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RAPID MAXILLARY EXPANSION: LONG-TERM HARD TISSUE PROFILE AND DENTAL ARCH WIDTH CHANGES

by

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Abstract

The present study investigated the effect of rapid maxillary expansion (RME) on (1) the sagittal and vertical skeletofacial dimensions and (2) on maxillary and mandibular dental arch width at the conclusion of orthodontic treatment and two years later. The total sample consisted of 40 subjects and was divided into two groups of 20 subjects each. The experimental group underwent comprehensive treatment plus RME with a banded type appliance, while the second group had comprehensive treatment only and served as a control. Pretreatment, immediate posttreatment, and two-year posttreatment lateral head films were used to retrospectively compare the skeletal changes between the experimental and control group. Statistically significant group differences were not found in any of the anteroposterior nor vertical cephalometric variables over any period of observation. Treatment and posttreatment changes in arch width were then assessed on dental casts of 13 subjects in each group treated without extraction of permanent teeth. Maxillary arches that had undergone RME showed significant average net increases of 5.60 mm between first bicuspids and 4.50 mm between first molars two years out of treatment, with relapse recorded at 15% and 11%, respectively. Mandibular arch width was not significantly altered within the RME subjects, nor were the changes in lower arch width shown to differ between the RME and non-RME control groups during any period. Therefore, from the present findings it can be inferred that RME with a banded type appliance does not significantly alter the hard tissue profile beyond that which is expected from conventional orthodontic treatment not involving RME. In addition, RME treatment results in comparatively stable expansion of upper dental arch width with no concurrent effect on lower dental arch width two years out of treatment.

Keywords: Rapid Maxillary Expansion, Skeletal Changes, Cephalometrics, Dental Arch Width Stability

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Introduction

Rapid maxillary expansion (RME) is recognized as a very successful method of orthodontic therapy, commonly used for the correction of maxillary transverse constriction and for alleviating arch perimeter deficiency. Previous studies have shown that RME leads to an increase of maxillary width mainly by orthopedic separation of the midpalatal suture and by lateral movement of the posterior maxillary teeth.[1-4] Inferior displacement of the maxilla and extrusion of the lingual cusps of the maxillary posterior teeth may also accompany these changes.[2-6] In response to these maxillary changes, the mandible rotates in a downward and backward direction.[2-6] In theory, this movement would generally improve the esthetics of patients with skeletal Class III malocclusions exhibiting short vertical facial height. The extrusive side effects of RME would, however, be an undesirable characteristic in patients with anterior open bite tendency and Class II skeletal patterns that are associated with long lower facial height and increased facial convexity. These observations are based on data obtained immediately following the RME phase which usually is completed early in the course of overall treatment. At three months post-expansion, Wertz[4] noted a tendency for the mandibular plane to relapse to pretreatment angulation, with final maxillary position being highly variable in both anteroposterior and vertical dimensions. Velazquez et al.[7] examined subjects at the end of comprehensive orthodontic treatment and concluded that no significant skeletal alterations were produced that could be attributed to the RME. In their limited cephalometric assessment of RME patients, Linder Aronson and Lindgren[8] observed a mandibular plane angle that was comparatively smaller five years out of retention than at pretreatment. These studies,[2,4,7,8] however, failed to include control subjects that did not

receive RME. As such, it is not possible to determine the extent to which the skeletal changes resulting from RME are compensated for, in time, by growth. Using control subjects for comparison purposes, Chang et al.[9] have recently shown no long term effects of RME treatment on various facial dimensions.

Few papers[10,11] document the long-term effect of RME on both upper and lower dental arch widths, whereas other studies limit assessment of arch width change to either maxilla[8,9,12] or mandible.[13] Nevertheless, when the research is reviewed collectively, considerable variation is noted in arch width stability many years posttreatment. Relapse of maxillary intercanine and intermolar width subsequent to initial expansion has been reported to vary from 22-62%[8,10,12] and 4-44%,[8-10,12] respectively. The corresponding residual expansion in upper intercanine width has been measured at 0.8 mm,[8] 1.9 mm,[12] and 2.7 mm.[10] In comparison, maxillary intermolar width has shown relatively greater long term stability with net expansion recorded at 2.1 mm,[12] 3.8 mm,[8] 4.6 mm[9] and 5.5 mm.[10] Even larger expansions of between 9 and 12 mm have been reported to be stable by Haas.[11] Expansion of the lower intermolar distance in conjunction with RME therapy has also proven to be a relatively stable orthodontic procedure. Minimal[13] or no relapse[10] has been demonstrated at posttreatment, with residual expansions of 2.8 mm[13] and 2.3 mm[10] produced between molars. In contrast, the mandibular intercanine dimension has shown to be more susceptible to relapse subsequent to initial expansion.[10,13] Relapse has been reported at 45%[13] and 61%[10] between canines for net increases of 1.1 mm and 0.7 mm, respectively. Haas[11] claims, however, that his cases demonstrate stable intercanine expansions of 4-5 mm in the lower arch many years out of retention. There are currently no studies that have utilized control subjects

to assess mandibular arch width change when orthodontic treatment has or has not included a phase of RME.

The purpose of the current retrospective investigation was three-fold: First, to cephalometrically compare the long-term anteroposterior and vertical facial changes of two groups of orthodontically treated subjects, both having shared similar pretreatment characteristics and treatment duration but differed in that only one group had RME. Second, to assess the stability of maxillary and mandibular dental arch width change in subjects that received RME. Third, to determine whether RME therapy results in significant alteration of lower dental arch width in comparison to a non-RME control group.

Thus, the following hypotheses were examined and tested in this study:

Null hypothesis I: The long-term changes to the facial skeleton as observed on serial headfilms do not significantly differ between subjects who had RME and those not exposed to RME during comprehensive orthodontic treatment.

Null hypothesis II: Individuals treated with RME do not demonstrate significant posttreatment change in maxillary or mandibular dental arch width.

Null hypothesis III: The change in lower arch width does not differ between subjects who received RME and those treated without RME.

Methods and Materials

Sample:

Twenty subjects who had RME as part of overall orthodontic treatment were compared to a control group of 20 individuals whose orthodontic therapy did not include RME. Patient records for this investigation were derived from the treatment files of the Graduate Orthodontic Clinic at the University of Western Ontario (London, Ontario, Canada; Appendix A). Both the RME and non-RME subject groups were matched as closely as possible at the time of initial records for gender, age, facial type, Angle Classification, extraction protocol, and various cephalometric parameters. Of the 20 subjects in each group, 15 were females while five were male. The RME group had a mean pretreatment age of 12.81 years, similar to that of the control group at 12.90 years of age (Table I). The majority of subjects were characterized as having a mesocephalic facial type (Table II) based on Ricketts' assessment of the following cephalometric measurements: facial axis, facial angle, mandibular plane angle, lower facial height, and mandibular arch.[14] An Angle Class II relationship was noted in 50 percent of the total sample, a Class I malocclusion was evident in 37.5 percent, while 12.5 percent of the total number of subjects displayed a Class III molar relationship (Table III). A Hyrax or Haas type of a banded RME appliance was prescribed with the first premolars and first molars usually serving as the abutment teeth. The activation protocol most commonly used was a quarter turn of the midline screw once or twice daily, usually for a period spanning one to three weeks. Once the objectives of RME were achieved the appliance was retained on average for five months after which time conventional fixed orthodontic treatment was initiated. The method of retention commonly used in both groups

was a maxillary removable Hawley appliance in combination with either a mandibular Hawley or a fixed wire retainer from canine to canine. Patients were expected to wear the removable retainers full time for a period of six to 12 months after which time part time wear was recommended.

Cephalometric Analysis:

Lateral headfilms of subjects taken at pretreatment (T1), immediate posttreatment (T2), and approximately two-years posttreatment (T3) were used to assess the anteroposterior and vertical skeletal changes that occurred over time in both RME and non-RME groups. The films were hand traced on acetate paper and digitized using the Jiffy Orthodontic Evaluation (JOE) software program* with purported measurement accuracy within 0.1 degrees and 0.1 millimetres. An electronic digital caliper^ was used for the measurement of certain linear dimensions which could not be assessed using the JOE program. The accuracy of the digital caliper is within 0.02 millimetres. In total, 13 variables were used to describe the skeletal changes (Figures I - III, Appendices B and C).

Cast Analysis:

Plaster casts corresponding to initial (T1), end of treatment (T2), and two-years posttreatment (T3) were used to assess dental arch width change in 13 of the 20 individuals

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*Jiffy Orthodontic Evaluation. Version 5.0. RMO Diagnostic Services. 1996.

^ 500-197, MTI Corporation, Japan.

in each group exposed to a non-extraction protocol. Treatment and posttreatment changes in arch width were then analyzed; first, within the RME group and second between the two groups. A between-groups comparison of maxillary arch width changes was not performed due to significant pretreatment group differences in arch width. Nonetheless, the changes in upper arch width as recorded within the non-RME group are found in Appendix D. Arch width was measured between the buccal cusps of the first premolars and between the first molars from a point in the buccal groove at the junction of the occlusal and buccal surfaces[15] (Figure IV). First premolars were used in measuring arch width in the anterior segment as a large percentage of RME subjects had permanent cuspids that were either unerupted or ectopically positioned in the maxilla at the time of initial records. Measurements were omitted in cases where a cast was either missing or had minor defects. The same electronic digital caliper reported on earlier was used for these measurements.

Statistical Analysis:

Means and standard deviations were computed for the cephalometric and cast data taken at the three different time points: T1, T2, and T3. T-tests were used to statistically compare the mean changes in each variable within the RME group and between the two groups during treatment (T1-T2), posttreatment (T2-T3), and as well over the entire period of observation (T1-T3). The SPSS software program was utilized for all statistical comparisons~. Since the RME and non-RME groups were matched at pretreatment, paired t-tests rather than independent t-tests were used for assessing between-group differences.

~SPSS for MX WINDOWS, version 6.1.3.

The level of statistical significance was set at $p \leq 0.05$ but adjusted according to the Bonferroni method to account for the measurement of multiple variables.[16,17] Using this method, the level of significance ($p \leq 0.05$ in this study) was divided by the total number of tests. Therefore, for the purpose of assessing the cephalometric findings, a p value ≤ 0.0038 (0.05/13 variables) was considered significant while a p value ≤ 0.0125 (0.05/4 variables) was required to demonstrate a statistically significant difference for the cast measurements. In addition, if significant differences were observed between the two groups at pretreatment for any of the cephalometric or cast variables, an analysis of covariance (ANCOVA) was used to adjust for treatment and/or posttreatment effects.

Measurement Error:

The magnitude of measurement error in cephalometric tracing and digitizing as well as in arch width recording was determined in the following manner: Measurements were repeated on the lateral headfilms and casts of the first three subjects in each of the RME and non-RME groups, for a total re-evaluation of 18 cephalograms and 18 upper and lower models. The second set of measurements was performed at least three months after the initial recording. Method error was then calculated according to the following formula:[18,19] Standard Error (S.E.) = $\sqrt{\sum d^2/2n}$, where d is the difference between duplicate pairs and n is the number of pairs.

Results

The standard measurement errors for all 13 cephalometric variables were determined to be within published limits,[20] never exceeding 0.62 degrees for the angular measurements nor 0.91 mm for any of the linear variables. In addition, the four measurements of arch width were shown to be highly reproducible and compared favourably with those reported in the literature,[10,12] with standard error less than or equal to 0.15 mm (Table IV).

A between-groups comparison of the cephalometric data revealed no statistically significant differences in any of the 13 pretreatment variables at the adjusted Bonferroni p value≤ 0.0038 (Table V). Furthermore, none of the anteroposterior nor vertical measurements demonstrated any statistically significant difference between RME and non-RME groups either during treatment (Table VI), posttreatment (Table VII), nor during the entire period of observation (Table VIII).

Table IX summarizes the maxillary and mandibular arch width changes recorded in the RME group. Cast measurements were considered statistically significant if the p value was found to be less than or equal to the adjusted Bonferroni value of 0.0125. On the maxillary casts, statistically significant mean increases of 6.61 mm and 5.08 mm were measured between premolars and molars, respectively, by the end of treatment (both p=0.000). An insignificant amount of relapse was shown two-years posttreatment. The overall change from T1 to T3 was statistically significant, with average net expansions of 5.60 mm and 4.50 mm recorded in inter-premolar and molar widths, respectively (both p=0.000). In the mandibular arch, the first premolars underwent a significant mean increase of 2.25 mm during treatment (p=0.004), but this expansion was not statistically significant by the end of

the observation period.

For the assessment of mandibular dental arch width, the two groups showed a statistically significant difference in intermolar width at the time of initial records (Table X). The RME group displayed a relatively larger intermolar width of 48.24 mm which on average was 3.32 mm greater than that measured in the control subjects ($p=0.003$). To determine whether the initial group difference in lower intermolar dimension was an influencing factor on the overall change from T1 to T3 an ANCOVA test was performed. The analysis indicated that the observed changes by two-years posttreatment were not a result of initial differences between the two groups. The change over time in lower arch width as recorded between first premolars or first molars did not demonstrate any group differences during any time period (Tables XI-XIII).

Discussion

The long term impact of RME treatment on the facial skeleton was assessed by having both the RME and control subjects matched in a pairwise manner at pretreatment based on gender, age and Angle Classification and type of extraction. In contrast to Chang et al.'s RME study,[9] the facial type of the individuals was also considered such that similar proportions of the different facial forms were represented in both groups. In addition, emphasis was placed on selecting control subjects with comparable cephalometric values; particularly the facial axis angle which essentially remains unchanged and displays relatively little variation over time in the absence of treatment (0.0 degrees mean change ± 1.5 degrees SD over 5 years).[21] Furthermore, matching the two groups according to type of extraction was done despite the view that vertical facial change has shown not to differ between individuals who had first premolar extractions and those treated non-extraction.[22] Nevertheless, utmost consideration was given to pairwise matching at the outset of this study in order to minimize variability and improve on the ability to detect the effects of RME treatment between the two groups.

A between-groups comparison of the initial head film measures revealed a difference in angles ANB and SN-MP as well as in the linear measure Pogonion to Nasion Perpendicular (Table V). Mean group differences of 1.51 degrees, 2.21 degrees and 3.31 mm were observed respectively indicating that both groups were at opposite extremes of what is considered to be a normal Class I skeletal relationship. Relative to the control group, the RME subjects displayed a reduced maxillomandibular difference in the sagittal plane along with a greater vertical tendency. These differences, however, were not statistically significant.

The cephalometric findings demonstrated that any vertical skeletal changes brought about by RME as reported on in earlier studies[2-6] were not evident by the end of comprehensive treatment and/or two years posttreatment. Hence, the short term effects of RME, namely the vertical drop of the maxilla and extrusion of the molars with subsequent posterorotation of the mandible, appear to be corrected over time. Based on clinical observations, some authors[4,9,23] have cited cuspal interferences created by overexpansion as contributing towards the downward and backward rotation of the mandible. Subsequent uprighting of the upper posterior teeth into normal positions of interdigitation most likely allows for some recovery from the transient bite opening. It is speculated that any one or a combination of the following factors may contribute towards reversing the short-term vertical skeletal side effects often associated with RME: skeletal/dental relapse, further orthodontic treatment or compensatory growth. The vertical changes observed in this study concur with those published by Velazquez et al.[7] and Chang et al.[9] who also reported no clinically significant treatment effects at the time of deband and six years out of treatment, respectively, in subjects exposed to a Haas type appliance. Nevertheless, some clinicians recommend use of a vertical-pull chin cup[3,23,24] or a high-pull headgear[3,23] for controlling the vertical dimension during expansion. Other practitioners[25,26] prefer to use a bonded type of expansion appliance that has acrylic coverage on the occlusal surfaces to control vertical growth and posterior eruption. The interocclusal acrylic may infringe on the freeway space, creating passive stretch of the elevator muscles which in turn generates intrusive forces to the maxillary posterior teeth.[27] Sarver and Johnston[25] observed on average 0.54 mm less downward displacement of PNS with a bonded appliance compared to a banded type appliance. It is doubtful,

however, that this cephalometrically determined difference is biologically meaningful, when considering measurement error[20,28]. Asanza[26] also noted inferior movement of PNS, but more so in patients treated with the Hyrax type than in subjects treated with the bonded design by a difference of 1.58 mm. Both studies[25,26] evaluated subjects immediately after RME appliance removal and although they reported relatively less vertical lowering of the posterior maxilla with a bonded appliance, they failed to show any significant group differences in mandibular plane angulation. Therefore, the claim[25,26] that posterior occlusal coverage during RME prevents posterorotation of the mandible needs to be further examined, preferably over the long term.

Statistically significant group differences were not observed for any of the anteroposterior cephalometric parameters (Tables VI-VIII). However, the mean changes recorded for the variables SNB, ANB and Pogonion to Nasion Perpendicular indicate that the chin was displaced distally in the RME group, while it underwent a net forward movement in the control subjects (Table VIII). The group differences in SNB (0.07 degrees), ANB (0.39 degrees), and Pogonion to Nasion Perpendicular (0.90 mm) at T3 were less than those measured at T1 (Table V) which would suggest a "converging" pattern with respect to chin position over time. From pretreatment (T1) to two-years posttreatment (T3), non-significant differences of 0.96 degrees in SNB, 1.12 degrees in ANB, and 2.41 mm in Pogonion to Nasion Perpendicular were also observed between the two groups (Table VIII). It may be argued that the sample size was not adequate to detect a statistically significant difference between groups. Regardless, mean group differences of 0.96 degrees in SNB and 1.12 degrees in ANB may not be clinically significant. The average group difference of 2.41 mm

in Na Perp-Po would be clinically meaningful if not for the large values of individual variation (Table VIII) and measurement error (Table IV) associated with this variable. One explanation for these observations may be the subtle differences that may have existed in treatment methods between the two groups other than exposure to the RME procedure. In a retrospective study as in this one, one must accept variability with respect to methods of treatment, differences between and within clinicians, as well as patient factors which unfortunately were not possible to control for and may have potentially influenced the findings. Considerable effort was made to ensure both RME and non-RME groups were exposed to similar modes of therapy. Earlier palatal expansion studies evaluating maxillary movement in the anteroposterior direction reported various degrees of forward positioning of A point[2-5] while other investigations[6] indicated no change. Again these investigations assessed RME therapy upon removal of the appliance in contrast to the present study and recent papers[7,9] that suggest no significant anteroposterior alteration of maxillary position in the long term. Those advocating use of a bonded type appliance have shown A point to be repositioned distally while it moved forward in a group treated with the Hyrax type of appliance, with the average difference between groups measured at 0.71mm[25] and 2.27 mm.[26] Hypothetically speaking, a patient with a Class II profile would benefit more with a bonded RME appliance by restricting forward maxillary movement, while a banded type appliance would be more suitable for the Class III subject by allowing greater forward movement of A point. Long-term studies comparing the two types of appliances are needed to assess the validity of this statement.

From the cast measures reported in Table IX, RME treatment in conjunction with

fixed mechanotherapy lead to a significant increase in maxillary arch width with no substantial effect on lower arch width over the total period of observation. The maxillary intermolar width underwent relapse of 11 percent after the initial expansion resulting in a mean net increase of 4.50 mm. This finding compares favourably with that reported by Chang et al.[9] who found a reduction of only 4 percent between molars, for a similar residual expansion of 4.60 mm six years out of treatment. Over a similar posttreatment period of 5.6 years, Herold[12] noted a net gain of only 2.10 mm on average in intermolar width. Interestingly, the RME subjects in Herold's study[11] underwent less expansion initially (3.90 mm) in comparison to Chang et al.'s study[9] (4.80 mm) or the current investigation (5.08 mm) but demonstrated the greatest amount of relapse at 44 percent. Linder-Aronson and Lindgren[8] similarly reported 40 percent relapse in maxillary intermolar width 6.9 years out of treatment, but unlike Herold[12], they demonstrated a greater average net expansion of 3.56 mm. In their assessment of RME cases, Mousa et al.[10] demonstrated an increase of 6.7 mm between molars during treatment with residual expansion reported at 5.5 mm, 14.5 years after deband which translates into 18 percent relapse over a relatively long recall period. From these studies,[8-10,12] it is apparent that much variability exists in the reporting of upper molar width change over the long term. Although the present study evaluated subjects only two years out of treatment, the changes in dental arch width compare favourably with the studies reviewed.[8-10,12] None of the previously reported investigations evaluated arch width change between maxillary first premolars and therefore comparisons cannot be made. From the current findings, expansion of the premolar width did, however, appear to be a relatively stable movement as relapse of only 15 percent was noted for a residual expansion of 5.60 mm. In addition, expansion was

found to be greater between the first bicuspids than the first molars which agrees with the biological concept that RME produces greater separation of the mid-palatal suture anteriorly[2,4] where the resistance of the facial structures is weaker. As stated earlier, mandibular dental arch width in the RME group was not significantly altered over the complete period of study. In contrast to our findings, Mousa et al.[10] reported a significant residual expansion of 2.3 mm in lower intermolar width eight years out of retention. However, with the greater net expansion of 5.5 mm they measured in maxillary intermolar width, the larger increase in lower intermolar width was most likely necessary in order to achieve interdigitation posteriorly. Sandstrom et al.[13] noted an even greater residual expansion of 2.8 mm between mandibular molars with minimum of two-years postretention, but did not report on the extent of maxillary dental arch changes arising from RME.

The mandibular arch width changes in the RME group were not significantly different than those noted in the control group during any period of observation (Tables XI-XIII). Therefore, lower arch width change cannot be differentiated between subjects that underwent rapid expansion of the maxilla and those that did not. However, the RME subjects had narrower maxillary arch forms in comparison to the controls at the start of the study. Nonetheless, arch width coordination in the RME group was achieved by widening the upper arch rather than by altering the lower arch width.

Conclusions

The purpose of this study was to examine the long-term effect of RME on both the skeletal profile and on dental arch width. The following observations and conclusions can be drawn from this investigation:

1. Comprehensive orthodontic treatment involving a phase of RME with a banded type appliance did not result in any significant alteration to either maxillary or mandibular jaw position, either in the vertical or anteroposterior dimension, by the end of treatment or two years later.

2. The stability of RME on upper dental arch width is not unlike the findings from other long term studies. An insignificant amount of relapse was recorded two years out of treatment between maxillary first bicuspids (15%) and first molars (11%) resulting in average residual expansions of 5.60 mm and 4.50 mm, respectively.

3. Rapid expansion of the maxilla lead to a significant mean increase of 2.41mm in lower first premolar width by the end of treatment but relapsed during posttreatment such that the net average expansion of 1.77 mm was not statistically significant but may be considered clinically relevant.

4. The change in lower dental arch width as observed during treatment and posttreatment did not differ between those subjects who had RME and the control subjects that did not. Contrary to previous findings,[10,13] RME therapy did not result in increased mandibular arch width over and above that which was produced in the non-RME group.

Table I: Age distribution

Group	Age (decimal years)					
	T1		T2		T3	
	mean	SD	mean	SD	mean	SD
RME	12.81	1.37	15.26	1.43	17.45	1.48
Control	12.90	1.30	15.04	1.33	17.20	1.34

Table II: Pretreatment facial type

Group	Brachyfacial	Mesofacial	Dolichofacial
RME	3	14	3
Control	4	15	1

Table III: Pretreatment Angle Classification

Group	I	II	III
RME	7	10	3
Control	8	10	2

Table IV: Standard error of measurements

$S.E. = \sqrt{\Sigma d^2/2n}$, n=18

Cephalometric Measurement		Standard Error
Angular (degrees):	SNA	0.38
	SNB	0.30
	ANB	0.26
	SN-PP	0.58
	SN-MP	0.62
	Facial Axis	0.31
Linear (mm):	Na Perp-Pt A	0.56
	Na Perp-Po	0.91
	ANS-SN	0.31
	PNS-SN	0.45
	U6-PP	0.64
	Na-Me	0.53
	ANS-Me	0.38
Cast Measurement		
Arch width (mm):	14-24	0.11
	16-26	0.13
	34-44	0.15
	36-46	0.13

Table V: Comparison of cephalometric measurements at pretreatment (T1)

Cephalometric variables	RME group n = 20		Control group n = 20		Mean group diff.	p value
	Mean	SD	Mean	SD		
Anteroposterior						
SNA (degrees)	79.90	2.26	80.54	3.38	0.64	0.369
SNB (degrees)	77.27	2.59	76.38	3.27	0.89	0.166
ANB (degrees)	2.65	2.19	4.16	1.73	1.51	0.023
Na Perp - Pt A (mm)	0.59	4.01	0.52	2.98	0.07	0.920
Na Perp - Po (mm)	-1.85	8.02	-5.16	5.11	3.31	0.027
Vertical						
SN - PP (degrees)	7.82	3.20	7.72	2.58	0.10	0.895
ANS - SN (mm)	54.08	3.69	53.34	3.13	0.74	0.354
PNS - SN (mm)	46.46	2.88	45.86	2.65	0.60	0.482
U6 - PP (mm)	23.66	2.51	22.68	2.21	0.98	0.145
SN - MP (degrees)	37.33	5.56	35.12	4.15	2.21	0.025
Facial Axis (degrees)	86.88	4.71	86.59	4.34	0.29	0.525
Na - Me (mm)	121.08	9.47	119.23	6.95	1.85	0.294
ANS - Me (mm)	69.54	7.44	68.40	5.12	1.14	0.448

Table VI: Comparison of cephalometric changes from pretreatment (T1) to immediate posttreatment (T2)

Cephalometric variables	RME group n = 20		Control group n = 20		Mean group diff.	p value
	mean	SD	mean	SD		
Anteroposterior						
SNA (degrees)	-0.54	1.44	-1.01	1.28	0.47	0.236
SNB (degrees)	-0.72	0.98	-0.10	1.25	0.62	0.066
ANB (degrees)	0.17	1.47	-0.92	1.40	1.09	0.009
Na Perp - Pt A (mm)	-0.46	1.46	-0.91	1.57	0.45	0.291
Na Perp - Po (mm)	-0.40	2.54	0.77	3.11	1.17	0.238
Vertical						
SN - PP (degrees)	0.32	1.33	0.65	1.45	0.33	0.466
ANS - SN (mm)	2.20	1.50	1.84	1.64	0.36	0.462
PNS - SN (mm)	1.54	0.94	1.20	1.14	0.34	0.377
U6 - PP (mm)	1.16	1.46	1.60	1.01	0.44	0.272
SN - MP (degrees)	0.96	1.42	-0.04	2.03	1.00	0.054
Facial Axis (degrees)	-1.02	1.48	-0.78	1.22	0.24	0.577
Na - Me (mm)	5.58	3.20	5.61	3.18	0.03	0.972
ANS - Me (mm)	3.32	1.88	3.40	1.62	0.08	0.888

Table VII: Comparison of cephalometric changes from immediate posttreatment (T2) to two-years posttreatment (T3)

Cephalometric variables	RME group n = 20		Control group n = 20		Mean group diff.	p value
	Mean	SD	Mean	SD		
Anteroposterior						
SNA (degrees)	-0.16	0.84	0.11	0.77	0.27	0.315
SNB (degrees)	-0.06	0.91	0.28	0.56	0.34	0.111
ANB (degrees)	-0.10	0.81	-0.14	0.77	0.04	0.920
Na Perp - Pt A (mm)	-0.30	1.09	0.32	0.93	0.62	0.061
Na Perp - Po (mm)	-0.35	2.45	0.88	1.51	1.23	0.074
Vertical						
SN - PP (degrees)	0.45	1.26	0.18	0.83	0.63	0.443
ANS - SN (mm)	0.67	1.44	0.64	0.58	1.31	0.918
PNS - SN (mm)	0.27	1.09	0.38	0.70	0.65	0.655
U6 - PP (mm)	1.00	1.07	0.67	1.07	1.67	0.160
SN - MP (degrees)	-0.38	1.37	-0.76	1.44	0.38	0.350
Facial Axis (degrees)	-0.22	1.12	0.46	0.58	0.68	0.019
Na - Me (mm)	1.81	2.40	1.52	1.67	0.29	0.553
ANS - Me (mm)	1.16	1.60	0.68	1.43	0.48	0.109

Table VIII: Comparison of cephalometric changes from pretreatment (T1) to two-years posttreatment (T3)

Cephalometric variables	RME group n = 20		Control group n = 20		Mean group diff.	p value
	Mean	SD	Mean	SD		
Anteroposterior						
SNA (degrees)	-0.70	1.52	-0.90	1.45	0.20	0.593
SNB (degrees)	-0.78	1.33	0.18	1.33	0.96	0.008
ANB (degrees)	0.06	1.26	-1.06	1.62	1.12	0.006
Na Perp - Pt A (mm)	-0.76	1.48	-0.58	1.70	0.18	0.649
Na Perp - Po (mm)	-0.75	2.95	1.66	3.25	2.41	0.008
Vertical						
SN - PP (degrees)	0.78	1.21	0.82	1.30	0.04	0.878
ANS - SN (mm)	2.86	2.17	2.48	1.87	0.38	0.389
PNS - SN (mm)	1.80	1.55	1.58	1.22	0.22	0.517
U6 - PP (mm)	2.16	1.41	2.28	1.56	0.12	0.728
SN - MP (degrees)	0.58	2.05	-0.79	3.10	1.37	0.059
Facial Axis (degrees)	-1.25	1.91	-0.33	1.44	0.92	0.081
Na - Me (mm)	7.39	4.14	7.14	3.95	0.25	0.739
ANS - Me (mm)	4.48	2.71	4.07	2.55	0.41	0.471

Table IX: Maxillary and mandibular arch width changes within the RME group

Arch width measurement	Treatment change (T1-T2)			Posttreatment change (T2-T3)			Net change (T1-T3)		
	Mean	SD	p value	Mean	SD	p value	Mean	SD	p value
Maxilla (n=13)									
Inter-first premolar (mm)	6.61	3.60	0.000	-1.01	2.13	0.113	5.60	2.42	0.000
Inter-first molar (mm)	5.08	1.84	0.000	-0.58	0.94	0.048	4.50	1.91	0.000
Mandible (n=12)									
Inter-first premolar (mm)	2.42	2.33	0.004	-0.64	1.12	0.073	1.78	2.25	0.020
Inter-first molar (mm)	-0.51	2.46	0.448	0.48	1.14	0.155	-0.03	1.92	0.904

Table X: Comparison of mandibular arch width at pretreatment (T1)

Arch width measurement (mm)	RME group n = 12		Control group n = 12		Mean group diff.	p value
	Mean	SD	Mean	SD		
Inter-first premolar	33.65	2.05	32.55	1.98	1.10	0.129
Inter-first molar	48.25	2.54	44.90	2.44	3.35	0.005

Table XI: Comparison of mandibular arch width changes from pretreatment (T1) to immediate posttreatment (T2)

Arch width measurement (mm)	RME group n = 12		Control group n = 12		Mean group diff.	p value
	Mean	SD	Mean	SD		
Inter-first premolar	2.42	2.33	2.78	1.57	0.36	0.580
Inter-first molar	-0.51	2.46	0.15	1.53	0.66	0.515

Table XII: Comparison of mandibular arch width changes from immediate posttreatment (T2) to two-years posttreatment (T3)

Arch width measurement (mm)	RME group n = 12		Control group n = 12		Mean group diff.	p value
	Mean	SD	Mean	SD		
Inter-first premolar	-0.64	1.12	-0.69	0.80	0.05	0.909
Inter-first molar	0.48	1.14	0.21	0.96	0.27	0.487

Table XIII: Comparison of mandibular arch width changes from pretreatment (T1) to two-years posttreatment (T3)

Arch width measurement (mm)	RME group n = 12		Control group n = 12		Mean group diff.	p value
	Mean	SD	Mean	SD		
Inter-first premolar	1.78	2.25	2.09	1.60	0.31	0.729
Inter-first molar	-0.03	1.92	0.36	1.14	0.38	0.580

Figure I: Lateral cephalometric landmarks

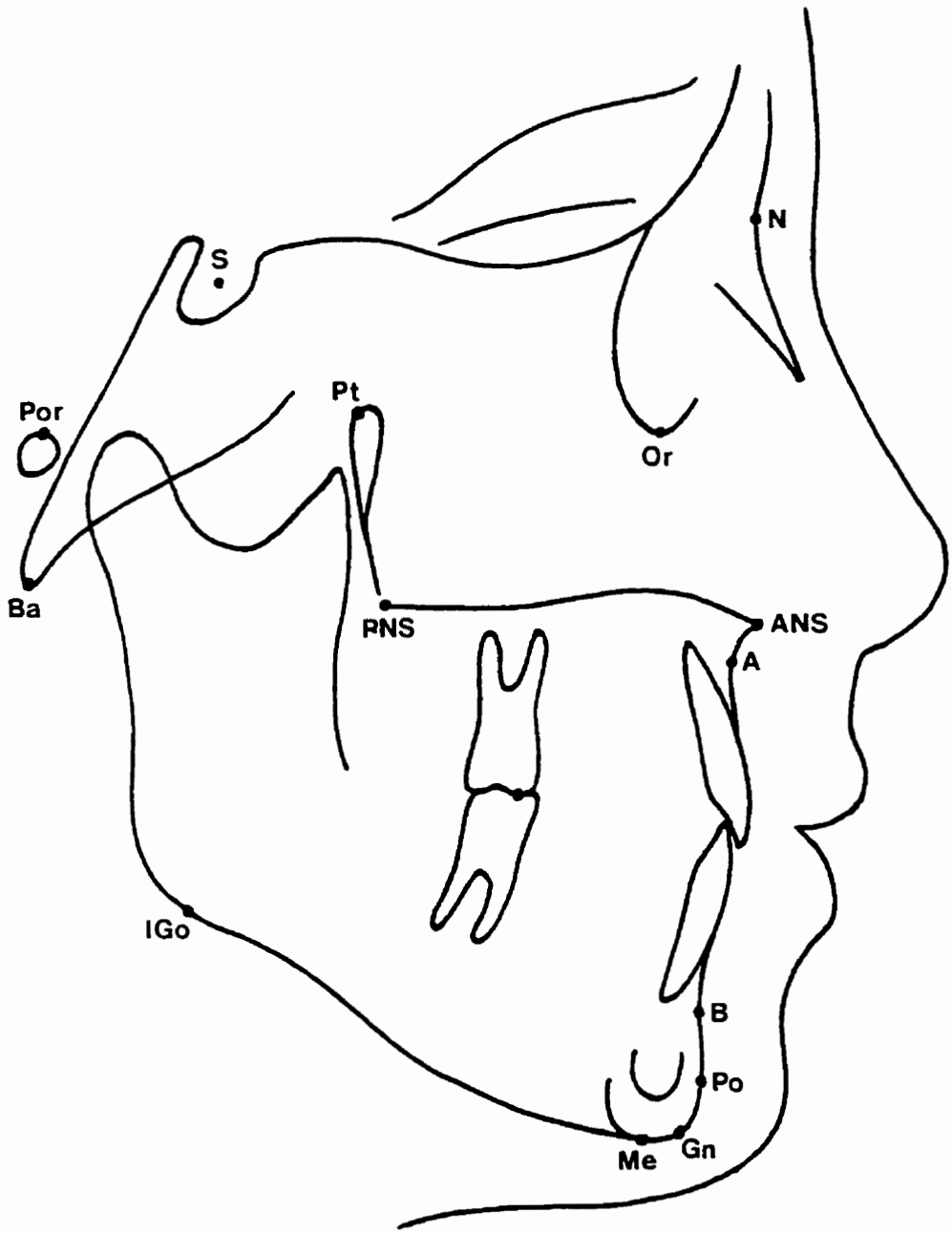
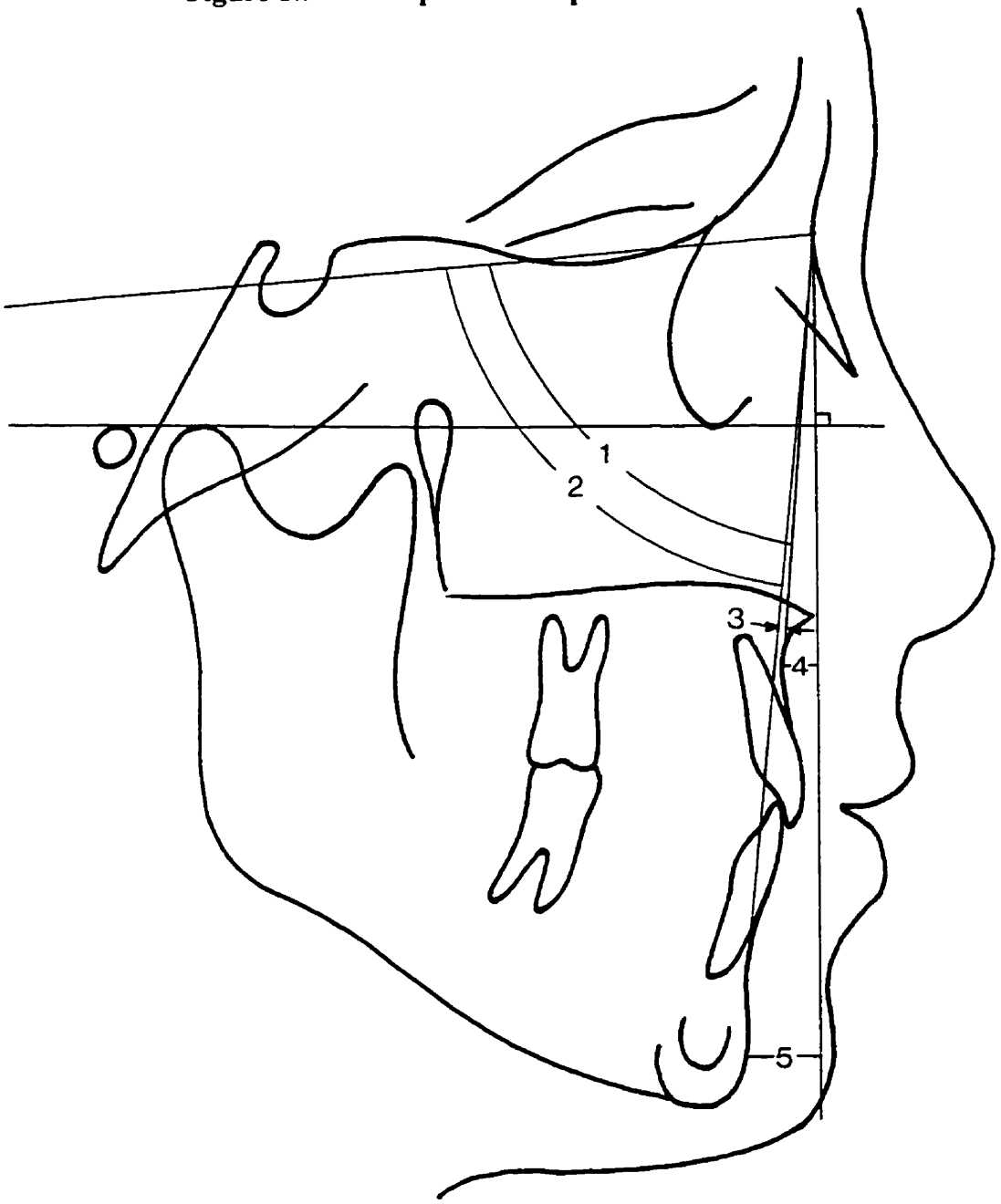
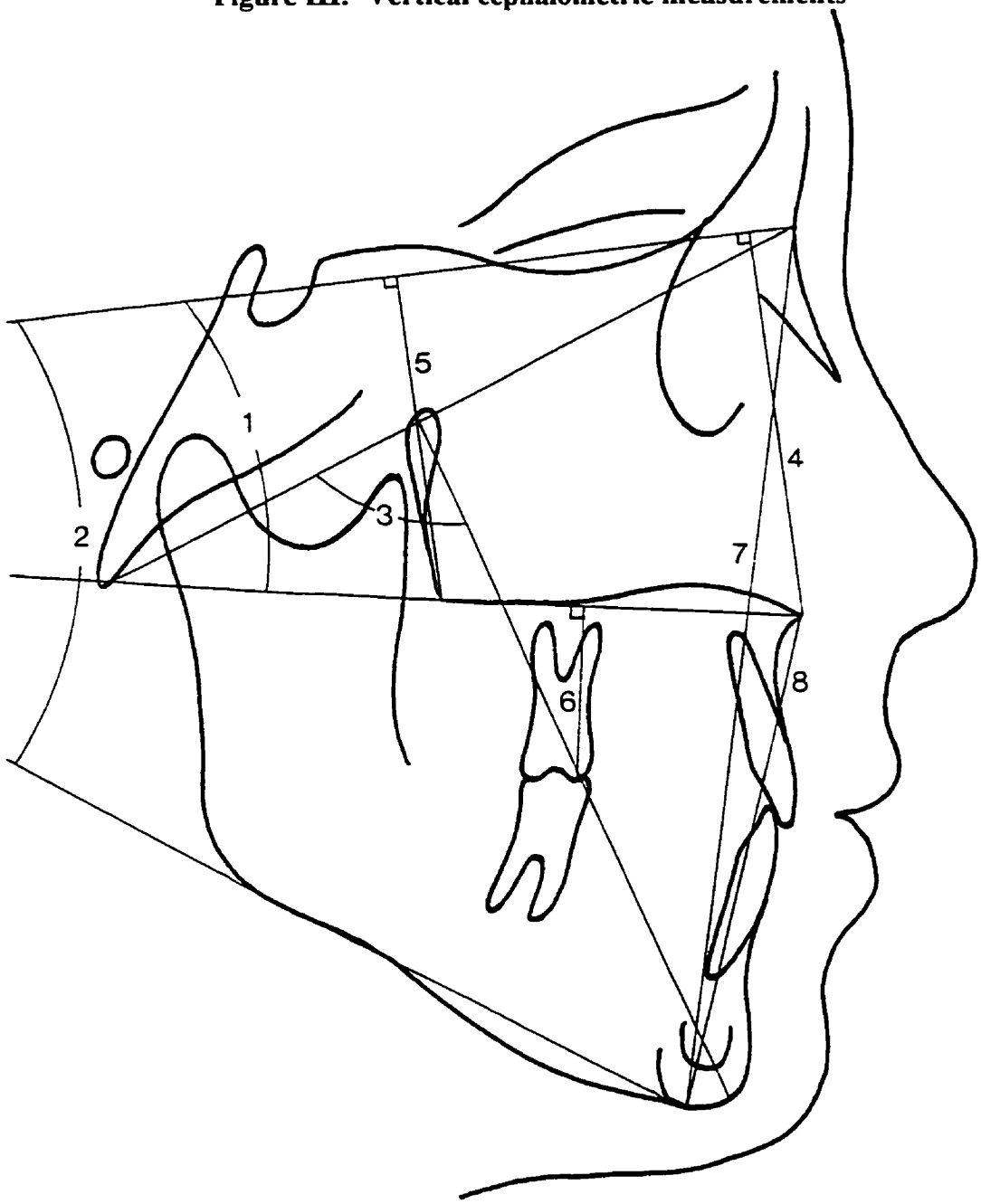


Figure II: Anteroposterior cephalometric measurements



Angular measurements (degrees)	Linear measurements (mm)
1. SNA	4. Na Perp - Pt A
2. SNB	5. Na Perp - Po
3. ANB	

Figure III: Vertical cephalometric measurements



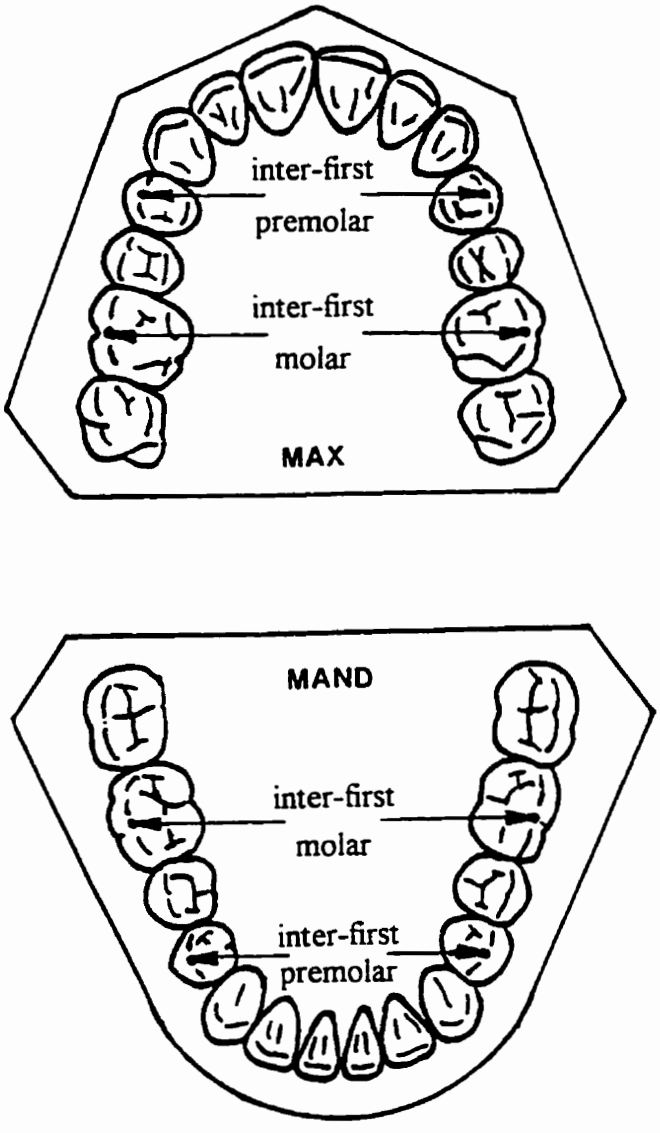
Angular measurements (degrees)

1. SN - PP
2. SN - MP
3. Facial Axis

Linear measurements (mm)

4. ANS - SN
5. PNS - SN
6. U6 - PP
7. Na - Me
8. ANS - Me

Figure IV: Dental cast landmarks for arch width measurements



Appendix A: List of chart numbers for the RME and control group

Chart number		Evaluation	
RME subject	Control subject	Cephalometric	Dental cast
1970	1843	Yes	No
1973	1803	Yes	No
1974	1876	Yes	Yes
1975	1897	Yes	Yes
1976	1124	Yes	Yes
1748	1806	Yes	No
1671	1971	Yes	No
1658	1691	Yes	Yes
1657	1972	Yes	Yes
1563	1890	Yes	Yes
1375	1739	Yes	Yes
1373	1724	Yes	Yes
1137	1357	Yes	Yes*
1116	1328	Yes	No
1106	1762	Yes	Yes**
1069	1698	Yes	Yes
860	1795	Yes	No
832	1877	Yes	No
796	1723	Yes	Yes
669	1866	Yes	Yes

*both RME and Control subjects had extraction of four second molars

**maxillary arch width evaluation only

Appendix B: Definition of cephalometric landmarks

Sella Turcica (S):	The center of the pituitary fossa of the sphenoid bone as determined by inspection.
Nasion (N):	The junction of the frontonasal suture at the most posterior point on the curve of the bridge of the nose.
Orbitale (Or):	The lowest point on the average of the right and left borders of the orbit.
Pterygomaxillary Point (Pt):	The intersection of the inferior border of foramen rotundum with the posterior wall of the pterygomaxillary fossa.
Porion (Por):	The most superior point of the bony external auditory meatus.
Basion (Ba):	The most inferior, posterior point on the anterior margin of foramen magnum.
Posterior Nasal Spine (PNS):	The most posterior point of the bony hard palate.
Anterior Nasal Spine (ANS):	The most anterior position of the maxilla at the lower margin of the anterior aperture of the nose.
A Point (A):	The most posterior point on the curve of the anterior maxilla.
B Point (B):	The point most posterior to a line from infradentale to pogonion on the anterior surface of the symphyseal outline of the mandible.
Pogonion (Po):	The most anterior point on the symphysis of the mandible determined by a line from nasion tangent to the symphysis.
Gnathion (Gn):	The most anterior and inferior point on the contour of the bony chin symphysis. Determined by drawing a line from pterygoid point to the intersection of the mandibular plane and a line through nasion and pogonion.
Menton (Me):	The most inferior point on the symphyseal outline.
Inferior Gonion (IGo):	A point tangent to the inferior border of the mandible located on the gonial curve.
Upper First Molar (U6):	The mesiobuccal cusp tip taken as an average between right and left maxillary first molars.

Appendix C: Definition of angular and linear cephalometric measurements

Angular:

SNA:	The angle formed by the points S, N and A.
SNB:	The angle formed by the points S, N and B.
ANB:	The angle formed by the points A, N and B.
SN-PP:	The angle formed by the intersection of the of the S-N plane and the ANS-PNS plane. Also known as the palatal plane (PP) angle.
SN-MP:	The angle formed by the intersection of the S-N plane and the IGo-Me plane. Also known as the mandibular plane angle.
Facial Axis:	The posterior inferior angle formed by the intersection of the Ba-Na plane and the Pt-Gn plane.

Linear:

Na Perp-Pt A:	The perpendicular distance from point A to a vertical line constructed perpendicular to the Por-Or plane (Frankfort horizontal) and extended inferiorly from nasion.
Na Perp-Po:	The perpendicular distance from pogonion to a vertical line constructed perpendicular to the Por-Or plane (Frankfort horizontal) and extended inferiorly from nasion.
ANS-SN:	The perpendicular distance from the S-N plane to ANS.
PNS-SN:	The perpendicular distance from the S-N plane to PNS.
U6-PP:	The perpendicular distance from the ANS-PNS plane to U6.
Na-Me:	The distance between points Na and Me. Also known as the total anterior face height.
ANS-Me:	The distance between points ANS and Me. Also known as the lower anterior face height.

Appendix D: Maxillary arch width changes within the non-RME group

Arch width measurement n = 13	Treatment change (T1-T2)			Posttreatment change (T2-T3)			Net change (T1-T3)		
	Mean	SD	p value	Mean	SD	p value	Mean	SD	p value
Inter-first premolar (mm)	4.47	2.08	0.000	-0.79	0.81	0.004	3.68	1.99	0.000
Inter-first molar (mm)	0.08	1.68	0.870	0.42	0.96	0.139	0.50	1.13	0.135

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IMAGE EVALUATION
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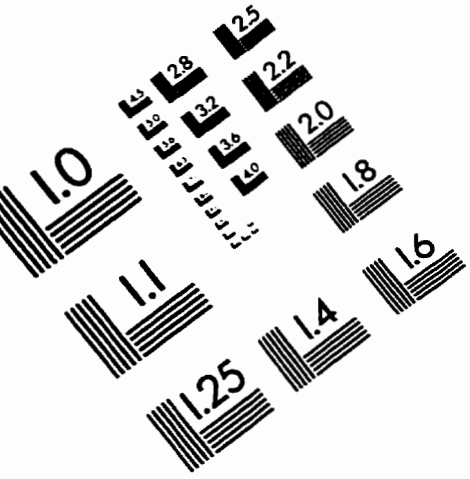

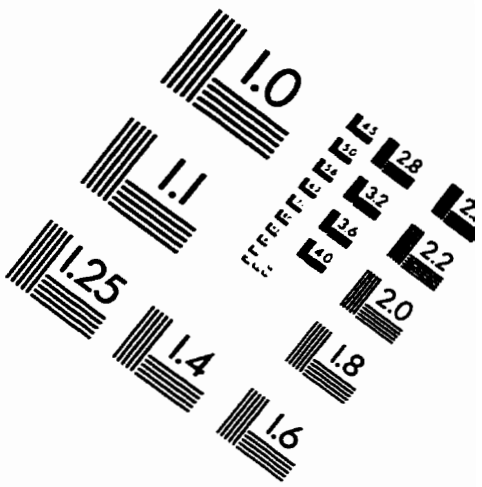

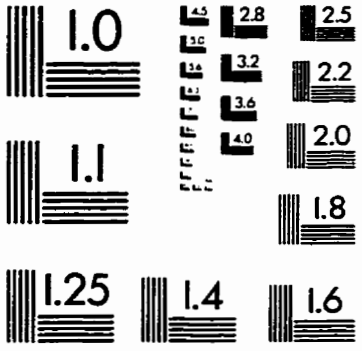

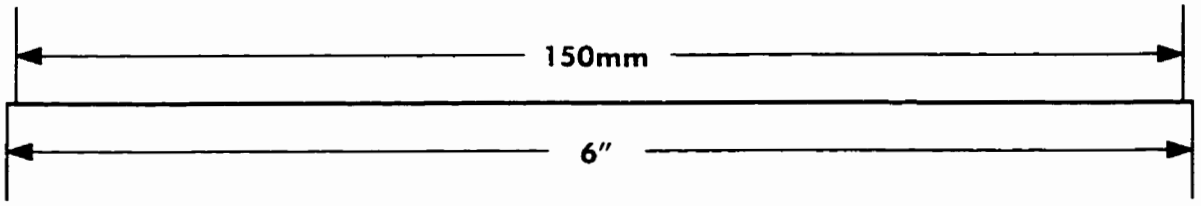

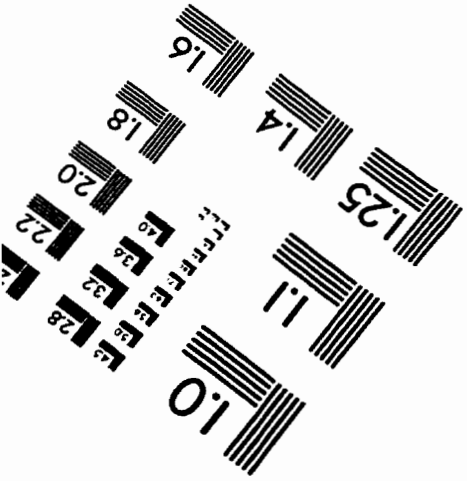

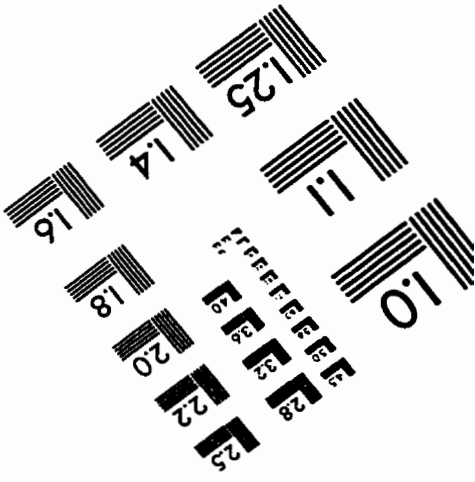

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