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Skeletal and dentoalveolar changes in the maxillary bone morphology using two-arm maxillary expander

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Abstract

Objective: The purpose of this study was to evaluate the dental and skeletal changes in the maxillary bone morphology, produced by two-arm rapid palatal expansion appliances. *Patients and Methods*: The study included 22 girls with an average age of 11.9 years treated with RPE appliances at the Department of Pedodontics and Orthodontics, Faculty of Dentistry, Timisoara, Romania. We evaluated the changes on study casts, using an optical 3D scanner – Activity 101 (SmartOptics) and also on radiographs. The level of statistical significance was set by comparing the changes between pre and post treatment values. We also used the Pearson's correlation coefficient (r) to measure the strength of the association between the recorded measurements. The correlations were significant at $p<0.05$. *Results*: Significant changes were found in intermolar width change, interpremolar width change, molar tipping and alveolar tipping. Less significant changes were found in molar rotation and palatal depth change. After rapid maxillary expansion, five of the 21 correlations were found to be statistically significant. Positive medium correlations were found between intermolar width change and alveolar tipping and between interpremolar width change and alveolar tipping. A negative medium correlation was found between palatal depth change and alveolar tipping. Weak, but statistically significant correlations were found between intermolar width change and interpremolar width change and between intermolar width change and palatal depth change. No statistically significant correlation was found between the other variables. *Conclusions*: This type of maxillary expander is capable of expanding the maxillary dentition and alveolar process, opening the midpalatal suture and changing the maxillary bone morphology. The most remarkable changes occurred in the transverse plane. Future research is required to evaluate a larger group of patients.

Keywords: morphology, maxillary bone, two-arm expander, skeletal changes, dentoalveolar changes, rapid maxillary expansion.

⊟ Introduction

The human hard palate is formed by the palatine processes of the maxilla and the horizontal plates of the palatine bones. All the components of the bony palate are joined together by the median and transverse palatine sutures. Arch dimensions change with growth; therefore, it is necessary to distinguish between the changes induced by appliance therapy and those that occur from natural growth [1]. Rapid palatal expansion has been a clinically accepted technique used by orthodontists for over 100 years. Its primary goal is to maximize orthopedic and minimize orthodontic tooth movement [2]. Rapid maxillary expansion can be defined as the expansion of the maxilla achieved through intermittent heavy forces that are able to separate the midpalatal suture at a rate of 0.2–0.5 mm/day. The skeletal expansion involves separating the maxillary halves at the midpalatal suture and dental expansion results from buccal tipping of the maxillary posterior teeth [3–5]. The proportion of skeletal and dental movement is dependent on patient's age, type of appliance, amount of force applied and rate of expansion [6–8]. Expansion appliances can be classified

as rapid or slow [9]. The interest in rapid maxillary expansion (RME) has increased markedly during the past decades; the correction of transverse discrepancies and the gain in arch perimeter as a potential non-extraction technique appear to be the most important reasons [10].

Rapid Palatal Expansion (RPE) has become a classical technique yielding a morphological expansion similar to that obtained with bone distraction. This non-surgical approach based on the application of orthodontic bands takes advantage of the incomplete closure of the facial sutures in children, especially the midpalatal suture, which opens under the pressure generated by the appliance [11]. Historically, this was best accomplished by including four teeth in the appliance. However, including more teeth makes construction and insertion more difficult. The appliance is also less comfortable for patients and hinders oral hygiene [2]. The morphological expansion assures the maxillary width correction, even when only two bands are used. The etiology is often determined with difficulty, but, interestingly, mouth breathing is associated in a large number of patients [11]. Spectacular effects

regarding dento-facial development can be observed, including the open bite closure and the reorientation of mandibular growth [11]. Stability is particularly dependent on the success of the functional correction. Early treatment (7–8-year-old) provides excellent results. RPE can be performed at an older age (13–14-year-old) but with less spectacular influence on growth [11].

RPE is recommended by [12, 13] for:

▪ Increasing maxillary arch width and length;

▪ Correction of unilateral or bilateral crossbite;

▪ Increasing the apical base width to facilitate buccal root torque of the posterior teeth;

▪ Correction of the class III midface deficiency;

▪ Reducing nasal resistance to airflow and providing a normal breathing pattern.

The RPE appliance design should be determined accordingly to the biomechanical requirements of the patient [14]. There is a considerable resistance to sutural separation; therefore, the rigidity of the expansion appliance is an important factor to obtaining nearly parallel opening of the suture, minimizing the buccal tipping of the posterior teeth [14]. Many different RPE appliances designs have been developed to eliminate the tipping and the extrusion of the posterior segments [14].

⯐ Patients and Methods

The study included 22 patients treated with RPE appliances at the Department of Pedodontics and Orthodontics, Faculty of Dentistry, University of Medicine and Pharmacy "Victor Babeş", Timişoara. The criteria for patient selection included patients in the later mixed dentition or early permanent dentition who required rapid maxillary expansion as part of their orthodontic treatment. All patients presented with space deficit in the anterior region, not allowing the proper alignment of the right canine. The adequate clinical crown length provided sufficient anchorage for the RPE appliance. The RPE group was comprised of 22 girls with an average age of 11.9 years.

Appliance and activation

We used a fixed two-arm maxillary expander, design by Veltri N in 2001 [6]. 4.5 kg of force was applied on each tooth, instead of 2.5 kg of force per tooth used in four-arm maxillary expanders. When referring to the exploitation of the hyalinized area, Veltri N suggested that in order to avoid the dispersion of the force generated by the screw activation, the force should be concentrated and transmitted to the anchorage units only through two arms, instead of four [6]. Expansion was carried out by the means of a midpalatal jackscrew. The patients (or the parents) were instructed to activate the jackscrew three times per day, 1/4 turn (approx. 0.25 mm/turn), once in the morning, once at lunch time and once in the evening. The screw was 13 mm in length and was activated for a period of 12 days. Overexpansion was considered adequate to compensate the relapse after expansion. The maxillary lingual cusp of the permanent first molar must be in contact with the mandibular buccal cusp of the permanent first molar. The opening of the midpalatal suture was confirmed both clinically (the formation of a median diastema) and radiologically (occlusal radiographs and frontal teleradiographs). The appliance was left in place for approximately five months.

Study cast analysis

The pre and post-expansion study casts of the patients included in this paper were analyzed using an optical 3D scanner – Activity 101 (SmartOptics). The cast model is fixed with a special model fixture. At first, a prescan is carried out and a scan definition is made by the user. The 3D sensor inside Activity 101 is based on white-light projection of fringes. The mechanical system will automatically perform measurements under different viewing angles of the object relative to the 3D sensor. The measurement process involves illuminating the surface of the measured object with a fringe pattern, while a camera observes the illuminated object from the side. The surface shape of the object is calculated according to the resulting displacement of the fringes. The measurements are merged by the specialized scanner software.

The results are available in STL format and can be used as an input source for CAD software. The 3D meshes provided by the STL files were analyzed using Magics v.12.01 (Materialise) and MeshLab v.1.0.3a. The software allowed us to rotate the 3D models in different directions around the three axes (X, Y, Z).

We analyzed several metric and angular measurements:

▪ The intermolar width before and after expansion;

▪ The interpremolar width before and after expansion;

▪ The molar rotation before and after expansion;

▪ The molar tipping before and after expansion;

▪ The alveolar tipping before and after expansion;

▪ The palatal depth before and after expansion.

The intermolar width

The intermolar width was measured on the 3D virtual model as the distance between the distobuccal cusps of the permanent maxillary first molars (Figure 1). The change in intermolar width was the difference between the post-treatment intermolar width (m') and the pre-treatment intermolar width (m).

The interpremolar width

The interpremolar width was measured on the 3D virtual model as the distance between the buccal cusps of the maxillary first premolars (Figure 1). The change in interpremolar width was the difference between the post-treatment interpremolar width (pm') and the pre-treatment interpremolar width (pm).
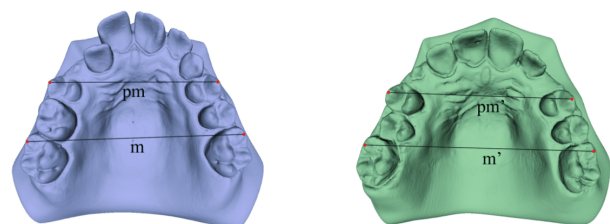

Figure 1 – *The changes in intermolar and inter-premolar widths (pm' minus pm; m' minus m).*

The molar rotation

The molar rotation was measured on the 3D virtual model using two coplanar lines, each intersecting the distobuccal and mesiolingual cusps of the permanent first molars on each side. The two lines define a plane parallel to the occlusal plane (Figure 2). The angle formed between these two lines on the post-treatment cast ($α'$) minus the angle formed on the pretreatment cast ($α$) represented the change in molar rotation. A positive value of the difference indicates a mesiobuccal rotation and a negative value indicates a mesiolingual rotation.
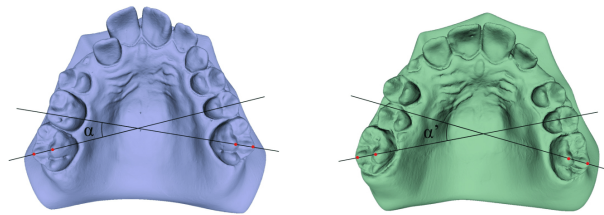

Figure 2 – *The change in molar rotation (α' minus α).*

The molar tipping

The molar tipping was measured on the 3D virtual model using two coplanar lines, each parallel to the occlusal surface (or tangent to the distobuccal and mesiolingual cusps) of the permanent first molars on each side. The two lines define a plane perpendicular to the occlusal plane (Figure 3). The angle formed between these two lines on the post-treatment cast ($β'$) minus the angle formed on the pretreatment cast ($β$) represented the change in molar tipping.
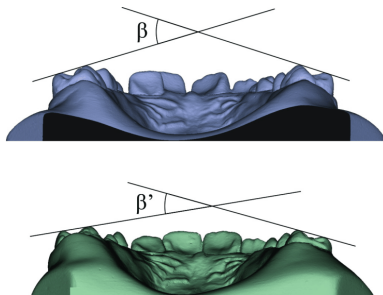

Figure 3 – *The change in molar tipping (β' minus β).*

The maxillary alveolar tipping

The maxillary alveolar tipping was measured by intersecting the 3D virtual model with a plane perpendicular on the mediosagittal plane of the model and positioned approximately across the mesiolingual cusps of the permanent first molars, for reproducible alignment. The measurements were made on the resulting 2D cross-section. A line was drawn from the midpoint of the curve of the junction of the alveolar process and tooth to the midpoint of the curve of the junction of the alveolar process and palatal shelf (bilaterally, on both pre- and post-treatment cross-sections). The pre- and post-treatment cross-sections were then superimposed on the lines representing the left (L) alveolus (Figure 4). To assess the changes in maxillary alveolar tipping, we measured the angle in degrees ($δ$) formed between the lines on the right side (R).
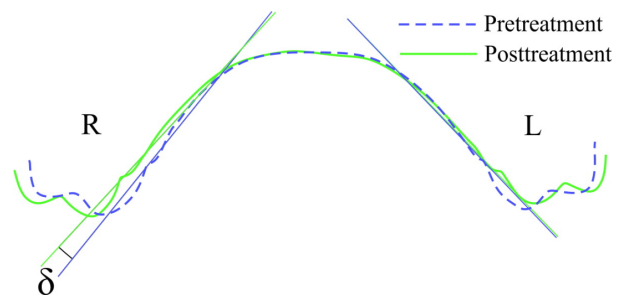

Figure 4 – *The construction of the lines representing the alveolar process. The change in maxillary alveolar tipping is represented by the δ angle. R – right; L – left.*

The palatal depth

The palatal depth was measured by intersecting the 3D virtual model with a plane perpendicular on the mediosagittal plane of the model and positioned approximately across the mesiolingual cusps of the permanent first molars, for reproducible alignment. Pre- and post-treatment measurements were made on the resulting 2D cross-sections by measuring the distance in millimeters between a horizontal line intersecting the tip of the mesiolingual cusps of the first molars and the mediosagittal point of the palate (Figure 5). To assess palatal depth changes, we recorded the difference between the post-treatment (d') and the pretreatment (d) palatal depth measurements.
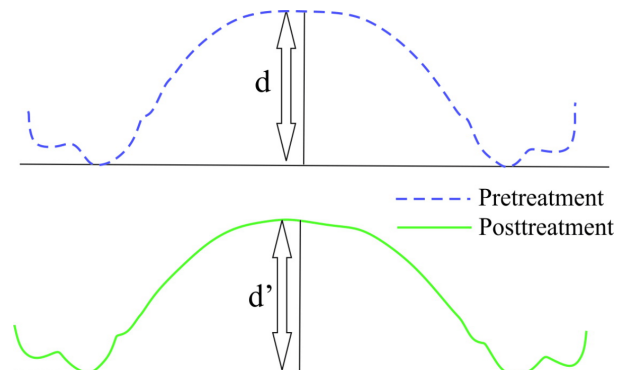

Figure 5 – *The change in palatal depth is the difference between the post-treatment (d') and the pretreatment (d) palatal depth.*

Statistical methods used

The arithmetic mean value and standard deviation were calculated for the complete series of 14 subjects, with emphasis on the following measurements:
- Intermolar width change [mm] – IWC;
- Interpremolar width change [mm] – IPMWC;
- Molar rotation [deg.] – MR;
- Palatal depth [mm] – PDC;
- Molar tipping [deg.] – MT;
- Alveolar tipping [deg.] – AT.

The level of significance was set by comparing the changes between pre and post treatment values. We also used the Pearson's correlation coefficient (r) to measure the strength of the association between intermolar width change, interpremolar width change, molar rotation, palatal depth, molar tipping and alveolar tipping. The correlations were significant at $p≤0.05$.

Radiographic evaluation

Maxillary occlusal radiographs and frontal tele-radiographs were taken before treatment and 12 days after rapid maxillary expansion. Two orthodontic specialists analyzed the patients' pretreatment and post-treatment radiographs for evidence of midpalatal suture opening.

⊟ Results

Table 1 shows the descriptive statistics of the changes that occurred in the RPE group: the arithmetic mean, the standard deviation and the minimum and maximum-recorded values. Significant changes were found in intermolar width change (4.23 mm), inter-premolar width change (3.43 mm), molar tipping (6.59^{0}) and alveolar tipping (4.14^{0}). Less significant changes were found in molar rotation (1.71^{0}) and palatal depth change (0.33 mm).

Table 1 – *Descriptive statistics of the changes that occurred in the RPE group*

	N	Minimum	Maximum	Mean	Std. deviation
IMWC [mm]	22	2.85	7.02	4.2327*	1.19451
IPMWC [mm]	22	2.82	4.10	3.4350*	0.46843
MR [deg.]	22	-1.80	4.67	1.7164	1.51823
PDC [mm]	22	-1.27	2.00	0.3314	0.96077
MT [deg.]	22	1.99	9.01	6.5932*	2.45647
AT [deg.]	22	0.00	7.02	4.1400*	1.98215

* – Significant changes from pre- to post-treatment; IMWC – Inter-molar width change; IPMWC – Interpremolar width change; MR – Molar rotation; PDC – Palatal depth change; MT – Molar tipping; AT – Alveolar tipping.

Table 2 shows the Pearson's matrix of correlation coefficients (*r*) for intermolar width change (IMWC), interpremolar width change (IPMWC), molar rotation (MR), palatal depth change (PDC), molar tipping (MT) and alveolar tipping (AT). After rapid maxillary expansion, five of the 21 possible correlations were found to be statistically significant. Positive medium correlations ($r{\geq}0.5$) were found between IMWC and AT (r=0.762, Sig.$\leq$0.01) and between IPMWC and AT (r=0.500, Sig.$\leq$0.05). A negative medium correlation ($r{\leq}$-0.5) was found between PDC and AT (r=-0.502). Weak, but statistically significant correlations (Sig.$\leq$0.05) were found between IMWC and IPMWC (r=0.477) and between IMWC and PDC (r=-0.427). No statistically significant correlations were found between the other variables.

Table 2 – *Pearson's matrix of correlation coefficients for changes in the RPE group*

Pearson correlation Sig. (two-tailed)	IMWC	IPMWC	MR	PDC	MT	AT
IMWC	1.000					
IPMWC	0.477*	1.000				
	0.025					

Pearson correlation Sig. (two-tailed)	IMWC	IPMWC	MR	PDC	MT	AT
MR	0.006	0.093	1.000			
	0.977	0.681				
PDC	-0.427*	-0.294	0.237	1.000		
	0.048	0.183	0.288			
MT	-0.083	0.204	0.144	0.292	1.000	
	0.712	0.363	0.523	0.187		
AT	0.762**	0.500*	-0.149	-0.502*	0.088	1.000
	0.000	0.018	0.509	0.017	0.698	

* Correlation is significant at the 0.05 level (two-tailed); ** Correlation is significant at the 0.01 level (two-tailed); IMWC – Intermolar width change; IPMWC – Interpremolar width change; MR – Molar rotation; PDC – Palatal depth change; MT – Molar tipping; AT – Alveolar tipping.

Table 3 shows the model summary of the stepwise multiple regression analysis for the RPE group. Alveolar tipping (AT) was set as dependent variable. The only predictor that met the criteria for inclusion in the regression model ($p{\leq}0.05$) was the intermolar width change (IMWC). 58.1% of the variance in alveolar tipping can be predicted by the intermolar width change. In Table 4, the ANOVA test demonstrates that the regression model fits the data very well (Sig.=0.000).

Table 3 – *Model summary of the stepwise multiple regression analysis for the RPE group*

Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.762[a]	0.581	0.560	1.31528

a – Predictors: (constant), IMWC; IMWC – Intermolar width change.

Table 4 – *ANOVA[b] test for the regression model*

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	47.908	1	47.908	27.693	0.000[a]
	Residual	34.599	20	1.730		
	Total	82.507	21			

a – Predictors: (constant), IMWC; b – Dependent variable: AT; IMWC – Intermolar width change; AT – Alveolar tipping.

Table 5 shows the coefficients of the stepwise multiple regression analysis for the RPE group. IMWC proved to be a very significant contributor to the model, with a very high level of significance (Sig.=0.000). The excluded variables that did not meet the criteria for inclusion in the regression model (p>0.05) are shown in Table 6.

Table 5 – *Stepwise multiple regression analysis coefficients[a] for the RPE group*

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	-1.212	1.055		-1.149	0.264
	IMWC	1.264	0.240	0.762	5.262	0.000

a – Dependent variable: AT; IMWC – Intermolar width change; AT – Alveolar tipping.

Table 6 – *Excluded variables[b] in the stepwise multiple regression analysis for the RPE group*

Model		Beta in	t	Sig.	Partial correlation	Collinearity statistics *Tolerance*
1	IPMWC	0.176[a]	1.072	0.297	0.239	0.772
	MR	-0.154[a]	-1.065	0.300	-0.237	1.000
	PDC	-0.216[a]	-1.377	0.185	-0.301	0.818
	MT	0.152[a]	1.051	0.306	0.234	0.993

a – Predictors in the model: (constant), IMWC; b – Dependent variable: AT; IPMWC – Interpremolar width change; MR – Molar rotation; PDC – Palatal depth change; MT – Molar tipping.

After RPE, the entire group of patients had frontal and occlusal radiographs available for evaluation. In all patients, the opening of the midpalatal suture was demonstrated, as indicated by the "yes" response (Table 6). On these radiographs, the separation was significantly larger in the anterior region opposed to the posterior one (Table 7).

Table 7 – *Radiographic evaluation for suture opening after RPE*

Orthodontic evaluator	No. of occlusal radiographs	Frontal radiographs	Suture opening after RPE
1	14	14	"yes"
2	14	14	"yes"

⊟ Discussion

The principle of sutural expansion through the application of orthopedic forces represents a method of effecting skeletal change in subjects with a transverse skeletal-palatal deficiency. The greatest increase in dimensions was found at the molar crowns, which may be expected to represent the sum of skeletal and dentoalveolar changes [15]. The principle, originally introduced by Goddard CL, in 1893 [16], and later developed by Haas AJ in 1961, 1965, and 1970 [17–19], has now become a standard treatment modality [15]. We were unable to make a solid comparison with similar studies in literature, because, to our knowledge and to this date, there were only a few studies published on this subject. Lamparski DG Jr *et al.* [2] published a study whose purpose was to determine the difference, if any, between midpalatal suture separation and dental expansion produced between 2-point and 4-point palatal expanders. According to Lamparski DG Jr *et al.* [2] there were slight differences in arch perimeter and midpalatal suture separation. The results of the study showed that the 2-point appliance produced similar effects on the midpalatal suture and the dentition, as did the 4-point appliance [2]. Because most orthodontic treatment whether it is in one or two phases, occur between 7 and 13 years of age, it is important for the clinician to take into consideration that intermolar and interpremolar widths significantly increase between 3 and 13 years of age, in both maxillary and mandibular arches. After the complete eruption of the permanent dentition, there was a slight decrease in dental arch widths, more significant in the intercanine widths than in the intermolar widths [8]. Most traditional palate expansion devices use bands for retention placed on the first premolars and first permanent molars. In the late mixed dentition, the first premolars are often not fully erupted and therefore are difficult to band [20]. In our study, only the first permanent molars were banded. The mechanism of rapid maxillary expansion occurs when the orthodontic forces are applied to the teeth and to the alveolar process and reach the required limit for tooth movement [20]. Applied pressure acts as an orthopedic force that opens the mid-palatal suture. The orthodontic appliance compresses the periodontal ligament and the alveolar process, changes the position of the anchor teeth and then, gradually opens the mid-palatal suture and separates the jaw bones [21]. The midpalatal suture opens wider and faster anteriorly, because the closure begins in the posterior area and there is a buttressing effect of the other maxillary structures in the posterior regions [20]. This results in increased transverse dimension. This effect is correlated to the strength of the suture, which increases with the individual's aging process. The force generated by the activation of the rapid maxillary expander is higher than the resistance of the suture and as a result, it separates not only the mid-palatal suture, but also all of the other maxillary sutures [7, 21, 22]. During expansion, the jawbone moves down and forward, rotating all its components in the horizontal and frontal planes. Some degree of relapse can be expected after palatal expansion because of the elasticity of the palatal soft tissue [15, 21, 22]. Molar tipping was also observed in nearly all subjects, confirming that the changes in the dentoalveolar component were considerable. The intermolar width change, because of the total amount of expansion produced by the two-arm expansion appliances was found to be significantly increased.

Several reasons could explain the difference between the total effect and the pure skeletal effect of RPE appliances [15]:

▪ The geometry of the induced changes on the maxillary bone. On frontal radiographs, it has been shown that maxillary expansion is by arcial movement. Anatomically, the dental arch on which the forces are applied represents the lowest part of the maxillary skeletal structure and the center of resistance of the maxilla is therefore at a much higher level.

▪ The flexibility of the appliance, as a result of the length of the arms from the screw to the orthodontic bands or acrylic, could significantly reduce force levels [23].

▪ Anatomical factors, such as the large surface area of the sutures surrounding the maxilla and the complex nature of the sutures.

⊟ Conclusions

This type of maxillary expander is capable of expanding the maxillary dentition and alveolar process, opening the midpalatal suture and changing the maxillary bone morphology.

The activation of the jackscrew at a rate of three times per day, 1/4 turn (approx. 0.25 mm/turn), 12 days determined the opening of the midpalatal suture. That was confirmed both clinically (the formation of a median diastema) and radiologically (occlusal radiographs and frontal teleradiographs).

Significant changes were found in intermolar width change, interpremolar width change, molar tipping and alveolar tipping.

In the RPE group, using Pearson's matrix of correlation, positive medium correlations were found between intermolar width change and alveolar tipping and between interpremolar width change and alveolar tipping. A negative medium correlation was found between palatal depth change and alveolar tipping.

The results of this study demonstrate a combination of a skeletal change accompanied by clear tipping of the dentoalveolar structures.

The rapid palatal expansion demonstrated significant dental and skeletal changes in all planes with the most remarkable changes occurring in the transverse plane.

Future research is required to evaluate a larger group of patients, in order to reach a higher level of statistical significance.

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