14 mm). Similar changes for the widths of both dental arches were assessed in the two studies for the overall observation period (T_3-T_1).

As for the measurement for maxillary arch perimeter, in the present study the increase during active treatment was greater (6.3 mm; Table 2) than the increase reported by Moussa et al[11] (4.1 mm), whereas a greater decrease during the posttreatment period (−3.5 vs −2.5 mm) produced a slightly greater increase in the overall observation period (2.8 vs 1.6 mm). The clinical significance of these values is hampered by the lack of untreated controls in the work by Moussa et al.[11] Mandibular arch perimeter exhibited a greater increase during active treatment in the sample reported in this study when compared with the sample by Moussa et al[11] (3.9 vs 2.7 mm), followed by a smaller decrease during the posttreatment period (−2.4 vs −3.5 mm). These changes produced an increase in the overall observation period for the treated sample reported in this study (1.5 mm) and a decrease in the sample described by Moussa et al[11] (−0.6 mm).

The therapeutic approach described in this study appears to be an effective protocol to increase the arch perimeter both in the maxilla and in the mandible in the long term, regardless of the duration of the period of posttreatment retention with a fixed lower appliance. No differences were found in posttreatment changes in subjects who wore the fixed lower retainer for just one or two years after the end of active therapy and subjects whose lower arch was retained until the completion of the overall observation period (approximately six years after removal of the fixed edgewise appliances).

CONCLUSIONS Return to TOC

RME and fixed appliance therapy have to be considered an effective treatment option to gain space on the dental arches in order to relieve tooth-size/arch-size discrepancies of mild-to-moderate degree. Approximately six mm of long-term net gain in maxillary arch perimeter and 4.5 mm in mandibular arch perimeter were observed in treated patients when compared with untreated subjects. RME and fixed appliances are able to induce stable favorable changes in the width of the dental arches and significant increases in arch depth. This treatment approach may be particularly effective in patients who present with a narrow maxilla (eg, $\lesssim$ 31 mm maxillary intermolar width) in association with an accentuated curve of Wilson, signs of maxillary deficiency syndrome.[15,16]

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TABLES Return to TOC

TABLE 1. Comparison of the Starting Forms Between the Treated and Control Groups

Measure (mm)	Treated Group (TG) at T_1 (n = 112)			Control Group (CG) T_1 (n = 41)			
	Mean	SD	SE	Mean	SD	SE	*t*-test
Maxillary arch width (centroid)							
Intermolar	39.3	2.8	0.3	45.2	2.0	0.3	***
Interpremolar (second)	34.4	2.8	0.3	40.0	2.2	0.4	***
Interpremolar (first)	30.0	2.6	0.3	35.1	2.3	0.4	***
Intercanine	27.9	3.1	0.4	30.9	2.2	0.4	***
Mandibular arch width (centroid)							
Intermolar	38.9	2.4	0.2	42.0	2.1	0.3	***
Interpremolar (second)	32.7	2.6	0.3	36.3	2.0	0.3	***
Interpremolar (first)	28.1	2.4	0.3	31.1	2.0	0.3	**
Intercanine	22.9	1.8	0.2	24.3	1.7	0.3	*
Maxillary arch width (lingual)							
Intermolar	29.7	2.7	0.3	35.6	2.2	0.3	***
Interpremolar (second)	26.2	2.6	0.3	31.9	2.2	0.4	***
Interpremolar (first)	22.6	2.8	0.3	27.4	2.3	0.4	***
Intercanine	22.8	3.2	0.4	25.8	2.4	0.4	***
Mandibular arch width (lingual)							
Intermolar	29.9	3.9	0.4	34.5	4.9	0.8	**
Interpremolar (second)	25.8	2.7	0.3	29.4	2.0	0.3	***
Interpremolar (first)	22.4	2.5	0.3	25.5	2.1	0.4	**
Intercanine	18.6	1.8	0.2	20.0	2.1	0.3	*
Maxillary arch depth							
First molar	27.1	2.7	0.3	28.7	2.3	0.4	*
Mandibular arch depth							
First molar	21.5	2.8	0.3	23.8	2.7	0.4	*
Maxillary arch perimeter	71.7	5.2	0.5	79.0	4.7	0.7	***
Mandibular arch perimeter	63.6	4.2	0.4	68.3	4.4	0.7	***
Maxillary molar angulation	169.8	9.4	0.9	176.4	4.9	0.8	**
Mandibular molar angulation	190.7	5.5	0.5	190.6	4.6	0.7	ns

* $P < .05$; ** $P < .01$; *** $P < .001$; ns = not significant.

TABLE 2. Comparisons of the Changes T_2-T_1, T_2-T_3, and T_3-T_1 Between the Treated and Control Groups

Measure (mm)	Treated Group (n = 112)								
	T_2-T_1			T_3-T_2			T_3-T_1		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
Maxillary arch width (centroid)									
Intermolar	4.4	1.8	0.2	−0.2	1.1	0.1	4.2	1.9	0.2
Interpremolar (second)	4.9	1.9	0.2	−0.4	1.0	0.0	4.6	2.0	0.2
Interpremolar (first)	4.9	1.8	0.2	−0.6	0.9	0.0	4.3	1.9	0.2
Intercanine	3.9	2.7	0.3	−1.6	1.0	0.0	2.5	2.5	0.3
Mandibular arch width (centroid)									
Intermolar	1.0	2.0	0.2	−0.1	1.4	0.1	0.9	1.8	0.2
Interpremolar (second)	2.2	2.4	0.2	−0.1	1.0	0.1	2.1	2.0	0.2
Interpremolar (first)	2.3	2.3	0.3	−0.1	0.4	0.0	2.2	2.3	0.3
Intercanine	1.9	1.7	0.2	−0.6	0.5	0.0	1.4	1.5	0.2
Maxillary arch width (lingual)									
Intermolar	3.8	2.0	0.2	0.1	1.2	0.1	4.0	2.1	0.2
Interpremolar (second)	4.8	1.8	0.2	0.0	1.1	0.1	4.8	1.9	0.2
Interpremolar (first)	4.0	2.2	0.2	−0.4	1.2	0.1	3.7	2.2	0.2
Intercanine	1.9	3.2	0.4	−1.7	1.7	0.2	0.2	3.0	0.4
Mandibular arch width (lingual)									
Intermolar	0.9	2.7	0.2	0.2	2.4	0.2	1.2	3.3	0.3
Interpremolar (second)	2.0	2.4	0.2	0.2	1.2	0.1	2.2	2.0	0.2
Interpremolar (first)	1.7	2.5	0.3	−0.2	0.6	0.0	1.4	2.5	0.3
Intercanine	0.5	1.8	0.2	−0.8	1.0	0.0	0.0	1.3	0.2
Maxillary arch depth									
First molar	0.2	2.4	0.2	−1.2	0.8	0.0	1.0	2.2	0.2
Mandibular arch depth									
First molar	1.7	3.1	0.3	1.1	2.1	0.2	2.8	3.0	0.3
Maxillary arch perimeter	6.3	4.4	0.4	−3.5	1.6	0.2	2.8	4.0	0.4
Mandibular arch perimeter	3.9	4.4	0.4	−2.4	1.2	0.1	1.5	4.1	0.4
Maxillary molar angulation	4.8	9.0	0.8	0.9	4.1	0.4	5.7	8.8	0.8
Mandibular molar angulation	−4.0	7.0	0.6	−1.0	5.3	0.5	−5.0	5.4	0.5

* $P < .05$; ** $P < .01$; *** $P < .001$; ns = not significant.

TABLE 2. Extended

Control Group (n = 41)									*t*-test		
T_2-T_1			T_3-T_2			T_3-T_1					
Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	T_2-T_1	T_3-T_2	T_3-T_1
0.6	0.9	0.1	−0.2	0.7	0.1	0.4	1.2	0.2	***	ns	***
0.5	1.1	0.2	−0.3	0.7	0.1	0.2	1.3	0.2	***	ns	***
0.3	1.2	0.2	−0.3	0.8	0.1	0.1	1.4	0.2	***	*	***
0.3	1.3	0.3	−0.6	0.8	0.1	−0.2	1.5	0.3	***	***	***
−0.3	1.5	0.2	−0.8	1.3	0.2	−1.2	1.8	0.3	***	**	***
−0.1	1.1	0.2	−0.5	0.6	0.0	−0.6	1.2	0.2	***	**	***
0.1	1.0	0.2	−0.4	0.7	0.1	−0.3	1.0	0.2	***	ns	***
−0.3	0.7	0.1	−0.5	0.5	0.0	−0.8	0.9	0.1	***	ns	***
0.4	1.3	0.2	−0.1	0.8	0.1	0.3	1.5	0.2	**	ns	***
0.6	1.1	0.2	−0.1	1.4	0.2	0.6	1.7	0.3	***	ns	***
0.0	1.3	0.2	0.0	1.7	0.3	0.0	2.3	0.4	***	ns	***
−1.1	1.6	0.3	−0.9	1.0	0.2	−2.0	1.7	0.3	***	**	***
−1.9	4.7	0.7	−2.3	4.2	0.7	−4.2	5.5	0.9	**	**	***
0.0	1.1	0.2	−0.3	1.6	0.2	−0.2	1.6	0.3	***	ns	***
0.0	1.3	0.2	−0.1	1.1	0.2	−0.2	1.1	0.2	**	ns	***
−1.1	1.3	0.2	−0.8	1.1	0.2	−1.8	1.4	0.2	***	ns	***
−0.9	1.1	0.2	−1.0	1.0	0.1	−1.9	1.5	0.2	**	ns	**
−1.8	1.9	0.3	−0.3	1.8	0.2	−2.1	2.6	0.4	**	**	***
−0.9	2.3	0.4	−1.9	1.8	0.3	−3.0	2.7	0.4	***	***	***
−0.8	2.3	0.4	−2.2	2.4	0.4	−2.9	3.0	0.5	***	ns	***
1.9	3.5	0.5	2.6	3.6	0.6	4.5	4.1	0.6	**	*	ns
−1.2	4.3	0.7	0.7	4.3	0.7	−0.5	4.3	0.7	**	*	***

TABLE 3. Comparison Between Treated and Control Groups at T_3

Measure (mm)	Treated Group (TG) at T_3 (n = 112)			Control Group (CG) T_3 (n = 41)			*t*-test
	Mean	SD	SE	Mean	SD	SE	
Maxillary arch width (centroid)							
Intermolar	43.5	2.7	0.3	45.6	2.3	0.4	***
Interpremolar (second)	39.0	2.4	0.2	40.2	2.4	0.4	**
Interpremolar (first)	34.3	2.1	0.2	35.5	2.1	0.3	**
Intercanine	30.2	1.9	0.2	30.7	1.8	0.3	ns
Mandibular arch width (centroid)							
Intermolar	39.8	2.5	0.2	40.9	2.1	0.3	*
Interpremolar (second)	34.7	2.1	0.2	35.7	2.2	0.3	*
Interpremolar (first)	30.0	1.7	0.2	30.9	1.7	0.3	*
Intercanine	24.4	1.3	0.1	23.6	1.5	0.2	**
Maxillary arch width (lingual)							
Intermolar	33.7	2.6	0.3	35.8	2.3	0.4	***
Interpremolar (second)	30.9	2.4	0.2	32.4	2.3	0.4	**
Interpremolar (first)	26.2	2.0	0.2	27.7	2.3	0.4	**
Intercanine	22.9	1.9	0.2	23.9	2.0	0.3	**
Mandibular arch width (lingual)							
Intermolar	31.1	4.1	0.4	30.3	3.7	0.6	ns
Interpremolar (second)	28.0	2.2	0.2	29.1	2.3	0.4	*
Interpremolar (first)	23.6	1.7	0.2	25.3	1.9	0.3	***
Intercanine	18.6	1.4	0.1	18.2	1.4	0.2	ns
Maxillary arch depth							
First molar	28.1	2.0	0.2	25.8	2.1	0.3	*
Mandibular arch depth							
First molar	24.3	2.5	0.2	21.7	2.6	0.3	*
Maxillary arch perimeter	74.4	4.7	0.4	76.1	4.3	0.7	*
Mandibular arch perimeter	64.1	4.2	0.4	64.2	3.9	0.6	ns
Maxillary molar angulation	175.5	5.8	0.5	180.9	5.6	0.9	***
Mandibular molar angulation	185.7	5.0	0.5	190.1	5.8	0.9	***

* $P < .05$; ** $P < .01$; *** $P < .001$; ns = not significant.

TABLE 4. Net Changes in the Treated Sample Compared with the Control Sample

	Maxillary Arch Width (centroid)		Mandibular Arch Width (centroid)		Maxillary Arch Perimeter	Mandibular Arch Perimeter
	Intermolar	Intercanine	Intermolar	Intercanine		
Treated sample (n = 112)						
T_1-T_2	4.5	4.0	1.0	2.0	6.5	4.0
T_2-T_3	0.0	−1.5	0.0	−0.5	−3.5	−2.5
T_1-T_3	4.5	2.5	1.0	1.5	3.0	1.5
Control sample (n = 41)						
T_1-T_2	0.5	0.5	−0.5	0.5	−1.0	−1.0
T_2-T_3	0.0	−0.5	−1.0	−0.5	−2.0	−2.0
T_1-T_3	0.5	0.0	−1.5	0.0	−3.0	−3.0
Net changes (treated vs controls)						
T_1-T_2	4.0	3.5	1.5	1.5	7.5	5.0
T_2-T_3	0.0	−1.0	1.0	0.0	−1.5	−0.5
T_1-T_3	4.0	2.5	2.5	1.5	6.0	4.5

FIGURES Return to TOC

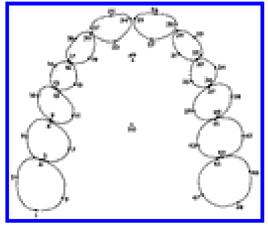

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FIGURE 1. Location of digitized landmarks on maxillary dental casts. Similar dental landmarks were located on the mandibular dental arch

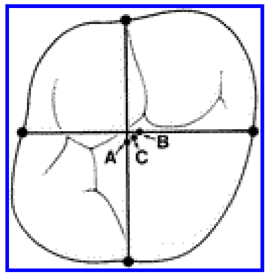

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FIGURE 2. Location of the centroid of each posterior tooth was determined first by determining the midpoint (A) of a line connecting the mesial and distal landmarks. A similar midpoint (B) was constructed midway between the buccal and lingual landmarks of the tooth. The centroid (C) was located midway between points A and B.[16]

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FIGURE 3. The angulation of the maxillary and mandibular first molars was determined by measuring the angle of intersection of lines passing through the buccal and lingual cusps. Angulation of less than 180° indicated that the molars were tipped buccally; values above 180° implied that they were tipped lingually

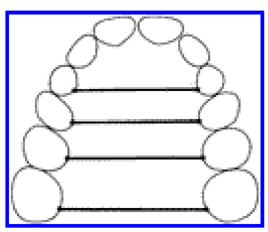

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FIGURE 4. Arch width was determined as the distance between the lingual landmarks in each posterior tooth. The lingual landmark on the maxillary first molars was located at the junction of the lingual groove with the palatal mucosa

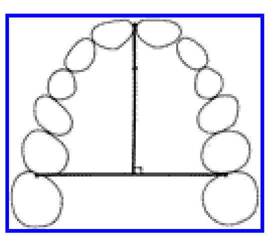

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FIGURE 5. Arch depth was determined by measuring the length of a perpendicular line constructed from the contact point between the mesial contact points of the central incisors to a line connecting the contact points between the second premolars and first molars

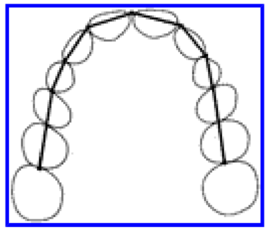

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FIGURE 6. Arch perimeter was determined by constructing a line from the mesial contact points of one molar through the mesial and distal contact points of the six anterior teeth to the mesial contact point of the opposite molar

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