Original Article

Rotational fulcrum and dentoskeletal changes after rapid palatal expansion with tooth-bone-borne (MARPE) and tooth-borne appliances in post-pubertal patients

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ABSTRACT

Objectives: To identify the rotational fulcrum (RF) and to evaluate the skeletal and dentoalveolar effects after rapid palatal expansion (RPE) with tooth-borne and tooth-bone-borne (MARPE) appliances.

Materials and Methods: 31 patients were selected (MARPE group: n = 14, age 16.2 ± 2 years; hyrax group: n = 17, age 14.7 ± 0.8 years) with RPE indication and having cone-beam computed tomography before (T1) and after RPE (T2) and after 6 months of retention (T3).

Results: In the MARPE group, the RF was at or above the frontozygomatic suture (FZS), whereas in the hyrax group, it was at or below the FZS. The skeletal response rates were 70% (2°) and 33% (1.09°); alveolar response rates, 18% (0.52°) and 20% (0.68°); and dental response rates, 12% (0.35°) and 47% (1.54°) in the MARPE and hyrax groups, respectively, with a significant difference between groups in skeletal ($P = .005$) and dental ($P < .001$) regions. After retention, no significant difference was found between groups.

Conclusions: Although MARPE resulted in a higher RF in the coronal view, both techniques effectively corrected transverse discrepancies with similar stability. Considering the between-group differences in relation to skeletal and dentoalveolar response, MARPE should be used for cases in which minimal compensatory tooth movement is desired. (*Angle Orthod*. 0000;00:000–000.)

KEY WORDS: Malocclusion; Palatal expansion technique; Orthodontic anchorage procedures

INTRODUCTION

Rapid palatal expansion (RPE) aims to increase the maxillary transverse dimension by separating the midpalatal suture.[1] RPE is indicated to correct posterior crossbite, increase arch perimeter to resolve dental crowding, and correct maxillary constriction.[2–4] Initially, it was performed only with tooth-borne appliances, but some adverse effects were reported, such as buccal inclination of posterior upper teeth,[3,5–13] root resorption,[13] and decrease in the thickness of buccal bone.[7,9,13,14] To minimize these dentoalveolar effects, miniscrew-assisted rapid palatal expansion (MARPE) was developed.[10,15] In general, studies comparing both expansion techniques observed greater maxillary expansion in patients who used skeletal anchorage,[7,9,11,12] although some controversy exists in the literature.

Cantarella et al.[16] evaluated 15 patients treated with MARPE and reported that the zygomaticomaxillary

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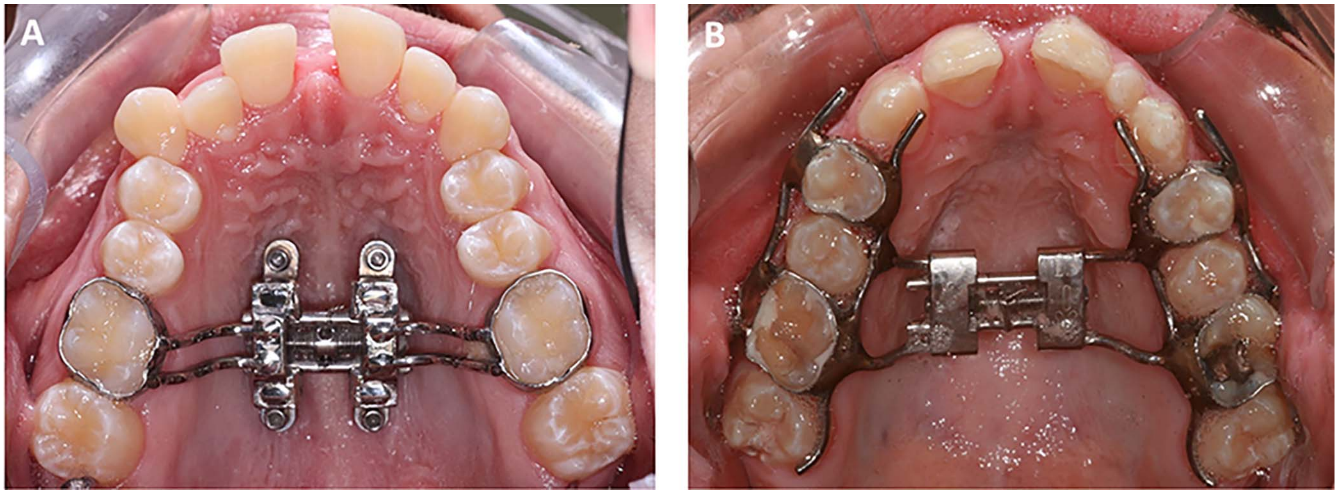

Figure 1. Expansion appliances: MARPE (A) and hyrax (B).

complex moved laterally with the center of rotation close to the frontozygomatic suture (FZS). Accordingly, Paredes et al.[17] proposed a new method for measuring dentoalveolar and skeletal effects of MARPE using angular measurements based on a previously defined rotational fulcrum (RF). Considering that MARPE causes this rotational movement, any measurement aimed at quantifying skeletal and dentoalveolar changes should be made using angles formed with the vertex at this center of rotation. Linear or angular measurements that do not use this RF of the zygomaticomaxillary complex as a reference may result in unreliable values. In addition, each expansion device has a different RF, which must be previously identified to allow for the measurement of expansion results. Therefore, new studies that seek to elucidate the true RF caused by different maxillary expansion appliances are warranted to clarify the real skeletal and dentoalveolar effects, since most studies comparing MARPE and conventional orthopedic expansion results used linear or angular measurements from arbitrary anatomical landmarks.[7–12,14,18,19]

This study aimed to identify the RF of the zygomaticomaxillary complex in the coronal plane after RPE with a tooth–bone-borne expander (MARPE) and with a tooth-borne expander (hyrax appliance), and to evaluate the effects of RPE on the bone base of the maxilla, alveolar process of the maxilla, and permanent upper first molars. The stability of both techniques after the retention period was also evaluated.

MATERIALS AND METHODS

Trial Design and Sample Size Calculation

This study was approved by the Ethics Committee of the Rio de Janeiro State University (No. 3.445.488). Based on the findings of Lin et al.[11] for skeletal effects in patients treated with RPE with tooth-borne and tooth–bone-borne expanders, considering a power of 80% and alpha level of 0.05, a sample size of 14 patients per group was required.

Patients who sought orthodontic treatment at the Orthodontics Clinic of the Rio de Janeiro State University were chosen using the following inclusion criteria: patients in the permanent dentition phase; age 13–21 years; CS5 and CS6 stages of cervical vertebral maturation;[20] and presence of unilateral or bilateral posterior crossbite and/or maxillary constriction. The exclusion criteria were: patients with systemic or genetic diseases, cleft palate, periodontal disease, history of fracture or surgery of the maxillary bones, and previous orthodontic treatment.

All participants and their guardians were informed of the characteristics and objectives of the study and signed the informed consent form.

Interventions

In the MARPE group, the expander was adapted to four mini-implants positioned on the palate and orthodontic bands cemented on first permanent molars (Figure 1). Initially, intraoral scanning and facial cone-beam computed tomography (CBCT) were performed, so that the positioning and size of the mini-implants and expander could be properly planned. All expanders in this group were from PecLab (Belo Horizonte, Minas Gerais, Brazil) and supplied by Kika Digital Orthodontics (Sorocaba, São Paulo, Brazil). The mini-implants used were also from the PecLab and had the same diameter (1.8 mm), whereas the length was individualized according to tomographic planning to achieve bicortical anchorage.[21] The step-by-step instructions for planning and installation of the expander were described by Fernandes, Capelli Jr,

Table 1. Abbreviations and Measurement Descriptions

	Descriptions
FAA	Frontoalveolar angle; formed by the IFD or MIFD and the distance between the fulcrum and the jugal point of the maxilla
FDA	Frontodental angle; formed by the IFD or MIFD and the distance between the fulcrum and the occlusal point between the buccal and palatal cusps of the first molar
FZA	Frontozygomatic angle; formed by the IFD or MIFD and the distance between the fulcrum and the outermost point of the zygomaticomaxillary suture
FZS	Frontozygomatic suture
IFD	Interfrontal distance; distance between the outermost and lower points of the zygomatic process
MARPE	Miniscrew-assisted rapid palatal expansion
MIFD	Modified interfrontal distance; when IFD was not at the zygomatic process of the frontal bone
RF	Rotational fulcrum
RPE	Rapid palatal expansion

and Miguel.[22] In the hyrax group, the expander had two bars of 0.040-in. diameter stainless steel wire (Dentaurum; Ispringen, Germany) adjacent to palatal surfaces in the cervical third of the canines to the second molars, which were welded to orthodontic bands cemented on the first permanent molars and first premolars (Figure 1).

Both groups were instructed regarding cleaning and activation of the device. In the MARPE group, one activation (0.25 mm) was performed daily and, in the hyrax group, two activations (0.5 mm) were performed daily. In both groups, activation was performed until overcorrection was achieved (the palatal cusp of the upper molar occluding on the buccal cusp of the lower molar). Thereafter, patients were followed up monthly for 6 months to retain the expansion. After this period, the device was removed, and corrective treatment was completed.

Measurements and Outcomes

CBCT was performed in three phases of treatment: before (T1) and after RPE (T2), and after 6 months of retention (T3). The I-CAT CT scanner (Imaging Sciences International, Hatfield, Pa, USA) was used, with a field of view of 22 $\times$ 16 cm, voxel size of 0.25 mm, and scanning time of 20 s, with 120 kVp and 5 mA. All CBCT images were randomly analyzed by the same examiner (L.Q.P.F.), who was blinded to which patient was being evaluated. Total blinding of the method was not possible, since the appliance could be identified in the images. To avoid fatigue, a maximum of two patients were analyzed per day.

Dolphin Imaging version 11.9 (Chatsworth, CA, USA) was used in measuring all CBCT images. The points and measurements of interest were performed as described by Paredes et al.[17] (except for the distobuccal root of the first molar as a reference for the alveolar point, which was replaced by the jugal point of the maxilla) and are described in Table 1. The head position was oriented in T1 and superimpositions were performed using the skull base as reference.[23] The RF was located by calculating the interfrontal distance (IFD), defined as the distance between the outermost and lower points of the zygomatic process, on T1 and T2 images. If the values were the same, it meant that the RF was at this point or that there was no expansion at this level; so, distances parallel to and below the IFD were calculated to confirm whether this was really the RF or if it was below. If the value on T1 was lower than that on T2, it meant that there was expansion at this point; so, distances parallel to and above the IFD were calculated until values on T1 and T2 were the same. Once the RF was found and, if it was not equivalent to the IFD, this distance was called the modified interfrontal distance (MIFD). To evaluate the RF position, the distance between IFD and MIFD was calculated and compared between groups (Figure 2).

The following angular measurements were performed on both sides: frontozygomatic angle (FZA), frontoalveolar angle (FAA), and frontodental angle (FDA) (Table 1 and Figure 3). To define the responses to RPE by region, the following calculations were performed:

1. Skeletal expansion = T2 FZA – T1 FZA.
2. Alveolar bone bending = (T2 FAA – T1 FAA) − (T2 FZA – T1 FZA).
3. Dental tipping = (T2 FDA – T1 FDA) − (T2 FAA – T1 FAA).

To evaluate changes during the retention period, the T3 tomograph was superimposed on the T2 tomograph.

The entire manipulation and measurement process was redone in six patients, with an interval of 15 days, to evaluate the method error.

Statistical Analysis

Jamovi version 2.3.21 was used for data analysis. The significance level used was 1%. The sample

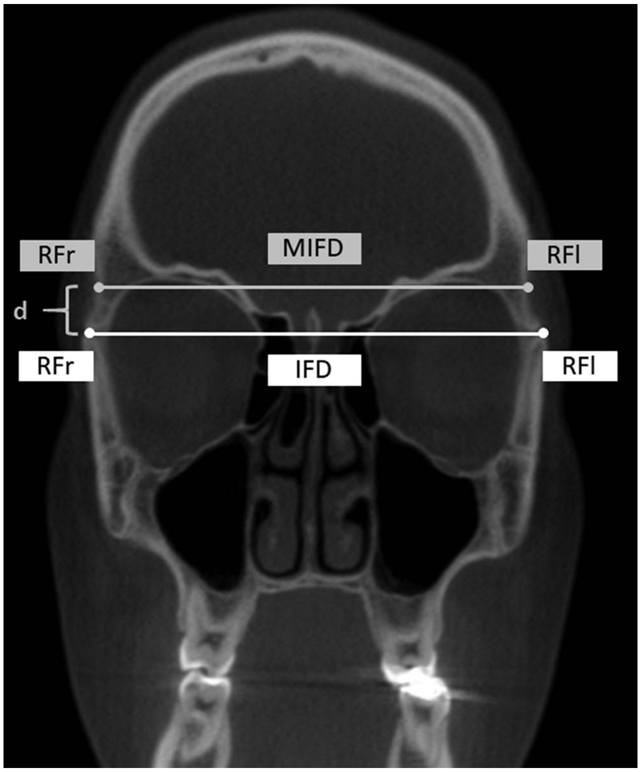

Figure 2. Rotational fulcrum and IFD and MIFD locations. IFD indicates interfrontal distance; DIFM, modified interfrontal distance; RFr, right rotational fulcrum; RFl, left rotational fulcrum; d, distance between IFD and MIFD.

normality was verified using Shapiro–Wilk test; because some variables had a low *P* value, nonparametric tests were applied in all statistical evaluations. The initial descriptive characteristics of the sample were evaluated using Mann–Whitney test and Fisher's exact test to verify whether the groups were similar at T1. The intraclass correlation index (ICC) was calculated to evaluate the method error. Wilcoxon test was performed to evaluate intragroup changes, and Mann–Whitney test was performed to evaluate differences between the two groups, both from T1 to T2 and from T2 to T3.

RESULTS

The sample consisted of 31 patients. The MARPE group included 14 patients (mean age, 16.2 $\pm$ 2 years; female, n $=$ 8; male, n $=$ 6) prospectively selected, whereas the hyrax group included 17 patients (mean age, 14.7 $\pm$ 0.8 years; all females). The initial descriptive analysis of each group is shown in Table 2. Using the Mann–Whitney test, no significant difference was found between the groups in relation to the amount of expander activation ($P = .679$). In both groups, the mean opening of the expander was 7 mm, with values ranging from 5–10 mm in the MARPE group and 5–9 mm in the hyrax group. Clinically, all patients showed improvement of the posterior transverse relationship, and a diastema was observed between the central incisors. No expander was damaged and there were no failures of any mini-implants. Because of the COVID-19 pandemic, one patient in the MARPE group who did not have adequate follow-up after RPE was not included in the T3 evaluation.

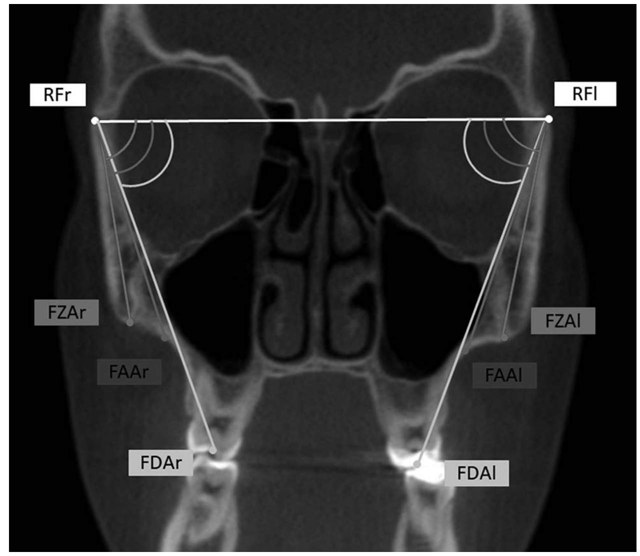

Figure 3. Angle locations. FZAr indicates right frontozygomatic angle; FAAr, right frontoalveolar angle; FDAr, right frontodental angle; FZAl, left frontozygomatic angle; FAAl, left frontoalveolar angle; FDAl, left frontodental angle; RFr, right rotational fulcrum; RFl, left rotational fulcrum.

The ICC for the IFD/MIFD (0.9958), AFZ (0.9969), AFA (0.9966), and AFD (0.9906) demonstrated excellent replicability of the method.

The position of RF caused by RPE in both groups is presented in Figure 4 and Table 3. For evaluations of the RPE results (Table 4) and retention phase (Table 5), the mean of the angles of both sides was used because the Wilcoxon test did not show a difference between the right and left sides for each group. Figure 5 illustrates total expansion and degree of relapse by region.

DISCUSSION

In the present study, the difference in RF position between groups may indicate that the skeletal anchorage in MARPE group caused higher levels of an expansion force in the skeletal base, which justifies the greater skeletal response in this technique than in the tooth-borne technique. Similarly, Paredes et al.[17] reported that, of the 39 patients who were treated with MARPE, 20 had the RF at the FZS level and 19 had this point slightly above it. On the contrary, Jia et al.[9] reported that the RF in both techniques would be located at the same

Table 2. Descriptive Analysis

Variables	MARPE group (n = 14)	Hyrax group (n = 17)	*P* Value
Maxillomandibular bone width discrepancy (mm)	−0.4 (±5.98)	−2.55 (±3.31)	.311*
Malocclusion (n)			
Unilateral posterior crossbite	6 (42.9%)	7 (41.2%)	.293+
Bilateral posterior crossbite	6 (42.9%)	10 (58.8%)	
Maxillary constriction without crossbite	2 (14.3%)	0 (0%)	
Cervical vertebral maturation (n)			
CS5	10 (71.4%)	11 (64.7%)	1.000+
CS6	4 (28.6%)	6 (35.3%)	

* *P* value for Mann–Whitney test; + *P* value for Fisher's exact test.

position, although they did not perform specific angular measurements to confirm this. In relation to tooth-borne expansion, the frontomaxillary suture was mentioned previously as the RF of expansion.[24]

Expansion appliances in both groups were efficient in correcting the initial transverse malocclusion; however, the MARPE group had greater skeletal expansion, whereas the hyrax group had greater dental tipping, indicating a significant difference. When evaluating MARPE, Paredes et al.[17] reported skeletal expansion of 96% (2.87°), alveolar bone bending of 0.3% (0.01°), and dental tipping of 3.7% (0.11°), further emphasizing the preponderance of skeletal expansion in this technique in relation to dentoalveolar response.

Altieri and Cassetta[7] also used the zygomaticomaxillary suture as a reference to assess skeletal expansion. Although they performed linear measurements, they also found a greater transverse increase in the MARPE group (8.15 mm) than in the tooth-borne expander group (4.8 mm). Conversely, Chun et al.[19] did not find a significant difference in the transverse increase at the level of zygomaticomaxillary suture when performing linear measurements in both hyrax (1.04 mm) and MARPE (1.49 mm) groups.

To evaluate alveolar bone, Paredes et al.[17] used the apex of the maxillary first molar as a reference. However, since the coronal CBCT slice at the three evaluation times did not always coincide with this reference, the present study used the maxillary jugal point as a reference to evaluate alveolar bone, as previously described in the literature.[8,12] In both groups, alveolar bone bending was significant but not clinically relevant, and no significant difference was found between groups, as demonstrated by other studies.[8,12]

Regarding the treatment stability after 6 months of retention, although both techniques demonstrated significant relapse in all three regions, this relapse was more pronounced in the skeletal base than in the dental region,

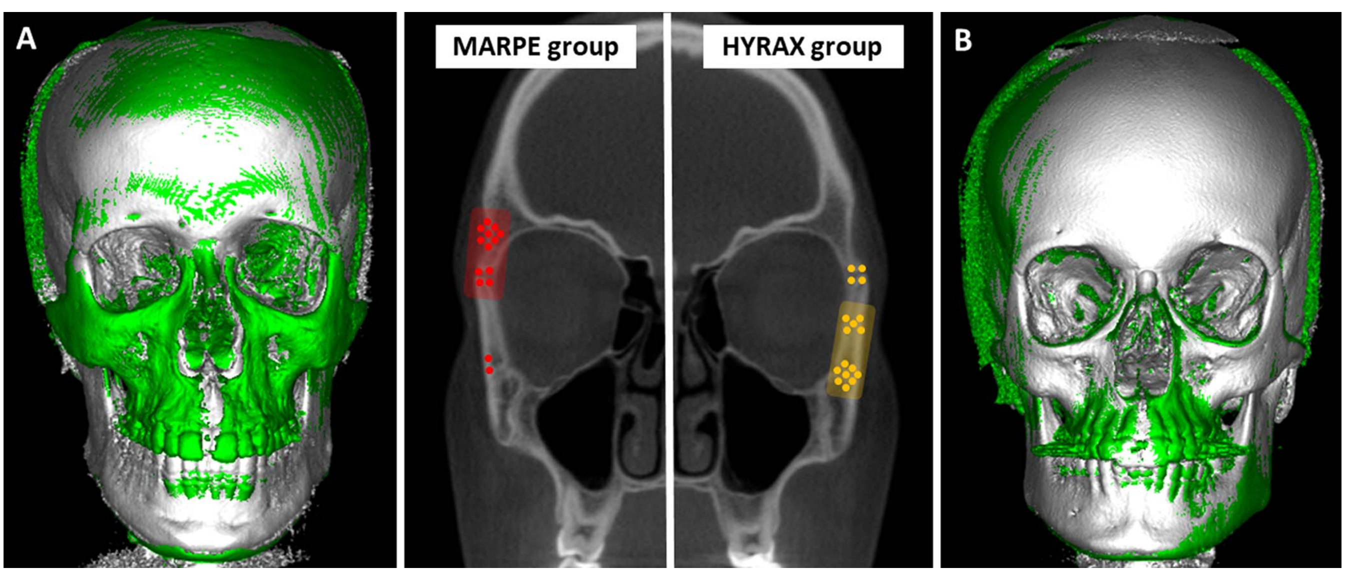

Figure 4. Rotational fulcrum caused by RPE in both groups. Legend: Approximate RF location of total sample. Note that, in the MARPE group, the majority of patients had the fulcrum at or above the FZS, close to the concavity region of temporal line, and the majority of patients in the hyrax group had the fulcrum below the FZS, in the region where the zygomatic frontal process meets the zygomatic maxillary process. Total cranial superimposition before and after RPE with tooth-bone-borne expander (A) and tooth-borne expander (B).

Table 3. Rotational Fulcrum Caused by RPE in Both Groups[a]

Location of Rotational Fulcrum	MARPE Group (n = 14)	Hyrax Group (n = 17)
Rotational fulcrum at the FZS		
n	4	4
Rotational fulcrum below FZS – distance between IFD and MIFD		
n	2	13
Mean (mm) (minimum / maximum)	22.75 (17.1/28.4)	18.76 (7.7/28.3)
Rotational fulcrum above FZS – distance between IFD and MIFD		
n	8	0
Mean (mm) (Minimum / Maximum)	7,7 (3.6/10.6)	

[a] IFD indicates interfrontal distance; DIFM, modified interfrontal distance; FZS, frontozygomatic suture.

demonstrating that both RPE techniques could be considered clinically stable, with no difference between the groups. Chun et al.[19] also found relapse in the skeletal region in both tooth–bone-borne and tooth-borne expansion, whereas Canan and Senisik[6] reported a slight relapse in the dental region in both techniques, in agreement with results of the present study. Bazargani et al.[18] and Bazargani et al.[25] also performed 6 months of retention and found similar stability after 1 year and 5 years post-expansion, for both RPE techniques.

Table 4. Skeletal, Alveolar Bone, and Dental Angular Changes After RPE (T2 – T1) in Both Groups[a]

	MARPE Group (n = 14)	Hyrax Group (n = 17)	*P* Value
Angle values			
FZA T1	80.33°	76.41°	
T2	82.33°	77.5°	
FAA T1	67.63°	60.46°	
T2	70.15°	62.23°	
FDA T1	67.26°	62.5°	
T2	70.13°	65.81°	
Skeletal expansion (FZA)			
Mean (SD)	2° (±0.94°)	1,09° (±0.04°)	
Percentage	70%	33%	
Minimum	0.5°	0.2°	
Maximum	3.4°	2.15°	
P value	<0.001*	<0.001*	.005+
Alveolar bone bending (FAA - FZA)			
Mean (SD)	0.52° (±0.47°)	0,68° (±0.36°)	
Percentage	18%	20%	
Minimum	0.1°	0.2°	
Maximum	1.75°	1.35°	
P value	0.001*	<0.001*	.146+
Dental tipping (FDA - FAA)			
Mean (SD)	0.35° (±0.66°)	1,54° (±0.69°)	
Percentage	12%	47%	
Minimum	−1.2°	0.35°	
Maximum	1.55°	3.2°	
P value	.033*	<.001*	<.001+

* *P* value for Wilcoxon test; + *P* value for Mann–Whitney test; FZA – frontozygomatic angle.

[a] FAA indicates frontoalveolar angle; FDA, frontodental angle.

Although MARPE provides greater skeletal expansion and tooth-borne expansion provides greater dental tipping, this difference may not be relevant clinically. In addition, considering that skeletal expansion relapsed in the retention phase and no clinical difference was noted in the degree of treatment stability in the dental region between groups, the indication for MARPE in adolescent patients with the characteristics of this sample should be restricted to borderline cases for upper arch expansion in which the orthodontist desires as little tooth movement as

Table 5. Skeletal, Alveolar Bone and Dental Angular Changes After Retention (T3 – T2) in Both Groups[a]

	MARPE Group (n = 13)	Hyrax Group (n = 17)	*P* Value
Angle values			
FZA T2	82.33°	77.5°	
T3	81.51°	76.95°	
FAA T2	70.15°	62.23°	
T3	69.47°	61.28°	
FDA T2	70.13°	65.81°	
T3	69.31°	64.75°	
Skeletal relapse (FZA)			
Mean (SD)	−0.82° (±0.48°)	−0.55° (±0.27°)	
Percentage	41%	50%	
Minimum	−1.8°	−1°	
Maximum	−0.15°	−0.15°	
P value	.002*	<.001*	.142+
Alveolar bone relapse (FAA)			
Mean (SD)	−0.68° (±0.53°)	−0.95° (±0.52°)	
Percentage	27%	53%	
Minimum	−2°	−1.55°	
Maximum	−0.05°	−0.25°	
P value	.002*	<.001*	.18+
Dental relapse (FDA)			
Mean (SD)	−0.82° (±0.47°)	−1.06° (±0.58°)	
Percentage	28%	32%	
Minimum	−2.05°	−2.3°	
Maximum	−0.15°	−0.05°	
P value	.002*	<.001*	.294+

* *P* value for Wilcoxon test; + *P* value for Mann–Whitney test.

[a] FZA indicates frontozygomatic angle; FAA, frontoalveolar angle; FDA, frontodental angle.

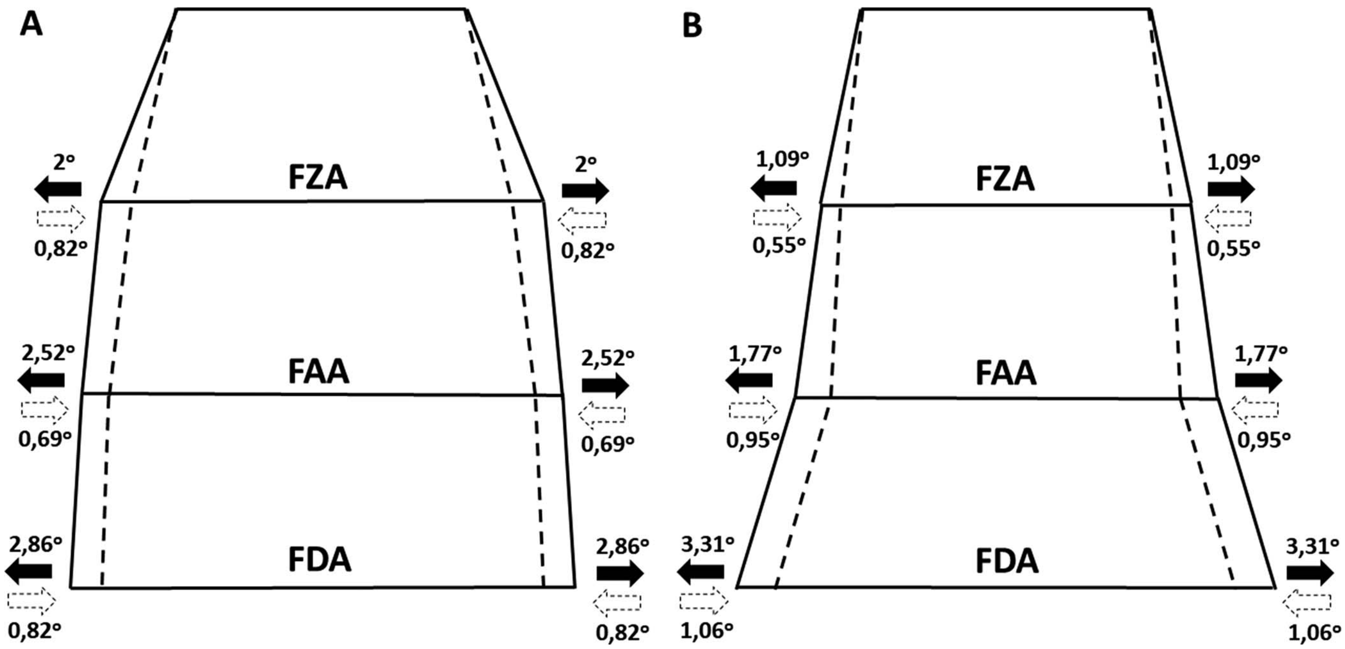

Figure 5. Diagram with total expansion and relapse by region in both groups. Legend: Transverse changes in MARPE group (A) and hyrax group (B). Black line represents the T2 – T1 differences and dashed line represents the T3 – T2 differences. FZA indicates frontozygomatic angle; FAA, frontoalveolar angle; FDA, frontodental angle.

possible. This may be due to either preexisting periodontal issues or significant compensatory tooth inclination at the beginning of treatment. When evaluating the cost–benefit ratio, MARPE has higher costs and risks involved[7,18,26] than hyrax, meaning that it is not indicated for all cases.

Despite limitations related to the study design, this was the first study to apply the angular measurement method introduced by Paredes et al.[17] to evaluate the skeletal and dentoalveolar RPE effects on CBCT of both techniques and to evaluate their stability after the retention phase in patients after the pubertal growth spurt who had a transverse maxillary deficiency. Further studies that seek to evaluate the location of zygomaticomaxillary complex RF in both techniques are warranted to confirm the findings of the present study.

CONCLUSIONS

- MARPE demonstrates the RF of the zygomaticomaxillary complex located in the region of FZS or above it, whereas the hyrax expander shows the RF below FZS.
- MARPE results in a greater response to expansion at the level of the maxillary bone base than at the level of the maxillary first molars, whereas the hyrax expander has a greater dental response than skeletal response, with no difference between groups in relation to the maxillary alveolar process.
- No between-group difference was found in stability of expansion, and both techniques of RPE provide stable correction of transverse deficiency.

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