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Change in Dental Arch Parameters—Perimeter, Width and Length after Treatment with a Printed RME Appliance

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Abstract: One of the important parameters in orthodontics is the perimeter of the dental arch. Precise assessment is necessary in cases of maxillary constriction treated with a rapid maxillary expander (RME). The orthodontic software allows customization of the processes from diagnosis to manufacturing of the treatment device. The aim of the present study is to evaluate a relationship between the parameters of the dental arch—perimeter, width, and length—and to follow the changes during treatment. The study is based on the digital measurements of 3D models of 33 patients treated with a digitally planned and printed RME. In the results an increase of 3.99 mm in perimeter was achieved. The rest of the parameters were changed as follows: The width of the dental arch was increased in the premolar area by an average of 3.3 mm; in the area of the first molars, the increase was 4.41 mm; the length of the dental arch in the anterior segment was reduced by an average of 0.54 mm; and the whole length by 0.52 mm. Correlation between the studied variables was described by linear equations. In conclusion, rapid maxillary expansion is a reliable method for gaining predictable space in the dental arch.

Keywords: digital dentistry; 3D printing; intra oral scanner; rapid maxillary expansion

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1. Introduction

Rapid and slow expansion of the maxillary arch are classical methods for increasing the perimeter of the arch. Rapid expansion of the upper jaw is achieved by applying heavy forces that can split the palatal suture [1]. This expansion results from a combination of skeletal [2–10] expansion and dental (orthodontic) inclination and displacement. The development of CAD/CAM technology allowed the fabrication of customized RME appliances that are very accurate, with dental or hybrid skeletal–dental attachment and action [11–15].

The ratio between skeletal and dental effects depends on the type of expansion method used and the maturation of the palatal suture. The goal of rapid maxillary expansion is to achieve maximal skeletal effect with minimal tooth movement, allowing physiological adaptation of the suture during expansion. The expansion of the maxilla with an RME appliance is a reliable and proven method for increasing the maxillary width and managing the transversal dimensions. The pattern of opening the midpalatal suture has been deeply investigated and described in the literature [16,17]. An appropriate time must be chosen for treatment with the RME appliance—most adequate results are achieved before midpalatal suture ossification, and the cervical vertebral maturation (CVM) method for determining the craniofacial skeletal maturational stage of an individual is an effective tool for clinical decision [18,19]. The best skeletal effects are achieved when the RME appliance is used before the growth spur (stages 1 to 3 of the cervical vertebral maturation (CVM) method) [1,18,19].

The expansion achieved with RME has an additional effect on the surrounding structures. The nasal cavity and the entire upper jaw are influenced by widening the airways [20–26]. According to a systematic review, there was a statistically significant increase in oropharyngeal and nasopharyngeal dimensions and an improvement in airway patency in cases treated with

RME appliances [21]. Also, this type of therapy can eliminate obstructive sleep-breathing disorders and restore and enhance normal nasal airflow. Often, RME treatment also contributes to the correction of mouth breathing by changing the anatomical structures—the maxillary palatine process and the palatine bone, which form the roof of the oral cavity and the floor of the nasal cavity. By increasing the surface of these structures during expansion, the volume of the nasal cavity is increased, and the breathing process is affected [25,27–31]. Garrocho-Rangel, in a review, shows the increase in nasal and oropharyngeal space volumes and a decrease in airway resistance in growing children and adolescents that occur immediately after RME and at 3, 6, and 12 months follow-up [24]. This is due to the fact that more air is breathed in and out when the airways are wider and have an enlarged volume. The method is highly effective and favors mouth-breathing patients and patients diagnosed with sleep apnea [21,30,31]. The condition of sleep apnea is improved by relieving respiratory function. All of the described effects make the RME appliance a contemporary tool for treatment with clinical implications, which is the reason for many authors from different fields to continue with their investigations of the achieved results and effects.

Another consequence that has been observed is posterior rotation of the mandible after RME treatment, which has been described by Baccetti [32]. In a systematic review, Chhutani1 [33] also concluded that the application of RME in the maxilla leads to posterior mandibular rotation. The mandible is shifted downwards and backwards, which increases the lower facial height. Observations were made immediately after RME treatment and favor treatment of skeletal class III. In patients with skeletal class II, medialization of the mandible is observed 6 months and more after treatment with an RME appliance [34,35].

Cossellu [36] reported a spontaneous adaptation of the mandible after a change in the transversal dimension of the maxilla, which included a correction of the inclination of the teeth in both the lateral and frontal areas, which was also due to a change in the balance between the tongue and the buccinator muscles. Some rotations of the maxillary anterior teeth, corrections, counter-clockwise rotation, and medialization of the mandible are reported. Spontaneous correction of class III malocclusion has also been described by other authors [37–39].

One of the most important parameters in orthodontic diagnostics is the perimeter of the dental arch (PA). Many methods have been developed to measure it and predictions have been made about its expected normal values. The fastest and most accurate in modern orthodontic practice is its digital measurement on scanned models with specialized software [40–43]. For patients, the new digital methods in dental practice are interesting and well accepted and are associated with less discomfort due to their precision [44–62]. Many authors propose their own methods for digital measurement of the dental arch perimeter, dividing dental arch in segments and measurement of the individual parameters [63–68]. Other authors use well-known equations in geometry such as Ramanujian's [69,70] to calculate the perimeter of the dental arch accepting the condition that the form of the arch is elliptical [71,72].

The changes in the parameters of the arch—width and length—affect both the perimeter and its shape. A number of scientists, through software and analysis of parameter values, report the existence of a relationship between parameter values and the shape of the dental arch [73–75].

There is no standardized method for digital measurement of the dental arch perimeter, and many authors propose their own methodologies [62–64,66,76]. Based on the digital measurements made, dependencies between the parameters are derived, and a model for the prediction of perimeter is created, most often in the form of an equation [64,68,70,72,77–82].

The gained space in the dental arch perimeter, after treatment with the RME appliance, is highly important in borderline cases when the clinical decision is between extraction and non-extraction treatment.

Adkins [82] finds that the maxillary arch perimeter increases at a rate of approximately 0.7 mm for each millimeter change in first premolar width.

Berlocher [83] reports an increase in the dental arch perimeter with the same magnitude as the increase in maxillary width.

McNamara [84], in a long-term evaluation, examined the records of 112 patients treated with RME followed by fixed appliances and examined the changes in dental arch dimensions. The study is of high clinical importance and gives full information about all parameters of the dental arch.

Geran [85] examines the effects of rapid maxillary expansion in the early mixed dentition. He finds a 4 mm increase in maxillary dental arch perimeter and proves that the results are reliable and stable with time.

In the reviewed literature, a lot of authors investigated the outcomes and results with RME appliances, analyzing only the changes in the transversal dimension of the dental arch. There is a need for deeper research on the changes in the sagittal dimension of the maxilla and for exploration of whether there is a relationship between dental arch parameters such as dental arch perimeter, width, and length.

The aim of the present study is to evaluate the change in dental arch parameters—perimeter, width, and length—after treatment with a printed RME appliance. The investigation follows the dynamics of changes in all parameters from a period before treatment until the removal of the RME and explores the correlational connections between them.

2. Materials and Methods

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of KENIMUS, Approval Code: N° 2873. Approval Date: 4 May 2022.

The study is based on the results of digital measurements on 3D models of 33 patients (12 male and 21 female) treated by the team over the past two years with a digitally planned and printed expander. The number of patients included in the study is over 30, which is important for the statistical calculations included in the study's design.

For both males and females, the appropriate time for treatment is during mixed dentition and early permanent dentition (before and at the start of the peak of adolescent growth), and treatment efficacy is likely to vary between the sexes depending on growth activity. The bone growth period is conventionally determined in practice by the maturity of the cervical spine, and in cases of doubt, a CBCT examination of the maxilla is performed to determine the maturity of the sutures before orthodontic treatment is planned.

The mean age of the patients was 13.39 years. Twenty-six (78.8%) of the patients were in the period of permanent dentition formation, and 7 (21.2%) were in mixed dentition (Table 1).

Table 1. Distribution of the participants in the study—by gender, age, and type of dentition.

Variable	RME (n = 33)
Mean age ± SD (years)	13.39 ± 3.97
Gender—number (%)	
Males	12 (36.4)
Females	21 (63.6)
Dentition—number (%)	
Mixed	7 (21.2)
Permanent	26 (78.8)

The criteria used for the inclusion of patients in the study are:

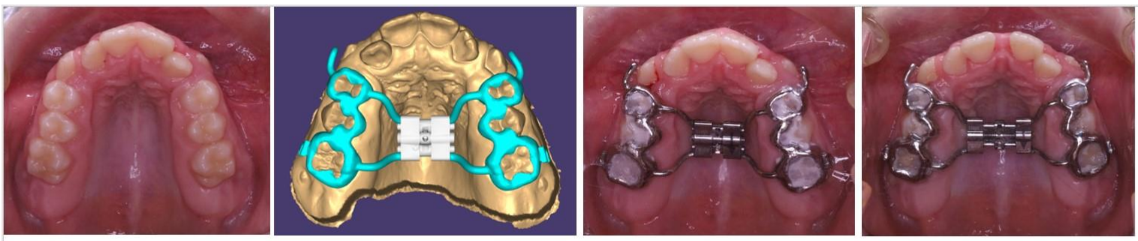
1. Complete documentation at each stage (initial phase, finished first treatment phase with RME, finished treatment and achieved satisfactory result, retention phase).
2. Informed consent, presented, discussed, and accepted treatment plan (non-extraction treatment) certified by the signature of the patient (or parent).
3. Strictly followed treatment protocol, without missed appointments for control.

4. Digital documentation before and after each stage and at the end of treatment (digital models without double images, all tooth surfaces visible, no missing areas in the scan).

The rapid maxillary expansion of all the patients is the initial phase (first phase) of main treatment, which includes active treatment with fixed techniques during the period of active growth and development in puberty.

Complete documentation is necessary for longitudinal study design and the assessment and evaluation of treatment results. Digital documentation before and after each stage is a powerful tool for accurate measurements. The STL digital models have not been influenced by any deformation over time. Strictly followed treatment protocols guarantee that the outcomes are due to treatment requirements and are not influenced by any patient's noncompliance. All the patients fills out the informed consent form in order to follow the protocols for good dental practice and to fulfils the ethical committee requirements.

Clinical protocol: The rapid maxillary expansion appliance used is individually planned and fabricated for each patient on a 3D model obtained after an intraoral scan. The design of the appliance is constructed so that the expansion screw is closer to the molars. The design of the appliance was made with Exocad software (Exocad DentalCAD 3.0 Galway) and was printed with CAM technology from Co–Cr alloy by laser sintering of the metal (Figure 1). The appliance was bonded to the distal teeth in the maxilla. The patient and accompanying parent are trained to activate the device. Activation takes place once a day at a fixed time—evening. The treatment clinical protocol includes 20–28 activations. The parents should turn the expansion screw per ¼ of its full rotation (0.25 mm per activation). It was done by the parents until optimal transverse contacts were achieved between the posterior upper and lower teeth. After the expansion, there was a 3-month retention period before the expander was removed. Follow-up appointments are scheduled once a month to monitor the results and follow the clinical protocol.



(**a**) (**b**) (**c**) (**d**)

Figure 1. Clinical protocol—(**a**) initial phase; (**b**) digital model of printed appliance; (**c**) adapted and fixed appliance; (**d**) state after completion of activation.

For the purposes of this investigation contemporary and reliable methods are used, which is possible through the new technologies that are incorporated into daily practice.

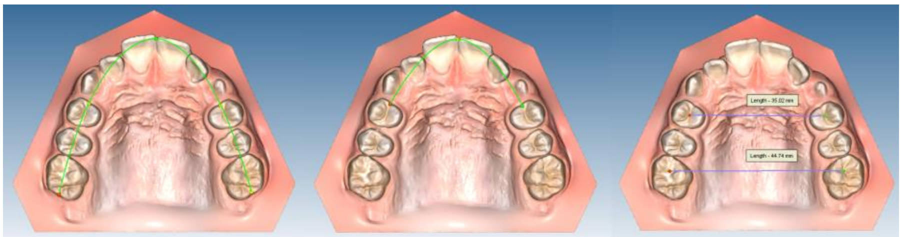
All patients were scanned with an intraoral scanner and 3D models were generated and stored in STL format. The intraoral scanner was calibrated, with calibration tool, every week to provide the accurate digital model. Scans were performed before starting treatment (phase 1), after completion of the expansion phase (phase 2) and at the end of orthodontic treatment (phase 3). After removal of the RME appliance (phase 2), the patients are photographed, and a control frontal cephalogram is performed.

The methodology is described in detail as follow:

Biometric protocol: The following parameters were measured on all digital models of all 33 participants in the study:

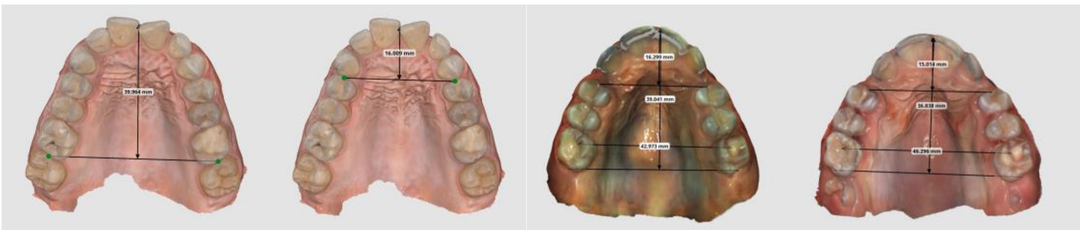
- PA—the perimeter of the upper dental arch (twelve teeth—from the right first permanent molar to the left first permanent molar). The measurement is made from a point positioned in the middle of the distal side of the first molar. The orthodontic software itself positions the arch on the alveolar crest and determines its shape, based on the information from the initial and final points and three additional points—two placed in the middle of the medial side of the first premolar and one located at the contact point between the central incisors. In the mixed dentition cases, the middle of the medial side of the first deciduous molar was used (Figure 2);

- aP—the perimeter of the anterior segment—from the distal surface of the canine to the distal surface of the opposite canine (deciduous or permanent)—six teeth measured with orthodontic software (Figure 2); when canines are not present, measurements are taken from the medial surface of the first premolars or first deciduous molars.
- PP—width of maxilla in the area of the premolars. The two points are in the middle of the central fissure, under the mediovestibular tubercul. In mixed dentition, when first premolars are not fully erupted, this parameter is not measurable (Figure 2);
- MM—width of maxilla in the area of the molars (Figure 2);
- L—length of the maxillary dental arch, measured from a point on the vestibular surface of the central incisors to a line connecting points in the middle of the distal surface of the first permanent molar (Figure 3);
- l—length of the anterior segment of the dental arch, measured from a point on the vestibular surface of the central incisors to a line connecting points in the middle of the medial surface of the first premolar (Figure 3);
- w—the width of the anterior segment—a straight line connecting points in the middle of the medial surface of the first premolar (Figure 3).



(**a**) (**b**) (**c**)

Figure 2. Measurements done with software: (**a**) Perimeter of the dental arch (line in green color – from distal surface of 16 to distal surface of 26); (**b**) perimeter of the anterior section of the dental arch (line in green color from distal surface of 14 to distal surface of 24); (**c**) measurement of the maxillary transversal dimension in the area of premolars and molars (line blue color between 14 and 24 and 16 and 26).



(**a**) (**b**)

Figure 3. (**a**) Measurement of the length of the dental arch—L (black arrow present where the measurement has been made); the anterior length of the dental arch—l (black arrow present where the measurement has been made); (**b**) measurement of w—width of the anterior segment of the dental arch (aP). The arrows shows where exactly the measurement has been made by software.

The described measurements were performed identically during the treatment phases: (1) before treatment; (2) at the end of the first phase (RME); and (3) at the end of treatment with brackets. In order to differentiate the same type of measurement in the different stages, the following designations are applied: the numerical sign after the letters indicates the phase: 1—before treatment (PA1, aP1, PP1, MM1, L1, l1); 2—the phase after the first appliance (PA2, aP2, PP2, MM2, L2, l2); 3—the end of treatment (PA3, aP3, PP3, MM3, L3, l3).

All the measurements were made by the same operator using the same methodology. This guarantees the precision and accuracy of the collected data. The 693 measurements were made twice on the described parameters.

Data were processed with the statistical packages IBM SPSS Statistics 25.0. and MedCalc Version 19.6.3. Microsoft Office Excel 2021 was used for the figures. A level of significance of $p < 0.05$ was accepted, at which point the null hypothesis was rejected.

- Descriptive analysis was used, and the frequency distribution of the considered signs is presented in tabular form.
- Graphical analysis was used to visualize the obtained results.
- Correlation analysis was carried out to check hypotheses about the presence of the relationship between quantitative characteristics.
- Shapiro–Wilk non-parametric tests were carried out to check the distribution for normality.
- Student's t-test was carried out to test hypotheses about the difference between the arithmetic means of two independent samples.
- Non-parametric Mann–Whitney U test—for testing hypotheses of difference between two independent samples.
- Non-parametric Wilcoxon test—for testing hypotheses of the differences between two dependent samples.
- Single-factor linear regression analysis was applied to determine the parameters of the equation of linear dependence between two quantitative characteristics.

3. Results

3.1. Changes in Dental Arch Perimeter

The perimeter of the dental arch after rapid maxillary expansion increased on average by 3.99 mm (Table 2). The perimeter of the anterior section increased by an average of 2.29 mm. The parameters that decrease are the length of the dental arch, with an average reduction of 0.54 mm for the anterior section, and a reduction of 0.52 mm for the entire dental arch length. The width of the dental arch increased on average by 4.41 mm in the molar area and by 3.3 mm in the premolar area.

Table 2. Reported changes in parameters of the dental arch during the treatment phase with RME.

Group	PA2-PA1	aP2-aP1	l2-l1	L2-L1	MM2-MM1	PP2-PP1
RME Average value	+3.99	+2.29	−0.54	−0.52	+4.41	+3.3
Std.Deviation	2.841	1.792	0.773	1.180	1.632	1.178

3.2. Correlation Analysis

Correlation analysis was performed between the parameters L1, L2, l1, l2, MM1, MM2, PP1, and PP2. The results are presented in Table 3.

Table 3. Correlation analysis between variables L1, L2, l1, l2, MM1, MM2, PP1, and PP2 in the RME appliance group.

Variables	L2	l1	l2	MM1	MM2	PP1	PP2
L1	0.860 ***	0.739 ***	0.635 ***	0.055	0.108	−0.092	0.238
L2		0.701 ***	0.765 ***	−0.056	−0.054	−0.083	0.280
l1			0.907 ***	0.299	0.179	0.181	0.243
l2				0.215	0.014	0.082	0.143
MM1					0.736 ***	0.293	0.304
MM2						0.261	0.506 **
PP1							0.836 ***

—$p < 0.01$; *—$p < 0.001$.

It can be seen from Table 3 that:

- All statistically reliable correlations are positive;
- L1 correlates strongly with L2, l1, and with l2;
- L2 correlates very strongly with l1 and l2;
- l1 correlates very strongly with l2;
- MM1 correlates strongly with MM2;
- PP1 correlates strongly only with PP2;
- MM2 correlates strongly with PP2.

The results of the correlation analysis between the variables MM2-MM1, PP2-PP, L2-L1, l2-l1, aP2-aP1 and PA2-PA1 in the studied group of patients, proved that (Table 4):

- The change in width MM2-MM1—correlates positively and strongly with PP2-PP1, aP2-aP1 and PA2-PA1;
- PP2-PP1 correlates with aP2-aP1 positively and strongly, and with PA2-PA1. PP2-PP1 correlates with l2-l1 and L2-L1—negatively;
- L2-L1 correlates only with l2-l1—positively and strongly;
- l2-l1 correlates with aP2-aP1 positively and moderately;
- aP2-aP1 correlates with PA2-PA1 positively and strongly.

Table 4. Correlation analysis between variables MM2-MM1, PP2-PP1, L2-L1, l2-l1, aP2-aP1 and PA2-PA1 in the RME device group.

Group	Variables	PP2-PP1	L2-L1	l2-l1	aP2-aP1	PA2-PA1
RME appliance	MM2-MM	0.749 ***	−0.051	−0.098	0.662 ***	0.683 ***
	PP2-PP		−0.023	−0.050	0.672 ***	0.752 ***
	L2-L1			0.714 ***	0.337	0.157
	l2-l1				0.351 *	0.195
	aP2-aP1					0.829 ***

*—$p < 0.05$; ***—$p < 0.001$.

All relationships established so far, as well as the results of the correlation analysis, show that there is a high degree of positive correlation between the variables PP2-PP1 and MM2-MM1 (Table 5). MM2-MM1 correlates significantly with PP2-PP1 and with PA2-PA1, which allows us to look for the presence of a linear regression model and evaluate the average statistical change in the dependent variables from MM2-MM1. A similar correlational relationship was also sought between PP2-PP1 and PA2-PA1. The established relationship is presented by mathematical equations and illustrated with a scatter diagram.

Table 5. Coefficients between variables MM2-MM1, PP2-PP1, aP2-aP1, and PA2-PA1 in the RME device group, obtained by linear regression analysis.

Group	Variables	PP2-PP1	aP2-aP1	PA2-PA1
Treated with RME	MM2-MM1	0.719 ***	0.726 ***	0.932 ***
	PP2-PP1			0.960 ***

***—$p < 0.001$.

3.3. Regression Analysis

The regression analysis (curve estimation) found that there is a significant ($p < 0.001$) linear relationship between PP2-PP1 and MM2-MM1, which can be presented by the following equation:

$$\text{PP2-PP1} = 0.719 \times (\text{MM2-MM1}) + 0.900$$

The coefficient 0.719 in front of the independent variable (MM2-MM1) points out that when it is increased by one unit (in this case, 1 mm), the dependent variable PP2-PP1 increases on average by about 0.7 mm.

The linear regression model between PP2-PP1 and MM2-MM1 is presented graphically in Figure 4.

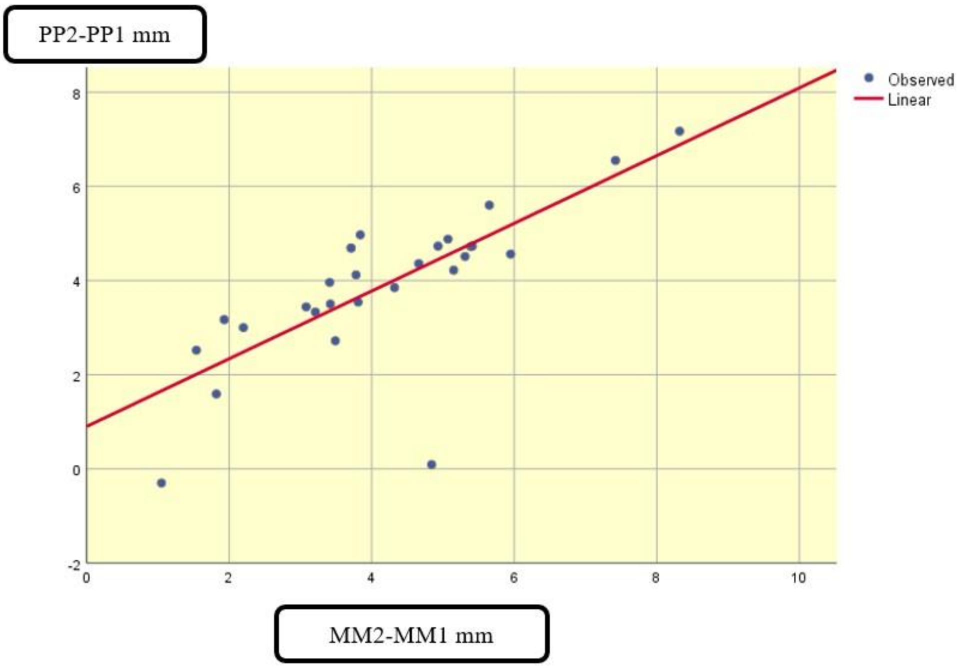


Figure 4. Scatter plot and linear regression model between PP2-PP1 and MM2-MM1. ($R^2 = 0.561$).

To follow the dynamics of the change of PA2-PA1 as a consequence of the change of MM2-MM1, a regression equation with statistical reliability ($p < 0.001$) was derived. This is shown graphically on Figure 5:

$$\text{PA2-PA1} = 0.932 \times (\text{MM2-MM}) - 0.289$$

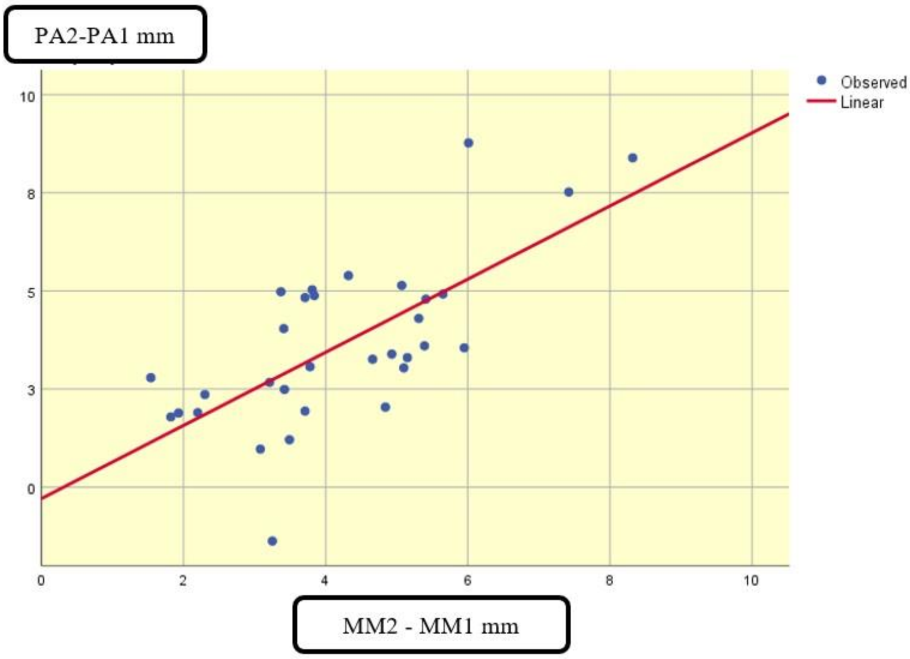


Figure 5. Scatter plot and linear regression model between PA2-PA1 and MM2-MM1. ($R^2 = 0.474$).

The coefficient 0.932 before the variable (MM2-MM1) means that when it increases by one unit (in this case, 1 mm), the dependent variable PA2-PA1 increases on average by about 0.9 mm.

To follow the dynamics of the change of PA2-PA1 and PP2-PP1, a regression equation with statistical reliability ($p < 0.001$) was derived. This is expressed by the equation:

$$\text{PA2-PA1} = 0.960 \times (\text{PP2-PP1}) - 0.212$$

The coefficient 0.960 in front of the independent variable (PP2-PP1) means that when it increases by one of its measurement units (in this case, 1 mm), the dependent variable PA2-PA1 increases on average by about 1.0 mm. A scatterplot and linear regression model between PA2-PA1 and PP2-PP1 are shown in Figure 6.

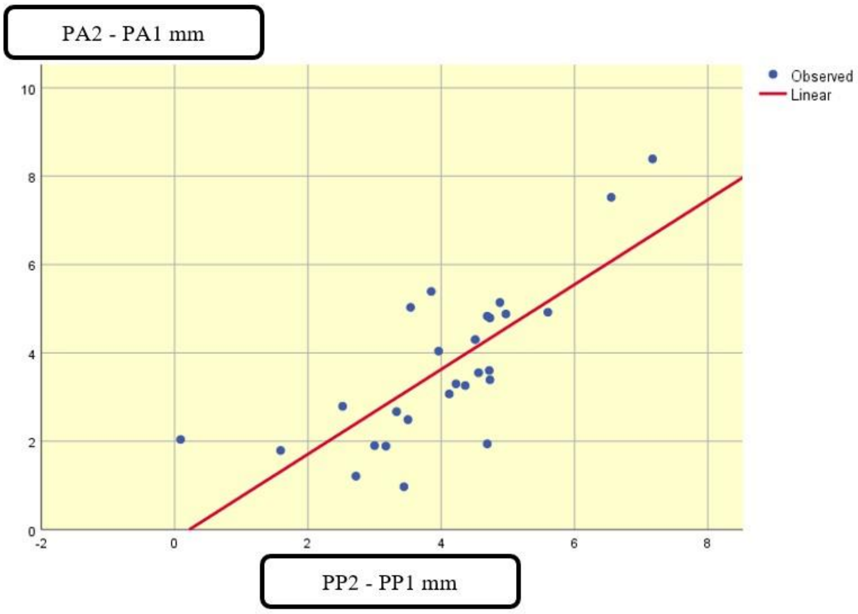


Figure 6. Scatter plot and linear regression model between PA2-PA1 and PP2-PP1. ($R^2 = 0.576$).

4. Discussion

As a result of maxillary expansion with an RME appliance, the increase in the perimeter of the dental arch was on average 3.99 mm, with a standard deviation of 2.84. The increase in maxillary width achieved with the RME appliance is 4.41 mm, with a standard deviation of 1.63 mm in the molar area. The result correlates with the results obtained by Woowon Jang values [86], as well as with those of other researchers [87–91]. Inchingolo, in a scoping review, reports an increase in the width of upper permanent molars by 5.4 mm through RME [89]. Colino-Gallardo found an intermolar width increase of 5.21 ± 1.55 mm [90]. Most of the research in the literature explores only the changes in transversal dimensions achieved with RME appliances.

McNamara [84] observed in a long-term evaluation the changes in dental arch dimensions in 112 patients treated with RME appliances. In its research, the methodology is described in detail and examines all the parameters of the dental arch. After the active phase with the RME appliance, the dental arch perimeter is increased by 7.5 mm. At the same time, the intermolar width increases by 4 mm. In a long-term stability evaluation, the increase of 6 mm in the dental arch perimeter in the upper jaw is proven to be stable.

In contemporary orthodontics, as described in the present study, the phase of the creation of physical casts and their transfer through digitalization preceding the stage of measurements is eliminated by intraoral scanning. There is no image deformation, and the data is more accurate and precise. The chance of human error decreases, and the variations due to deformation of the physical model, such as material modification by time—constriction or impaired physical integrity—are eliminated. The measurements can be made almost immediately after intraoral scanning, which takes a few minutes of clinical time. The treatment goals may be visualized and presented to the patients before the start of the treatment. That gives more accessible information. It is really helpful in cases where there is more than a single option for orthodontic treatment. After visualization of treatment objectives (VTO), the patients are more motivated, and the compliance level increases. The patients really give their informed consent and know what the clinician wants to achieve at the end of the treatment. That is helpful for the right attitude about treatment outcomes.

In the McNamara [84] study, the Haas-type RME appliance was used. The expansion screw was incorporated in the same place by the dental technician laboratory team. In the present study, digital planning gives the opportunity for individual placement of expansion screws according to clinical needs. It may be moved in three dimensions (transversal, sagittal, and vertical), and the zooming options give excellent visualization from different perspectives. The orthodontist can make the appliance design by itself or at the same time with the dental technician. They can open the file, discuss the appliance design, and work on it from different offices. The different elements can be incorporated into appliance design and can be used after the expansion is achieved [11,13–15].

The results closest to ours are those provided by Geran [85]. In a prospective long-term study, an evaluation of the effects of rapid maxillary expansion in the early mixed dentition was made. He reported that the dental arch perimeter in the upper jaw increased by 4 mm, which is the same as the results of the present study. The methodology of measurements described in the McNamara study [84] was used. The RME expander with acrylic splint was used on 51 patients. The used appliances are different in two investigations—in the McNamara study, it is a Haas-Type RME, and in the Geran examination, it is an RME expander with an acrylic splint. In the present study, the RME is digitally assisted and printed on a 3D printer. This process provides the appliance with maximal accuracy and makes it maximally comfortable for the patients [13–15]. This gives the opportunity to make the device as individualized as possible and concerned with the specific needs of the patient. The individual approach in each case guarantees contemporary and specialized treatment with predictable and clear results.

The observed groups in the Geran examination [85] are in the early mixed dentition. The time for treatment with the RME appliance is really important. The appliance is most effective before the maturation of the midpalatal suture. After the ossification of the midpalatal suture, the use of an appliance with a bone anchorage is recommended.

Another difference comes from the fact that in all cases observed in McNamara [84], the expansion screw is opened to the same level, which provides a 10.5 mm increase in palatal width. However, in the Geran study, the activation of the expansion screw had a significantly lower count.

In the present study, the screw has been activated once a day, until the clinical needs are achieved—the cross bite in the distal area is improved in each clinical case.

D'Souza [92] investigates how dental arch changes are associated with rapid maxillary expansion and finds a significant increase in dental arch perimeter with an increase in arch width at the canine, premolars, and molar regions. According to its study, the dental arch perimeter increases by 3.2 mm, while the other parameter increases as follow:

The canine region arch width increased by 2.9 mm, the interfirst premolar width increased by 3.2 mm, and the intermolar width increased by 4.4 mm. The interesting finding that corresponds to our results is the decreased arch length by 1.8 mm from pretreatment to posttreatment.

Akkaya [93] investigates the dental arch perimeter changes due to slow and rapid maxillary expansion. The reported results are: the expansion between the first molars is 9.05 mm, and the arch perimeter increases by 5.91 mm. These results have larger values than in the present study. This fact is due to the inclusion criteria, which is a maxillary bilateral cross bite. In the present study, the achieved results are according to the clinical needs of each case.

Kinzinger showed that in adolescent patients, the splitting of the palatal suture is symmetrical and parallel, and after growth is completed, it is more "V" shaped [94]. In the present study, an average increase in size of 3.3 mm was observed in the premolar area and an average of 4.14 mm in the molar area. This is explained by the location of the screw of the RME appliance, which is closer to the molars. The increase in the arch perimeter in the treated group is due to an increase in the transversal size, which is clinically seen as a diastema that closes spontaneously after activation cessation. Since the changes were measured immediately after removing the RME appliance, the result obtained is its actual size. The treatment protocol includes 20–28 activations per ¼ rotation (0.25 mm per rotation), and the average result achieved is 4 mm. These are average cases, while in other cases, more or less activation is required. The value of the standard deviation of the studied variable is 2.84 mm. Rapid maxillary expansion achieved without the use of a surgical procedure to release the areas of resistance has been shown to increase the perimeter of the dental arch for every millimeter of expansion in the molars and canines. For patients, this is evident from the emerging diastema, which spontaneously closes under the tension of the periodontal ligament. However, this is not a sign of a loss of arch perimeter. Analysis of the changes in the dental arch shows that there is a negative correlation between the change in the width and the length of the arch. The width in the molar area increases by an average of 4.41 mm, and the length decreases by an average of 0.52 mm and, respectively, for the anterior segment by 0.54 mm. This established dependence indicates that not only the parameters of the dental arch change, but its shape has also changed as a result of the rapid expansion—the arch becomes wider and a little shorter, which means that it becomes rounded.

Rapid expansion is known to cause simultaneous processes of cortical bone resorption and calcified bone formation at the suture margins.

When a rapid and large force is applied to the distal tooth, the applied force is actually transferred to the suture without sufficient time for tooth movement. When the forces generated by the device exceed the biological limits of orthodontic tooth movement and suture stability, the sutures open and the teeth move only minimally against the supporting bone. Pressure from the device compresses the periodontal ligament, flexion of the alveolar ridge is observed, the supporting teeth involved in the device tilt, and the middle palatal suture and all other maxillary sutures gradually open.

The correlation analysis between the values of the parameters before and after the treatment phase L1, L2, l1, l2, MM1, MM2, PP1, and PP2 (Table 3) shows that all statistically reliable correlations are directly proportional. The strong relationships between the values of MM1 and MM2, PP1 and PP2, L1 and L2 l1 and l2 are due to the fact that expansion changes all parameters in an established and predictable pattern.

Correlation analysis (Table 4) demonstrates that the change in the intermolar width (MM2-MM1) correlates highly and positively with PP2-PP1 (change in premolar width). Therefore, it is not possible for the appliance to change only a particular section of the arch. It affects the entire lateral segment, although to varying degrees.

The effect on the palatal suture is the splitting of the palate with equal space between the two palatal segments. Some of this space may be lost by the end of treatment if the stability of the lateral segments is not ensured until new bone is formed between the palatal plates and the result is stable. For this purpose, after the desired result is achieved with the RME appliance, various methods can be used to maintain the new width of the arch. One of them is keeping the appliance fixed for some time. The appliance stayed fixed for three months after the activation was finished to ensure the stability of the achieved results. Individually printed rapid maxillary expansion appliances can include specially designed tubes and brackets to facilitate the beginning of multibracket treatment.

Additional attachments incorporated into the digital laser-sintered rapid maxillary expander design allow for separate tooth movements to be made in the period after the main effect of expansion has been achieved [95].

Another method of maintaining width after RME removal is the use of a transpalatal arch with extended arms for the premolars. The arch is used passively until the treatment reaches a stage in which the width of the arch can be preserved in an alternative way—by means of rigid orthodontic archwires (full-size stainless steel, which will guarantee the stable position of the teeth or archwires with an expanding effect that will preserve the result).

Correlation analysis showed that there is a strong positive correlation between aP2—aP1 and PA2-PA1, which leads to the conclusion that with the increase of the dental arch in general, the perimeter in the anterior section increases as well. Although the effect of the appliance is directed more in the distal segment, it changes the perimeter in the entire arch and in its frontal section. This is logical, given the mechanics of the device.

The high positive correlation between PP2-PP1 and aP2-aP1 means that the perimeter of the frontal segment is highly dependent on the width of the arch in the area of the first premolars. If the perimeter is considered part of the ellipse, then the width of the dental arch is one of its diameters, which explains the strong correlation between the parameters.

The established correlations between the studied parameters and their changes prove that the action of the RME appliance with dental support affects both the palatal suture, achieves dental-alveolar changes, and remodels the shape and perimeter of the dental arch. With the derived correlations and the following of a strict treatment protocol, it is possible to predict the changes, which will help in the planning of the orthodontic treatment.

The expectations for digital planning in orthodontics are to reduce the number of extraction treatments. They have been justified by the expanded possibilities for prognosis and prediction of treatment results. In this regard, any derived linear dependence between the individual characteristics of the dental arch allows for predicting the changes in the applied treatment plan. In borderline orthodontic cases, if the limit of possible changes in the perimeter of the dental arch is known and the clinician is sure that they will achieve the desired results by applying different treatment approaches, he or she will choose non-extraction therapy. Therefore, compared to extraction treatment, conservative treatment with expansion and/or distalization can be planned. This corresponds with the contemporary tendency for more non-extraction treatments.

The rapid maxillary expander is a contemporary treatment appliance. Digitally assisted RME techniques are more precise and accurate than traditional. The advantages come from the opportunity that digital appliance planning gives for better visualization and zooming of the working area. The borders of the appliance can be outlined more precisely [14]. The precise positioning of the RME screw in three dimensions—sagittal, transversal, and vertical—allows for the prediction of outcomes and makes the approach more individual for each clinical case. All this makes the appliance more comfortable for the patient and easier for adaptation.

The new technologies incorporated into daily practice are well received by the patients. The intraoral scanning is interesting and beneficial for patients with gag reflexes and children. The patients became more motivated and involved in the treatment through good visualization and presentation of treatment objectives. The period of adaptation with the appliance is shortened [45].

The limitation of this study is the small sample size, despite the fact that the observed group is large enough for reliable statistical inferences. Another limitation is imposed by the type of used appliance. The printed RME is for tooth anchorage only and can treat patients with a non-maturated midpalatal suture. This includes criteria that restricted the patient to a matured midpalatal suture [96]. For these patients, an appliance with bone anchorage, such as a miniscrew, is needed.

The RME appliance has an undeniable effect on the midpalatal suture and the surrounding structures. The enlarged transversal dimension is achieved through changes in the anatomical structures—maxillary palatine process and palatine bone. These are the structures that form the roof of the oral cavity and the floor of the nasal cavity. Therefore, the expansion achieved with RME influences the nasal cavity and the entire upper jaw by widening the airways. There is a requirement for future investigation on how the transverse expansion influenced the volume of airways. For this purpose, the careful analysis of CBCT images of the airways before and after the treatment with RME, or in particular the digitally assisted RME, would be useful. Such an analysis was made by Tsolakis and co., but with a small sample size [23]. More precise investigations are needed to deepen our knowledge of this connection.

Further investigations of how the parameters of the dental arch, such as perimeter, width, and length, are influenced and changed by the action of different types of orthodontic appliances and the derivation of equations and linear or other correlations will deepen and expand the findings of this research.

5. Conclusions

There exists a relationship between the parameters of the dental arch, and any change in one of these parameters leads to a change in the others as well. When a change in arch occurs according to a certain pattern, as when applying an RME, namely transverse expansion, the other parameters also change according to a certain pattern, described by a linear equation. The effect of the device is proven and predictable, which makes it an indispensable tool for the orthodontist when conducting orthodontic treatment.

The rapid maxillary expander is a contemporary treatment appliance. The advantages of digitally assisted RME techniques are: increased accuracy, individual approach through digital design, better visualization, more precise positioning of the RME screw, more precise definition of the borders of the appliance, easy communication with the technician laboratory, better visualization, opportunities for visualization of treatment objectives, easy long-term storage, and transfers in contemporary orthodontic practice.

Digitally aided RME and good planning are the tools that reduce the number of extraction treatments.

The stability of the achieved results is the same with traditional RME appliance and the digitally aided RME, because both stay passive in the mouth for 3 months, to ensure the stability. Despite that, the digitally aided RME is more comfortable for the patients.

The digital planning of treatment objectives and clinical application of digitally-assisted RME, which provide reliable and predictable outcomes are useful tools in border cases for extraction therapy.

The creation of physical casts is eliminated. That led to a decrease in human errors and more accrual results.

The new technologies incorporated into daily practice are well received by the patients. Intraoral scanning is interesting and beneficial for patients with gag reflex and children. The treatment became more "interesting" and "understandable" through good visualization and presentation of treatment objectives. The appliance is more comfortable for the patient. The period of adaptation to the appliance is shortened.

The detailed observation and analysis of clinical benefits and outcomes, achieved with digitally aided RME for the patients is recommended for future investigation.

Technological progress and the digitization of orthodontic practice facilitate orthodontic diagnostics, make the assessment of problems more accurate, and facilitate the predictability of the expected result from the treatment. The availability of 3D models and software facilitates orthodontic measurements and analysis and has become an integral part of modern orthodontic practice.

Summarizing the conclusions, advantages, and limits of the article:

1. There is not enough evidence in the literature about the effect of the RME appliance on all parameters of the dental arch, such as the perimeter of the dental arch and the length of the dental arch.

2. There was no established and standardized methodology for digital measurements of basic parameters in dental arch.
3. The present methodology must be interesting for practitioners, because it is simplified, quick, accurate, and described in detail.
4. The creation of physical casts is eliminated, which decreases the chance for human errors and other mistakes in data due to compromised cast integrity.
5. There is not enough evidence for a correlation between the parameters in the dental arch in the literature.
6. The main function of the RME appliance is to increase the dental arch width. At the same time, the dental arch perimeter is increased. The article investigates if the dental arch perimeter is increased in a certain pattern.
7. The valuable and interesting discovery of this research is the correlation between maxillary width and length. The increase in dental arch width is connected with a decrease in dental arch length. The form of the dental arch has been changed.
8. It is of critical importance in border cases for clinicians to evaluate the space in the dental arch that will be rough for tooth alignment and to know all the effects that certain appliances can achieve.
9. The observed group must be enlarged in future examination to provide increase in results credibility.
10. The presented linear equations may serve as a guide. They will be supported by more data in future examinations.
11. The clinicians must think about the dental arch as a whole, and very carefully observe the action of different appliances in three dimensions and to all dental arch parameters.
12. The knowledge of how the used appliance influences the dental arch perimeter is highly important to providing the treatment goals.

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