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Three-Dimensional Photographic Evaluation of Immediate Soft Tissue Changes Following Rapid Maxillary Expansion

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Three-Dimensional Photographic Evaluation of Immediate Soft Tissue Changes Following Rapid Maxillary Expansion

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

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Table of Contents

List of Tables

List of Figures

Abstract

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The skeletal and dental changes associated with rapid maxillary expansion (RME) are well documented. Effects on the soft tissues and the potential impact on facial esthetics have not been well researched. The purpose of this study was to evaluate immediate changes in facial soft tissues as a result of RME by comparing three-dimensional digital photogrammetric images before and after RME treatment.

The 3dMDface System was used to obtain photographic images of 21 patients (mean age = 11.8 years) before and after RME treatment for transverse maxillary deficiency. A control group of 13 patients (mean age = 12.7 years) also had two images taken at a similar time interval. Mean expansion was 6.5 mm in the RME patients.

Intercanthal distance, nose width, and intercommissural width changed significantly in the RME patients from T_0 to T_1 ($P = 0.011$, $P = 0.050$, and $P = 0.003$, respectively). Intercommissural width, however, was the only measure that significantly changed as compared with the control group ($P = 0.041$). Changes in intercanthal distance and nose width were significantly related to the amount of expansion achieved ($R^2 = 0.428$, $P = 0.0013$ and $R^2 = 0.501$, $P = 0.0003$, respectively).

Introduction

A device for achieving rapid maxillary expansion (RME) was first described by Angell[1] in 1860. The purpose of his device was to assist in correcting irregularities of the teeth, specifically to create space for the alignment of maxillary canines in arches without adequate space. Treatment with RMEs following Angell did not become popularized until Haas[2] introduced his device in the 1950s. While several variations in design have evolved, the underlying goal of widening the maxilla by transverse expansion across the midpalatal suture has remained the same. Reported benefits of RME treatment include skeletal correction of transverse maxillary deficiency,[3] increased arch perimeter,[4,5] increased nasal airway volume,[6] downward and forward movement of the maxilla,[3,7,8] improvement of auditory function in patients with conductive hearing loss,[9,10] and reduction in nocturnal enuresis in children.[11]

Currently, RME devices are frequently used by orthodontists.[12] There is little doubt that they achieve the dental and skeletal modifications necessary (at times requiring surgical assistance) for correction of transverse discrepancies due to maxillary constriction. The basic goals of orthodontic treatment include improvement of esthetics, function, and stability of the occlusion. However, the modern orthodontist needs to focus on more than these three factors as they relate simply to the occlusion. Facial proportion, anterior tooth display at rest and during movement, and many other features have an impact on dentofacial esthetics. As such, societal esthetic demands require that orthodontists take into consideration the intra- and extra-oral soft tissues that are affected by orthodontic treatment.[13,14]

Transverse maxillary deficiency is a commonly encountered problem in orthodontic patients. In an epidemiological study of Brazilian schoolchildren, da Silva Filho et al[15] found that the incidence of all different types of posterior crossbite in the primary dentition was 20.81%. An NIH study of data gathered from 1988-1991 found that the prevalence of posterior crossbites among Americans (whites, blacks, and Mexican-Americans) aged 8-50 years was 9.4% with insignificant variation associated with ethnicity or age.[16]

Maxillary expansion, when indicated, can be accomplished using one of a wide variety of appliances and protocols. The design selected is affected by the skeletal maturity of the patient and the severity of the transverse deficiency. In the early mixed dentition the midpalatal suture requires less force to open.[17] For these patients the appliance can be fixed, such as a W-arch or quad-helix appliance,[18] or removable, such as an acrylic plate with a jackscrew[19] or midline spring.[18] The midpalatal suture becomes more tortuous in the late mixed dentition. Due to the additional force required to open the suture, a fixed palatal expander with a jackscrew or midline spring, with or without acrylic palatal and/or occlusal coverage, is more frequently used for these patients.[7,8,12] Resistance to maxillary expansion comes from several of the articulations of the maxillary bones, with the midpalatal suture perhaps not providing the most significant resistance. Other locations of stress were found to include the zygomaticomaxillary and sphenoidal sutures, as well as at the pterygoid plates of the sphenoid bone.[20,21] In the adult, skeletally mature patient, there is increasing bony interdigitation and fusion of the maxillary sutures. Therefore, it may be necessary to include adjunctive surgical relief of the midpalatal and/or zygomaticomaxillary sutures[22] or use skeletal anchorage in the form of temporary skeletal anchorage devices (TADs)[23] in order to obtain an orthopedic effect.

While individualized protocols are used, rapid maxillary expansion is most often accomplished using a banded appliance with a jackscrew activated 0.5-1.0 mm/day.[12,20] Activation of the appliance by the patient or their parent continues until the desired amount of expansion is achieved, normally for 2-4 weeks.[24] As some relapse is inevitable, and because some degree of uprighting or widening of the mandibular posterior teeth is often anticipated during treatment, it is normal to overcorrect the expansion. A common endpoint is that at which the palatal cusps of the maxillary molars are in an edge-to-edge relationship to the buccal cusps of the opposing mandibular molars.[12]

Activation of the expansion screw produces a lateral load which is immediately directed against the teeth. As soon as the expansion exceeds the width of the periodontal ligament, the facial skeleton acts as a unit in offering resistance to the expansion.[20] The pressure on the facial skeleton causes bending of the alveolar process which then results in a distraction force across the midpalatal suture.[7] Clinically, skeletal expansion is observable by the creation or increase in width of a maxillary midline diastema.[1,7] The width of the midline diastema created was shown by Haas[7] to measure half the amount of the actual activation of the appliance.

It was demonstrated that the forces of the initial activations during RME do not fully dissipate before additional activations are made.[20] The forces from additional activations accumulate, causing a reduction in the mineral content of the suture. Using a dynamometer to measure forces created with RME treatment, Zimring and Isaacson[20] showed that pressure on the appliance did not decrease to zero until up to 45 days after the final activation. For this reason, retention of the achieved expansion is commonly accomplished by maintaining the appliance in place for a period of 3-6 months.[12]

The dental effects of RME include buccal tipping of the molars and premolars and tend to comprise a greater proportion of the total expansion with increased age at the time of treatment.[4,20,25] In a meta-analysis of the immediate skeletal and dental effects of RME treatment, Lagravere et al[24] found greater expansion at the molar crown than was observed at the molar root apex, indicating dental tipping of the molars an average of 3 degrees, which was not considered to be clinically significant. In order to maximize skeletal expansion and minimize the effects on the dentition, Baccetti et al[25] recommended that RME treatment be accomplished prior to peak growth velocity. A longitudinal radiographic study[26] found that greater than 80% of transverse maxillary development was completed by age 6 and that the greatest period of additional transverse growth of the maxilla occurred from 7 to 11 years in males and from 6 to 11 years in females. Haas[8] stated that in older patients, because of the resistance to opening of the midpalatal suture, it is possible that abutment teeth could perforate the buccal plate if using only dental anchorage.

The skeletal effects of RME have been well described in the orthodontic literature. To determine the skeletal alterations resulting from RME treatment, Wertz[3] evaluated 60 treated cases in his private practice as well as 2 dried skulls that he subjected to the same treatment. Downward displacement of the maxilla was routinely observed, but forward movement to any degree occurred only in isolated cases. Studied in the frontal plane, the maxillary halves arced laterally with the fulcrum located close to the maxillofrontal suture with greater skeletal expansion seen inferiorly. Similarly, the midpalatal suture opened in a non-parallel manner with the widest opening at ANS and decreasing posteriorly. Haas[7,8] quantified the movement of the maxilla at 2.5 mm downward and 3.5 mm forward. Da Silva Filho et al[27] found that the mandible was also affected by the downward movement of the maxilla. The result was a downward and backward rotation and an increase in the mandibular plane angle.

In addition to increasing the transverse dimension of the maxilla, RME treatment can be used to resolve crowding by increasing the arch perimeter.[4] Thus, expansion could potentially change a treatment plan from extraction to non-extraction. Addressing this idea, Adkins et al[4] found that an increase of 1 mm in inter-premolar width added approximately 0.7 mm of arch perimeter. In a prospective study, Geran et al[5] expanded patients an average of 4.3 mm and found that the long-term arch perimeter increase, when compared to controls, was 3.8 mm.

The reported esthetic changes resulting from RME treatment include decreasing the size of the buccal corridors while producing a wider smile.[28] While there may be enhancing or detrimental effects to the facial soft tissues of a patient treated with RME, there is a relative lack of research in this area. Karaman et al[29] used lateral cephalometric films to evaluate skeletal, dental, and soft tissue profile changes occurring with RME. They observed that, as the maxilla and maxillary anterior teeth moved anteriorly, the nose tip, soft tissue A point, and upper lip followed. Vertically, the middle and lower face dimensions, both skeletal and soft tissue measurements, increased.

Berger et al[30] used serial frontal facial photographs to evaluate soft tissue changes of the face as a result of RME treatment. They observed an increase in nasal width that remained significant throughout the retention period. The upper lip length, lower lip-chin length, upper face width, lower face width, upper lip vermilion, and lower lip vermilion demonstrated changes during treatment but showed no significant change from initial values after 1 year of retention. Overall face height, intercanthal distance, average eye width, and nose length did not change over time. In an unpublished thesis, Adams[31] used cone beam computed tomography (CBCT) to quantify immediate soft tissue changes in the transverse and anterior-posterior dimensions with RME in growing patients. Intercanthal distance, the width of the alar base, and intercommissural width each increased as a result of RME treatment. The tip of the nose and subnasale both moved anteriorly. Johnson et al[32] evaluated changes in soft tissue nasal widths associated with RME using direct anthropometry. They reported a statistically significant increase in the width of the greater alar cartilages but considered the amount to be clinically insignificant.

The purpose of this study was to evaluate immediate changes in facial soft tissues as a result of RME treatment by comparing three-dimensional digital photogrammetric image measurements before and after RME treatment. In addition, the changes occurring in the RME patients were compared to those of a control group over a similar period of time. RME causes changes in the facial skeleton and dentition that may affect the balance of the facial soft tissues and have an impact on dentofacial esthetics. An orthodontist who understands the skeletal, dental, and soft tissue effects of rapid maxillary expansion can better anticipate the final esthetic result and plan appropriately to meet individualized patient treatment goals.

Materials and Methods

Before the start of this clinical study, approval was obtained from the Institutional Review Board of the Virginia Commonwealth University, Office of Research. The treatment sample consisted of 21 consecutively consenting patients, diagnosed with transverse maxillary deficiency, that had been planned to have rapid maxillary expansion as part of their orthodontic treatment. The control group included 13 consecutively consenting patients of a similar age range without transverse maxillary deficiency. Both groups were selected from a larger sample of patients planning to undergo treatment in the Department of Orthodontics of the School of Dentistry at Virginia Commonwealth University in Richmond, Virginia. Exclusion criteria for the RME and control groups were: (1) any anomaly of the facial soft tissue, (2) any craniofacial defect (cleft palate and/or alveolus), or (3) inability, for any reason, to sit for the 3dMD photograph acquisition.

Each patient treated with RME received an 11 mm fixed maxillary expander (Straight Arm RPE model 17-002-04, Dentsply GAC International, Bohemia, NY). The stainless steel appliance was soldered to orthodontic bands fit to the maxillary first molars and supporting arms were added extending anteriorly to the first premolar or primary molar region. The rapid maxillary expander was cemented in place and activated with one one-quarter turn (0.25 mm of expansion) of the jackscrew at the time of delivery. It was then activated one-quarter turn twice each day by the patient or parent. Expansion of the appliance continued until overcorrection of the transverse discrepancy was achieved. Completion of expansion was determined to be when the palatal cusps of the maxillary molars were in an edge-to-edge relationship to the buccal cusps of the opposing mandibular teeth.

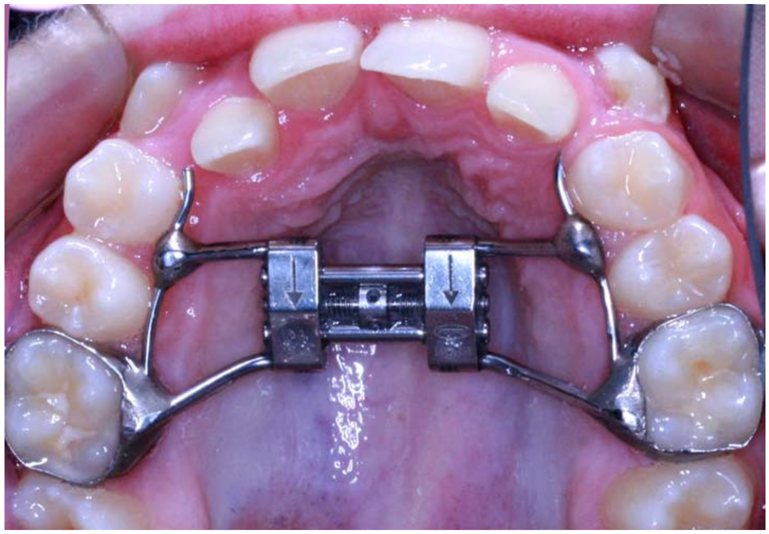


Figure 1. Rapid maxillary expander

Three-dimensional photographic data were obtained using the 3dMDface System (3dMD, Atlanta, GA). In a recent study,[33] the 3dMDface system was compared to direct anthropometry and other facial soft tissue measurement systems and was determined to be highly accurate and reliable. For the RME patients, an image was obtained pre-treatment (T_0) and a second image was obtained immediately post-expansion (T_1). For the control subjects, an initial image was obtained pre-treatment (T_0) and the second image was obtained after approximately 6 weeks (T_1), but prior to bonding brackets, to mimic the approximate time during which expansion occurred in the RME patients. Images were obtained with the patient's teeth in occlusion and with the lips at rest.

Figure 2. 3dMDface System

Each image was imported into Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, CA) for anthropometric evaluation. The software allowed for orientation and measurement of the three-dimensional image along three axes: x (transverse), y (vertical), and z (antero-posterior) of a Cartesian coordinate system. As no hard-tissue landmarks were visible to use for image orientation, the image was oriented with the soft-tissue facial features balanced symmetrically across the y- and z-axes. For alignment relative to the x-axis, the Frankfort Horizontal plane was oriented as closely as possible to parallel with the floor.

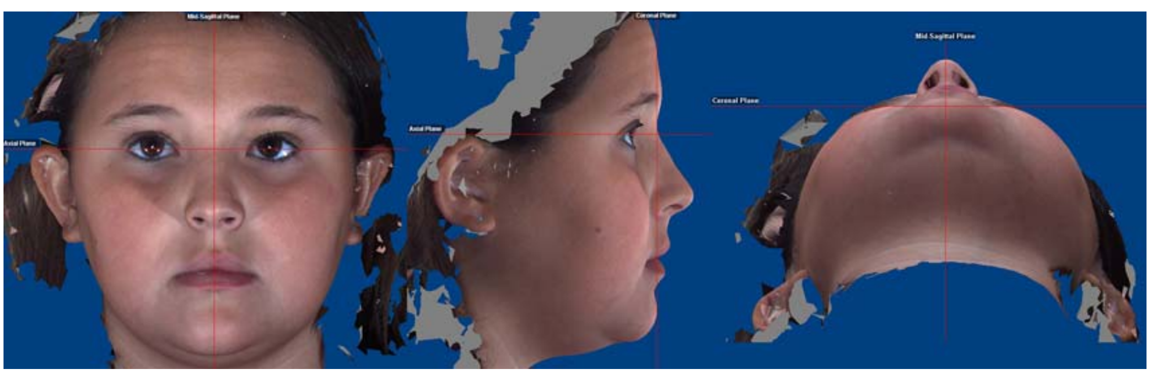


Figure 3. Image orientation

Twelve landmarks were identified on each image using the x, y, z Cartesian coordinate system. Table I lists and defines the nine photographic measures calculated for each patient. Measurements were made using both the three-dimensional coordinate information as well as using only the coordinates along the dimension of interest. The single-dimension measure clarified the change observed, but was potentially limited by the reproducibility of orientation. The measure using all three dimensional coordinates did not clarify the plane in which the change had occurred but, because it was an absolute measure, removed orientation error. Additionally, a boley gauge was used clinically to measure the increase in the transverse dimension of the RME device itself. This value was recorded as the actual amount of expansion achieved for each patient.

Table I. Photographic measurements

Measurement	*Definition*	*Axis*
Intercanthal distance	Distance between right and left endocanthia	X
Nose width	Distance between right and left alae	X
Columella width	Horizontal distance between right and left medial limits of the nostrils	X
Intercommissural Width	Horizontal distance between right and left labial commissures	X
IEP-Subnasale	Vertical distance between a point bisecting a line connecting the two endocanthia and subnasale	Y
Subnasale-Stomion	Vertical distance between subnasale and stomion	Y
Stomion-Menton	Vertical distance between stomion and menton	Y
IEP-Menton	Vertical distance between a point bisecting a line connecting the two endocanthia and menton	Y
Subnasale-Pronasale	Sagittal distance between subnasale and pronasale	Z

Statistical Analysis

Statistical analyses were accomplished using JMP (version 8.0.2, SAS Institute, Cary, NC). Descriptive statistics were calculated for each measure. Paired t-tests were used within the groups to determine changes from T_0-T_1. T-tests were used to determine significant differences in changes between the RME and control groups. Regression analysis was performed to assess the relationship between changes in measures from T_0 to T_1 and the amount of expansion performed. Fourteen patient images were randomly selected and all landmark identification and measurements were replicated. Cronbach's α values were calculated to assess the repeatability of landmark placement and measurement reliability.

Results

Cronbach's α values calculated for each measure are shown in Table II. As the measures showed good repeatability (and thus repeatable orientation), the single-dimension measurements were used for all ongoing statistics due to the clarity of dimension of change. The overall average magnitude of intrainvestigator error between repeated measurements was 0.25 mm.

Table II. Cronbach's α values for each measurement

Measure	*Cronbach's α*
Intercanthal distance (mm)	0.998
Nose width (mm)	0.999
Columella width (mm)	0.952
Intercommissural Width (mm)	0.998
IEP-Subnasale (mm)	0.993
Subnasale-Stomion (mm)	0.997
Stomion-Menton (mm)	0.998
IEP-Menton (mm)	0.999
Subnasale-Pronasale (mm)	0.995

The average age of the RME patients was 11.8 years at T_0, with a range from 9.3 to 15.1 years. The RME group included 11 male and 10 female patients (15 White, 6 Black). The average age of the control patients was 12.7 years at T_0, with a range from 10.6 to 16.9 years. The control group included 5 male and 8 female patients (6 White, 6 Black, 1 Asian). The average time between T_0 and T_1 was 60 days for the RME patients (range: 7 - 110 days). The increased time in some cases was due to inability of the patient to activate the expander according to the protocol prescribed by the treating doctor. Additionally, missed appointments increased the time between images in some patients. The average time between photographs for the control group was 44 days (range: 14 – 70 days). The average amount of expansion, measured as the change in the transverse width of the RME in the RME group was 6.5 mm (range: 2.5 - 15.0 mm). Average measurements at T_0 and T_1, the average amounts of change within each group and the differences between groups, are presented in Table III.

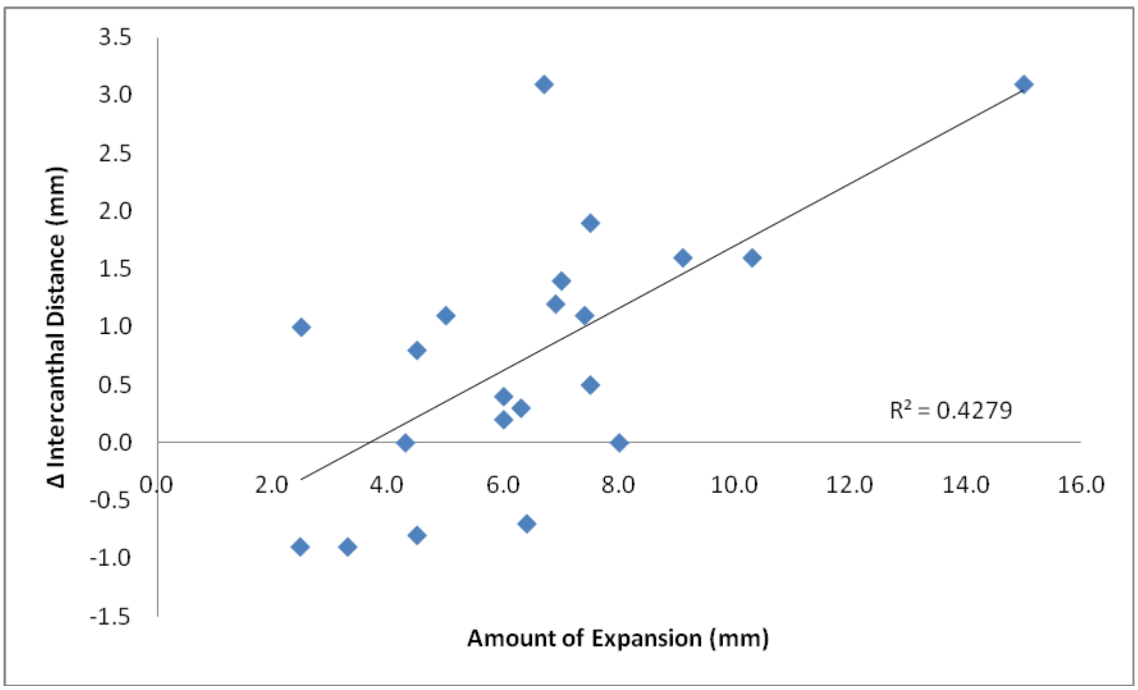
Table III. Soft tissue measures and changes $T_0 - T_1$, RME group (n = 21), Control group (n = 13)

Soft-Tissue Measure (mm)	*Group*	*T_0*			*T_1*			*Change*	*SD*	*P*	
Intercanthal distance	RME	33.3	±	2.4	34.0	±	2.5	0.76	1.15	0.011	*
	Control	33.6	±	3.8	33.8	±	3.9	0.17	0.53	0.276	
	Difference							0.59		0.051	
Nose width	RME	34.5	±	4.9	35.0	±	5.3	0.55	1.21	0.050	*
	Control	36.2	±	3.3	36.4	±	3.3	0.17	0.98	0.546	
	Difference							0.38		0.137	
Columella width	RME	6.9	±	1.0	6.9	±	0.9	-0.01	0.58	0.941	
	Control	7.0	±	0.7	6.9	±	0.7	-0.10	0.50	0.370	
	Difference							0.09		0.516	
Intercommissural width	RME	43.2	±	4.4	44.7	±	4.4	1.48	2.03	0.003	‡
	Control	44.9	±	4.2	45.3	±	4.2	0.40	0.90	0.178	
	Difference							1.08		0.041	*
IEP-Subnasale	RME	38.7	±	3.8	38.5	±	3.6	-0.17	0.79	0.338	
	Control	39.8	±	2.2	39.8	±	1.8	0.04	0.63	0.830	
	Difference							-0.21		0.365	
Subnasale-Stomion	RME	21.3	±	2.4	21.4	±	2.4	0.08	0.98	0.709	
	Control	21.3	±	2.1	21.6	±	2.4	0.32	0.87	0.216	
	Difference							-0.24		0.473	
Stomion-Menton	RME	43.6	±	3.8	43.0	±	3.2	-0.62	2.35	0.241	
	Control	43.0	±	3.9	43.1	±	4.0	0.17	0.89	0.508	
	Difference							-0.79		0.177	
IEP-Menton	RME	103.8	±	8.2	103.4	±	7.0	-0.42	2.10	0.373	
	Control	104.6	±	5.6	105.1	±	5.7	0.56	1.31	0.149	
	Difference							-0.98		0.104	
Subnasale-Pronasale	RME	11.3	±	2.3	11.4	±	2.1	0.03	0.80	0.871	
	Control	11.7	±	2.2	11.8	±	2.2	0.06	0.35	0.541	
	Difference							-0.03		0.870	

*$P \le 0.05$; ‡ $P \le 0.01$.

Within the RME group, intercanthal distance, nose width, and intercommissural distance (each transverse measures) increased significantly. However, when compared to similar changes within the control group, only the increase in intercommissural width was significantly greater in the RME patients. There were no significant changes in any soft tissue features in either the sagittal or vertical dimensions. No changes between T_0 and T_1 were found to be significant in the control group in any dimension.

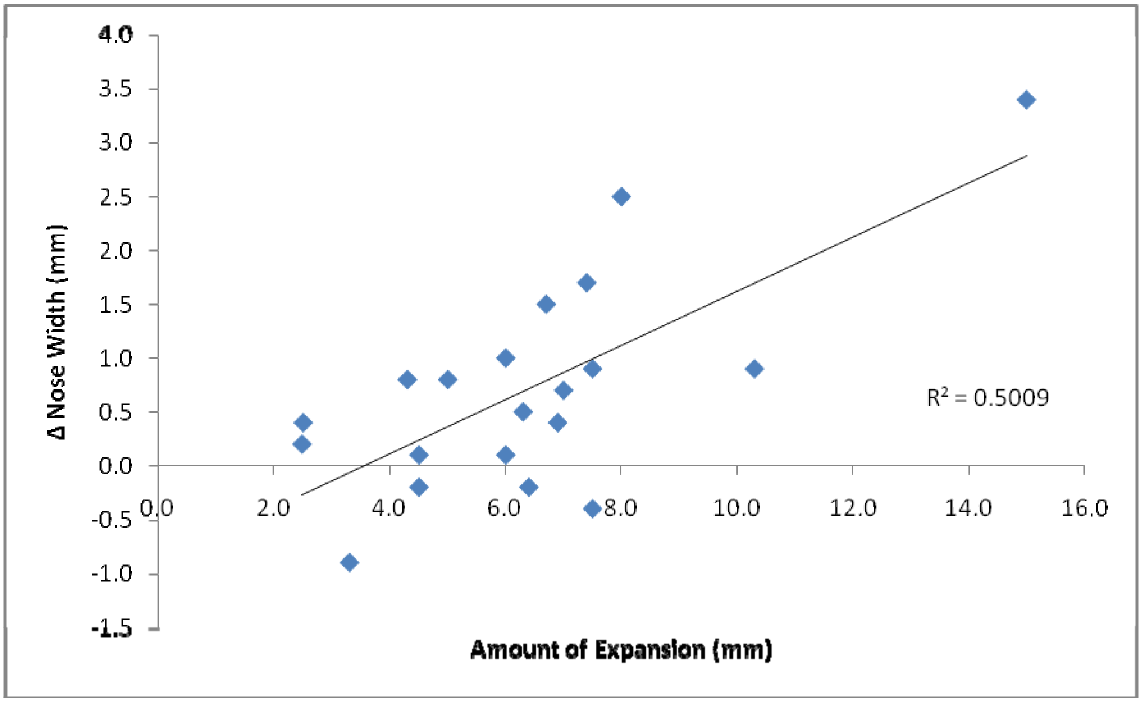
For the three measures demonstrating significant soft tissue increases from T_0 to T_1 in the RME group, regression analysis was used to determine the relationship between the changes observed and the amount of expansion performed. These relationships are shown graphically for intercanthal distance, nose width, and intercommissural width in Figures 4-6.



$P = 0.0013$.

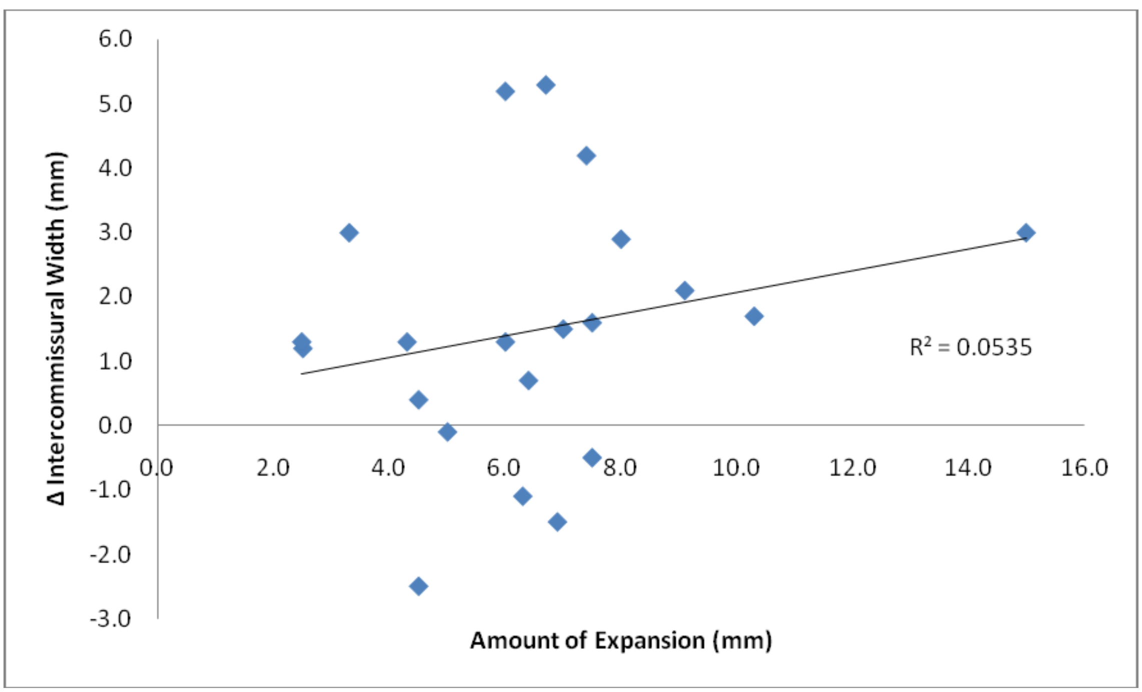
Figure 4. Change in intercanthal width as a function of amount of expansion

The amount of expansion explained 42.8% of the observed increase in intercanthal distance ($P = 0.0013$), 50.0% of the observed increase in nose width ($P = 0.0003$), and was not significantly related to the variability seen in intercommissural width changes ($P = 0.3154$).



P = 0.0003.

Figure 5. Change in nose width as a function of amount of expansion



P = 0.3154.

Figure 6. Change in intercommissural width as a function of amount of expansion

Discussion

The present study evaluated immediate changes observed in the facial soft tissues as a result of rapid maxillary expansion (RME). Measurements made using three-dimensional digital photogrammetric images before and after RME treatment were compared. Increases in intercanthal width, the width of the nose, and intercommissural width in patients with RME were significant, but only the change in intercommissural width remained significant when the RME and control groups were compared.

Increases in intercanthal width and nose width were significantly correlated with the amount of expansion performed, demonstrating that the amount of expansion achieved is predictive of the change in these facial soft tissues. The increase in intercommissural width, however, was not found to be significantly correlated with the amount of expansion. This may be because of the role that the muscles of facial expression play in positioning of the labial commissures,[34] while the soft tissues of the nose and, especially, those surrounding the eyes are more directly influenced by changes in the underlying skeleton.

Columella width did not change significantly with RME treatment in this study. Columella width was the only transverse feature for which no significant change occurred. A change in columella width may follow after a greater period of time during which the soft tissues remodel in response to the change in the underlying skeletal structures. However, as this study evaluated only immediate changes, no such changes were observed.

That intercanthal distance increased due to RME was in agreement with results previously reported, with one study[31] finding a greater increase and another[30] finding a smaller increase. Similarly, a mean increase in nose width was observed. Previous studies[30-32] reported larger changes but this may have been due to more consistently greater amounts of expansion performed in those patient samples. The mean increase in intercommissural width found in this study was in close agreement with the results of a recent study.[31] In agreement with a meta-analysis of immediate skeletal and dental changes with RME,[24] the present study suggests that potentially clinically relevant transverse increases in the facial soft tissues can result from RME treatment, but are less likely in the sagittal or vertical dimensions.

In future studies, it would be appropriate to limit the sample to patients with greater than a minimal level of expansion, use a larger number of patients, and evaluate only those soft tissue characteristics that are likely to change significantly. Including patients with small amounts of expansion (as low as 2.5 mm), in the current study, may have minimized the average changes observed. As soft tissue changes are expected to be smaller in magnitude that the associated hard tissue movements, it is possible that small amounts of expansion would result in little or no measurable change in the overlying soft tissues. As shown by the results of this study, increased expansion is likely to result in more pronounced changes in soft tissues that are closely associated with the underlying skeleton. Previous studies have reported significant soft tissue transverse increases, but changes in the vertical or sagittal dimensions have been inconsistent. Ongoing studies should focus on soft tissue features in which significant changes are anticipated.

This study focused on the immediate soft-tissue effects of RME. Future studies with an increased number of patients should evaluate the differences in soft-tissue effects of RME related to age, sex, and racial origin. In order to maximize skeletal rather than dental changes, it has been recommended that expansion be completed prior to peak growth velocity.[25] Consequently, greater soft tissue changes are more likely to be seen in less skeletally mature patients. Due to the relapse potential of maxillary expansion, future studies should also evaluate the long-term soft-tissue effects of RME to see if significant changes observed immediately after expansion are still evident at the end of orthodontic treatment or after growth is completed.

RME causes changes in the facial hard tissues that affect the balance of the facial soft tissues and have an impact on facial esthetics. In this sample, the average changes were small and, for most patients, would not be significant clinically or esthetically. However, an orthodontist who understands the skeletal, dental, and soft-tissue effects of rapid maxillary expansion can better anticipate the final esthetic result and plan appropriately to achieve individualized patient treatment goals.

Conclusions

1. 3D photographic images offer an appropriate and non-invasive technique to record and evaluate changes in facial soft tissues. 3dMD images are accurate and can be reliably measured.

2. Significant increases in intercanthal width, the width of the nose, and intercommissural width were observed in patients with RME, but only the increase in intercommissural width was significant when compared to a control group.

3. In patients undergoing RME treatment, increases in nose width and intercommissural width were significantly associated with the amount of expansion performed.

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Vita

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