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CBCT Comparison of Dentoskeletal Effects of Haas-Type and Hyrax-Type Expanders Using Deciduous Teeth as Anchorage: A Randomized Clinical Trial

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Abstract: The aim of this study was to compare the three-dimensional dentoskeletal effects of Haas-type and Hyrax-type expanders using primary teeth as anchorage for rapid palatal expansion (RPE). Thirty-four subjects in mixed dentition were divided according to their expander's type: Hyrax (n = 16; 6F, 10M; mean age 8 ± 3 yrs) or Haas (n = 18; 14F, 4M; mean age 8 ± 2 yrs). Each patient underwent CBCTs before (T0) and after RPE (T1). Dentoskeletal changes were collected. A paired sample t-test and independent t-test were used to compare each variable within the same group and between groups, respectively, with a 5% significance. The Hyrax group showed an increase in all dentoskeletal parameters; skeletal expansion was significantly increased anteriorly (1.76 mm) and posteriorly (1.93 mm). The greatest dental expansion was observed in the anchorage unit (6.47 mm), about twice as much as permanent molars (3.42 mm). The same statistical significance of Haas group measurements was observed; anteriorly skeletal expansion (2.97 mm) was greater than posteriorly (1.93 mm) and dental expansion was greater on anchored teeth (6.80 mm) than non-anchored teeth (4.57 mm). No statistical significance was observed between Hyrax and Hass groups. CBCT analysis showed that, in RPE, the dental expansion was greater than skeletal expansion. No significant or clinical changes were observed between Hyrax and Haas appliances anchored to primary teeth.

Keywords: CBCT analysis; deciduous teeth; orthodontic anchorage; rapid palatal expansion; randomized clinical trial

1. Introduction

When an orthodontist diagnoses a skeletal constricted maxillary arch, the orthopedic expansion involving the separation of midpalatal suture is the treatment of choice to normalize the transversal dimension of the upper jaw. Rapid palatal expansion (RPE) is recommended, especially in growing patients before the complete calcification of the craniofacial sutures, to prevent any development of skeletal asymmetries and to relieve anterior arch crowding [1]. RPE technique was first described by Angell in 1860; since then, several banded loops or helices, jackscrew devices, and spring-loaded devices have been incorporated in the group of fixed tooth-borne maxillary expanders [2]. Several criteria should influence the choice of an appliance, e.g., the age of patients, transversal discrepancy amount, rate of screw activation, and the patient's capability for correct care of oral hygiene. Usually, the appliance is anchored to the first maxillary permanent molars, even if the expansion can often cause a deleterious buccal tipping of these teeth [3] that can partially relapse during the postretention phase [4]. Furthermore, anchoring teeth may develop gingival recessions, root resorption, and pulp diseases affecting their survival and functioning [5].

The uniqueness of this procedure lies in the appliance anchorage. As a matter of fact, to avoid these undesirable effects on permanent teeth and attain a more physiological tissue reaction, RPE in the transitional dentition can be achieved by using primary teeth to anchor the appliance [6–8]. Two types of palatal expanders have been mostly recognized in the literature and the main difference between them is reported to be only the presence in the Haas type, or the absence in the Hyrax type, of acrylic pads close to the palate, in contact with mucosa. The first type was assumed to distribute the expanding force between the posterior teeth and the palatal vault [9]. The Hyrax expander was believed to deliver the force mostly to the maxilla through the appliance-supporting teeth, jointly, so as to be easy to clean [10].

Despite this, cephalometric analysis has not demonstrated any differences between these two appliances, and there is no consensus regarding their method of action [11]. The skeletal and dental effects of RPE have usually been investigated on dental casts and radiographic evaluations such as latero-lateral and posteroanterior cephalograms, which have their limitations and do not allow for an accurate assessment of the structure involved without structure overlapping [12]. Nowadays, it is possible to use cone beam computed tomography (CBCT) for more precise reproduction of maxillary structures in all three spatial planes. This technology offers a reproducible three-dimensional (3D) image without the limiting factors of magnification and distortion, which affect conventional two-dimensional (2D) radiography and its subsequent accuracy.

To date, only a few 3D studies are available to know if there is any difference between the Hyrax and Haas appliances when using permanent teeth as a support for the appliances, without any evidence about which is the most efficient device [9,13,14]. Moreover, only one other study has compared these two appliances when using primary second molars as anchorage and analyzing the data by CBCT images indirectly obtained from a 3D airway analysis [15]. Indeed, primary teeth have weaker roots when compared to permanent teeth and the different design and rigidity of the appliances, with or without the acrylic pad, might make a difference when compared to permanent teeth, with longer supporting roots, used as the anchor unit.

Thus, the present randomized clinical trial aimed to three-dimensionally compare the skeletal and dental effects of Haas-type and Hyrax-type expanders using the primary teeth of growing patients as anchorage units, and to test the null hypothesis that there are no differences between tissue-borne and tooth tissue-borne expanders in growing patients treated by RPE.

2. Materials and Methods

This study followed a randomized prospective longitudinal design and enrolled subjects who were seeking orthodontic treatment and who had never been treated before, presenting at the Department of Orthodontics (University of Milan, Milan, Italy). As a routine procedure, a signed informed consent for releasing diagnostic records for scientific purposes was obtained from the parents of the patients prior to the beginning of treatment. The protocol was reviewed and approved by the Ethical Committee of University of Milan (updated protocol code #51/21) and all the procedures adhered to the World Medical Organization Declaration of Helsinki. The following inclusion and exclusion criteria were applied to select the population study: (1) no systemic disease or syndromic features, (2) early mixed dentition with incisors and first permanent molars erupted and non-mobile maxillary primary second molars, (3), no pathologic periodontal status or tooth decay on both deciduous and permanent teeth, (4) skeletal Class I and II, (5) maxillary transverse deficiency with or without unilateral/bilateral posterior cross-bite.

Sample size was calculated, considering as the primary outcome the changes in the transverse diameter at the pulp chambers, on the data of a preliminary selected pilot sample of 5 patients per group [16]. To retrieve β = 0.80 with α set at 0.05, a sample of at least 13 subjects per group was necessary. The initial sample involved 44 consecutive patients (28 females and 16 males) enrolled in 2019. An electronic computer program was used for the allocation sequence generation. Each new patient presenting, and adherent to the inclusion and exclusion criteria, was allocated to the tooth-borne Hyrax expander group or the tissue-borne Haas expander group (using www.random.org; accessed on March 2020). Then, the allocation information (randomization results) was concealed in opaque and sealed envelopes by the statistician. The treating clinicians were blinded from the randomization procedure but not during the treatment period (registration number "RCT_4_19_2.3"). Figure 1 shows the consort diagram showing the flow of patients through the trial. Patients who did not correctly follow the protocol of activation, who did not come back for control appointments, or whose skeletal and dental structures were difficult to visualize on the CBCT due to the low quality of scans, were dropped from the study sample. The final sample involved 34 patients (20 females and 14 males): Hyrax group (16 patients) included 6 females and 10 males (mean age 8 ± 3 years; range 7.3–9.0 years), Haas group (18 patients) included 14 females and 4 males (mean age 8 ± 2 years; range 7.1–9.0 years).

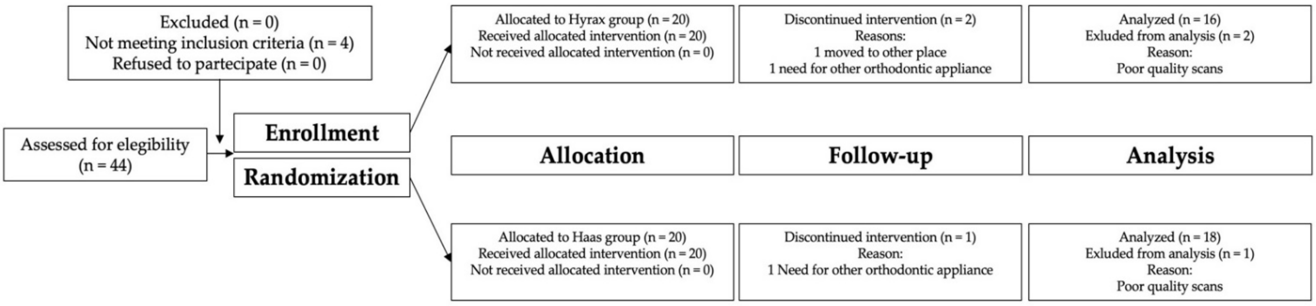


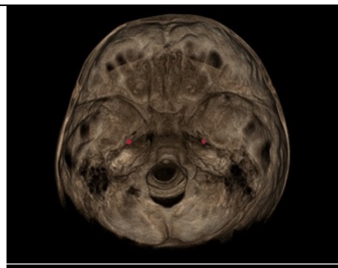
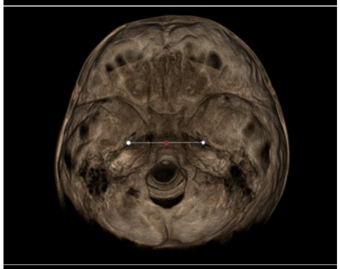
Figure 1. Flow diagram of patient selection according to consort statement.

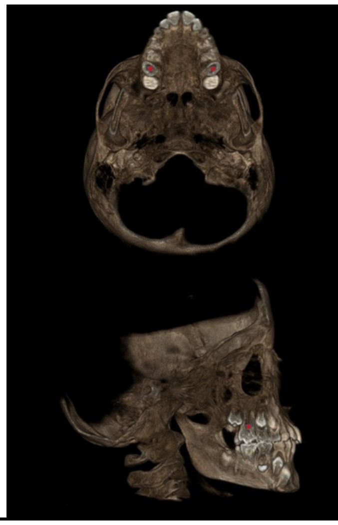
Palatal expanders were composed of two bands bonded on second deciduous molars and with palatal extensions bonded onto deciduous canines. The expander's screw was initially activated and turned twice (0.45 mm initial activation) during the first appointment. Afterwards, it was turned once per each of the following day (0.225 mm activation/day). Maxillary expansion was performed until dental overcorrection, defined as when the lingual cusps of the upper first molars occluded onto the buccal cusps of the lower first molars, was achieved. The screw was then locked, and the expander was kept on the teeth as a passive retainer. During this period, none of the patients underwent any further orthodontic treatment. The mean activation and retention times were 3 ± 1 months (range 1–5 months) and 10 ± 2 months (range 6–12 months), respectively.

CBCTs and dental casts were taken before (T0) and after treatment (T1). Ultra low dose 3D imaging protocol and adjusted field of view (FOV) were used to respect ALARA principle (Planmeca ProMax 3D Mid; Planmeca, Helsinki, Finland). The entire treatment lasted a mean time of 13 ± 3 months (range of 9–13 months). CBCT scans were traced, and data was subsequently recollected by the same expert orthodontist (C.V.). DICOM files were processed using Mimics Software (version 10.11, Materialise Medical Co, Leuven, Belgium) and exported in IGES format for both right and left sides. For each CBCT image, skeletal and dental landmarks were taken using a coordinate system previously proposed in a similar study [17]. ELSA (midpoint of line connecting both foramen spinosum landmarks) was set as x, y, and z origin and corresponding coordinate planes (x: coronal; y;

sagittal; z: axial) that started from ELSA point passing through RPo (Right auditory external meatus) and LPo (Left auditory external meatus) points was constructed. Table 1 summarizes the landmark's definition and their identification.

Table 1. Landmark definition, description, and positioning on 3D rendering.

Cranial References		
Foramen spinosum (**RFs, LFs**)	Geometric center of the upper and smallest circumference with defined borders viewed axially on the foramen spinosum.	
ELSA	Midpoint on a line connecting left and right foramen spinosum landmarks.	
Auditory External Meatus (**RPo, LPo**)	Most upper, posterior and lateral point of Auditory External Meatus circumference with defined borders viewed saggitally.	
Skeletal landmarks		
Nasal Floor (**RNF, LNF**)	Junction of palatal cortical alveolar bone and lateral cortical nasal bone located in the coronal scan passing through the PC of the first permanent molar.	
Lateral pterygoid (**RLPt, LLPt**)	Most posterior border of the pterygoid lateral plate at the vertical level of the palatal shelves.	

Dental landmarks		
Pulp chamber (**PC tooth** #)	Center of pulp chamber floor viewed in all 3 planes of space.	
Furca (**Furca tooth** #)	Buccal furcation of upper first permanent molars.	

From IGES data on the three planes, the following calculation was subsequently applied to obtain bilateral linear measurements

$$\sqrt{(x^{(1)} - x^{(2)})^2 + (y^{(1)} - y^{(2)})^2 + (z^{(1)} - z^{(2)})^2}$$

All calculated measurements of skeletal and dental landmarks are described in Table 2.

Table 2. Skeletal and dental linear measurements and their definition.

Skeletal Landmarks	
Nasal Floor width (**NF**)	Distance between **RNF** and **LNF** points
Pterygoid width (**LPt**)	Distance between **RLPt** and **LLPt** points
Dental landmarks	
Upper first permanent molar distance (**6 + 6**)	Distance between 1.6 and 2.6 **PC** points
Upper second primary molar distance (**E + E**)	Distance between 5.5 and 6.5 **PC** points
Furca distance (**FURCA**)	Distance between 1.6 and 2.6 **Furca** points

The IBM SPSS software, v.22.0 (IBM Corp., Armonk, NY, USA) was employed to perform statistical analysis. Shapiro–Wilk test revealed a normal distribution of the data and, therefore, parametric tests were employed for statistical analysis. Student t-test was used to compare groups. A paired sample t-test was used to compare each variable within the same group, between T0 and T1; independent t-test was used to compare each variable between groups, with a 5% of significance. All measurements were previously performed 3 times on 10 randomly selected patients to evaluate measurement error in x, y, and z directions (Table 3). Statistical analyses were performed considering the mean of the three measurements. Casual and systematic errors were calculated comparing the first and second measurements with Dahlberg's formula and dependent *t*-test, respectively, at a significance level of 5%. The mean error and 95% confidence interval among the repeated data were 0.6 mm (0.5–0.7); reliability coefficient ranged from 95% to 97%.

Table 3. Intraoperator error on x, y, and z axes.

Axis / **Landmark**	**X**	**Y**	**Z**
Cranial			
RFs	0.39	4.18	0.28

LFs	0.32	4.04	0.27
ELSA	0.29	0.24	0.19
Rpo	0.31	5.57	0.37
Lpo	0.27	0.12	0.64
Skeletal			
RNF	0.29	0.61	0.23
LNF	0.17	0.43	0.23
RLpt	0.07	0.35	0.37
LLpt	0.03	0.27	0.36
Dental			
PC 1.6	0.21	0.43	0.29
PC 2.6	0.21	0.24	0.19
PC 5.5	0.27	0.33	0.29
PC 6.5	0.25	0.17	0.29
FURCA 1.6	0.41	0.19	0.23
FURCA 2.6	0.32	0.28	0.22

3. Results

Table 4 summarizes the inferential analysis of the cranial landmarks used for the present study. It was shown that none of the variables tested resulted in statistical significance ($p > 0.05$) regarding all three directions of space (x, y, and z axes). Thus, the reliability of RFo, LFo, ELSA, RPo, and LPo was confirmed providing a stable three-dimensional reference system for maxillary dental and skeletal measurements.

Table 4. Intragroup comparison of cranial references observed in all three directions of space (x, y, and z axes) for both Hyrax and Haas group ($p < 0.05$).

	Transversal (x)						**Sagittal (y)**						**Vertical (z)**					
	Hyrax			**Haas**			**Hyrax**			**Haas**			**Hyrax**			**Haas**		
	Mean	**SD**	***p***	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***
RFs	0.13	0.41	0.11	0.02	0.72	0.89	−0.43	1.11	0.99	−0.61	1.98	0.54	−0.69	0.82	0.36	−0.08	0.70	0.75
LFs	−0.33	0.48	0.09	0.05	0.90	0.88	0.16	1.09	0.70	0.61	1.61	0.32	−0.29	0.62	0.23	−0.11	0.66	0.38
ELSA	0.03	0.30	0.76	−0.07	0.27	0.49	−0.13	0.15	0.06	0.05	0.25	0.57	−0.05	0.30	0.63	−0.05	0.31	0.63
RPo	0.00	0.05	0.13	0.01	0.05	0.55	0.40	1.14	0.35	−0.06	2.35	0.95	0.30	0.50	0.13	0.33	0.73	0.24
LPo	−0.11	0.26	0.29	−0.09	0.25	0.32	0.06	0.73	0.83	0.39	1.32	0.43	0.32	0.83	0.31	0.39	1.32	0.43

Table 5 shows the starting forms comparison between Hyrax and Haas groups. Based on the fact that none of the skeletal measurements were statistically significant ($p > 0.05$) between groups before the treatment start (T0), it can be postulated that there was homogeneity among the compared groups; statistically significant differences between dental measurements of the two groups, except for 6 + 6 distance, could be correlated to a different compensation of dental structures, and were irrelevant since the main outcome of the study was the observation of skeletal expansion.

Table 5. Starting forms intergroup comparison at T0 (* $p < 0.05$).

	Hyrax		**Haas**		**Hyrax vs. Haas**
Measurements	**Mean**	**SD**	**Mean**	**SD**	***p***
Skeletal					
NF	29.55	1.96	28.17	2.52	0.227
LPt	50.74	4.53	49.51	3.64	0.544
Dental					

6 + 6	42.30	3.72	39.06	3.13	0.067
E + E	39.20	2.95	35.85	2.26	0.018 *
FURCA	47.52	4.04	38.97	3.28	<0.001 *

Finally, Table 6 shows the results of the inferential analysis of the differences within the same group and between the Hyrax and Hass group in the interval T1-T0.

Table 6. Intraclass comparisons between transversal differences (Mean and Standard Deviation) between T0 and T1 and interclass significance (* $p < 0.05$).

	Hyrax			Haas			Hyrax vs. Haas
Measurements	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***	***p***
Skeletal							
NF	1.76	0.86	<0.001 *	2.97	1.84	0.003 *	0.081
LPt	1.93	1.69	0.006 *	1.91	1.12	0.002 *	0.998
Dental							
6 + 6	3.42	1.50	<0.001 *	4.57	2.32	0.001 *	0.222
E + E	6.47	1.54	<0.001 *	6.80	2.26	<0.001 *	0.724
FURCA	4.36	1.79	<0.001 *	4.14	2.58	0.003 *	0.837

3.1. Hyrax Group

The Hyrax group showed an increase in all dental and skeletal parameters. In particular, it was observed that, between T0 and T1, there was a statistically significant increase in the NF distance of 1.76 ± 0.86 mm ($p < 0.001$), with little difference in defect with the LPt measurements. The greatest transversal dental expansion was observed in the anchorage unit (E + E = 6.47 ± 1.54 mm), that was approximately double of the expansion obtained on the first permanent molars (6 + 6 = 3.42 ± 1.50 mm); both values were statistically significant ($p < 0.001$). Finally, the FURCA point (4.36 ± 1.79 mm) increased more than 6 + 6 but less than the E + E distance.

3.2. Haas Group

The same statistical significance of the Haas group was observed for the same measurements of the Hyrax group between T0 and T1. Small dissimilarities were shown for the amount of skeletal expansion (NF distance 2.97 ± 1.84 mm) that was greater than the LPt distance (1.93 ± 1.12 mm), but both were statistically significant ($p < 0.05$). Dental expansion was greater on the anchorage unit (E + E = 6.80 ± 2.26 mm) than on the non-anchored teeth (6 + 6 = 4.57 ± 2.32 mm), but both were statistically significant ($p < 0.05$). The FURCA point (4.14 ± 2.58 mm) moved a little less than 6 + 6.

3.3. Hyrax vs. Haas Group

None of the dental and skeletal measurements were statistically significant between the Hyrax and Haas groups in the interval T0–T1. Considering the anchorage unit on the second primary molars and the E + E distance as 100% of the dental expansion performed, the following percentages can, therefore, be calculated: the Hyrax expander allowed a skeletal expansion of 27% (NF = 1.76 ± 0.86 mm) compared to the dental expander (E + E = 6.47 ± 1.54 mm), with an indirect expansion of the upper first permanent molar of 53% (6 + 6 = 3.42 ± 1.50 mm), while the Haas expander guaranteed a greater skeletal expansion of 44% (NF = 2.97 ± 1.84 mm) compared to the dental expander (E + E = 6.80 ± 2.26 mm) with a spontaneous drift of the first molars of 67% (6 + 6 = 4.57 ± 2.32 mm). The FURCA point moved differently between Hyrax and Haas groups: in the first group the upper first molars suffered a lingual tipping differently from the second group, in which they showed a slight buccal tipping. Figure 2 represents the amount of dental and skeletal expansion among groups.

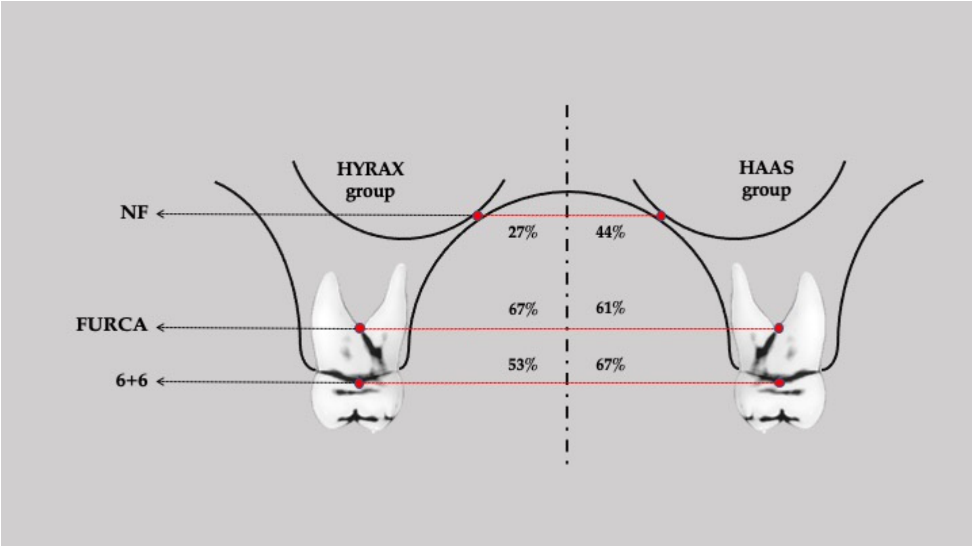


Figure 2. Representation of the percentage amount of expansion at different levels (NF, FURCA, and 6 + 6) compared to the total amount of dental expansion on the anchorage unit (E + E) between Hyrax and Haas group after RPE.

4. Discussion

A few authors have studied the effects of maxillary expansion with appliances anchored to deciduous teeth and, to the best of our knowledge, none of them have compared Hyrax and Haas with CBCT technology. The present study compared three-dimensional dental and skeletal effects of rapid palatal expansion using deciduous teeth as anchorage but comparing a tissue-borne and a tooth tissue-borne maxillary expander. Based on the obtained results, skeletal maxillary expansion is lightly affected by the appliance design, and it can be stated that, statistically and clinically, no differences between these two appliances exist; the null hypothesis was therefore confirmed.

In the literature, there are several studies that used 2D radiographs and dental casts to evaluate and measure the structural changes produced by RME [2,3,6,7,18–20]. Some authors studied these effects using 3D technologies when the first permanent molars were used as anchorage [17,21,22], also comparing tooth-borne and tooth tissue-borne appliances [2,9,13,14]. Furthermore, a few authors have studied the three-dimensional effects of maxillary expansion with appliances anchored to deciduous teeth [19,23] but, to the best of our knowledge, none of them compared the Hyrax and Haas expanders in mixed dentition using CBCT technology. As a matter of fact, CBCT technology allowed clinicians to measure the distance between anatomic landmarks, eliminating the drawbacks of traditional auxiliary examinations such as 2D radiographs and dentals casts, thus ensuring more reliable and accurate measurements, which may have been biased in previous studies [16]. Based on these premises, a stable 3D reference system was used to analyze any dental or skeletal changes after RPE; the result of intraoperator error confirmed the reliability and sensitivity of this method.

RPE on deciduous teeth is, nowadays, a common strategy to correct several transversal and sagittal discrepancies. The high forces exerted during RPE can affect the periodontal and endodontic status; thus, the anchorage onto deciduous teeth could be performed avoiding root resorption, bone loss, gingival recessions, and carious lesions on permanent dentition [18]. All of these side-effects could be avoided by using deciduous teeth as anchorage but without any statistically significant difference concerning the skeletal expansion compared to the RPE with anchorage onto permanent molars [6,7,24,25]. There was an advantage in not using permanent molars as anchorage: they were free from buccal tipping, as has been described in several studies in which the appliance was bonded on them [9,17,21,22]. Due to this, special attention must be paid regarding the spontaneous movement of the upper first molars when the expander in bonded onto deciduous teeth, independently of Hyrax or Hass type expanders. As a matter of fact, expansion onto deciduous teeth does not direct forces to the permanent molars and they can achieve a more physiological inclination and rotation to counteract bone bending and dentoalveolar compensation of posterior cross-bites, obtaining a less buccal angulation, as previously reported [26]; in the present study, first permanent molars spontaneously expanded by approximately 48% and 33% less than deciduous molars, in favor of the Haas expander compared with the Hyrax expander. This is due to a simultaneous expansion and decompensation that reduces the ability to overexpand but achieves a more physiological molar inclination. Furthermore, a spontaneous distorotation of maxillary molars implies a significant increase in the upper arch length, a possible improvement in the Class II molar relationship, and less invasive orthodontic treatments [25,27–29].

RME was effective in increasing maxillary transverse dimensions. Only a few studies have compared Hyrax and Haas appliances, but none used deciduous molars as anchorage. Nevertheless, a similar study was performed regarding nasal changes induced by RPE comparing Hyrax and Hass appliances anchored to primary teeth [15]. In that study, it was reported that no statistically significant changes in skeletal expansion were found comparing the Hyrax-type and Haas-type expanders; even if the results of skeletal expansion are similar to those of the present study, it is impossible to calculate the ratio between dental and skeletal expansion caused by the lack of the amount of dental expansion obtained on anchorage teeth. Comparing the total expansion of dental or skeletal measurement is not a reliable method as it depends on the amount of screw activations needed by each patient. The same trial analyzed the reduction in the permanent molar tipping since no direct forces were exerted on them, also reported by other authors and in accordance with the findings of the present study [7]. Another study reported a rate between skeletal expansion—the distance between nasal floor points—and dental expansion at the level of the upper first permanent molars of about 55% when RPE was performed by Hyrax expander anchored to deciduous teeth [30]; this data were comparable with that obtained in our study. However, as already mentioned, different methods from other trials mean a comparison with our result is not possible.

The expanders analyzed in the present study are certainly the most recognized in the literature but their mechanotherapy is not totally well known. The Hyrax expander has easier hygiene, greater comfort, and prevention of decubitus lesions to the palatal vault; on the other hand, the Haas expander, thanks to the acrylic pads, may guarantee a more significant expansion of the maxillary base because of the distribution of the expanding forces between the posterior teeth and the palate. Independently of the design, RPE should be performed applying forces in the range of 7 to 15 kg to maximize the skeletal separation of the midpalatal suture before any dental movement can occur [31]; for this reason, the skeletal parameters are the most investigated and clinically relevant due to smaller dentoalveolar side-effects. It has been stated that only the Haas expander optimizes the orthopedic effects of RME, avoiding all dentoalveolar effects, but this statement seems to be controversial [9]. It is probable that the different effects produced by the two analyzed devices may reflect the different force delivery systems; as a matter of fact, it has been reported that the sutural expansion designs that use an acrylic interface with teeth were far less stiff than those constructed solely of stainless-steel wires [32]. Increasing the rigidity of the appliance with acrylic results in a superior migration of the center of resistance to the frontonasal suture, resulting in a more linear separation of maxillary halves and decreasing buccal tipping of the anchorage teeth [33]; less tilting of the alveolar process and a reduced degree of dental tipping are probably the effects of the use of the Haas expander as observed in the present study. In fact, if the entire amount of dental expansion on the anchorage teeth—deciduous molars—that is the amount of screw activation considered to be 100% of the transversal expansion achievable, then it has been shown that the Haas expander produces a greater skeletal expansion (44%) compared to the Hyrax expander (27%) as the maxillary permanent molars expanded spontaneously more in the

Haas group (67%) than the Hyrax group (53%). Starting with these different dentoalveolar effects, a subsequent decompensation in the inclination of the permanent molars was observed. The Hyrax group, supposing that alveolar tilting was augmented, suffered a greater decompensation by palatal tipping of the first maxillary molars demonstrated by an increased value or transversal dimension at a level of FURCA points (67%) compared to 6 + 6 (53%); on the contrary, the Haas group showed a little buccal tipping because of a reduced expansion of FURCA points (61%) compared to 6+6 (67%). A speculative explanation could also refer to the different mechanics and skeletal consequences produced by the Hyrax or Hass expanders. Unfortunately, all of these measurement and percentages cannot be compared to other studies about deciduous teeth anchorage because of their non-existence; recently, a similar study reported about the proportion between skeletal and dental expansion, but RPE was performed anchoring both Hyrax and Haas devices onto permanent molars [14]. Furthermore, RPE produces a greater separation of the midpalatal suture anteriorly with proportionally less separation posteriorly because of the presence of a center of rotation located distal to the third molar area, corresponding to pterygomaxillary suture. The results of the present study suggest a different behavior of RPE if it is performed with the Hyrax or Haas expanders; the Hyrax group showed a little greater skeletal expansion in the posterior transvers dimension (1.93 mm) compared to the anterior area (1.76 mm) but the results of posterior measurements are superimposable to those obtained by Haas group that showed a smaller transversal increase in posterior (1.91 mm) than anterior dimensions (2.97 mm). These results were not statistically nor clinically significant between groups, but the reason for this phenomenon should be investigated, probably focusing on the biomechanics of the devices, for example, by a different location of the RPE screw into a more posterior position that may result in a more linear opening of the midpalatal suture. However, the acrylic pads against the palatal vault would be important, especially during the retention phase when they would prevent the orthopedic relapse of the expanded maxilla [13].

Finally, the most important bias in this study is represented by the difficulty in discerning the degree of transverse expansion attributable to the equipment used for the disjunction of the palate and the growth, which, in the period under analysis, could be significant from a clinical point of view; moreover, our investigation lacks a control group to compare our data with. Therefore, further studies and new reference systems must be promoted to verify these results, especially in growing patients.

5. Conclusions

Looking at the outcomes of this study, we can draw the following conclusions:

- When measuring 3D maxillary complex structural changes during RME, both Hyrax and Haas appliances anchored on primary teeth showed similar results without any differences in term of skeletal and dental expansion; deciduous teeth could achieve a comparable expansion to permanent teeth but avoiding the possible side-effects reported in the literature.
- Dental expansion was always greater than skeletal expansion; the difference in the appliance design and its subsequent rigidity may play an important role in the effectiveness and in the ratio between dental and skeletal expansion.
- The maxillary expansion on primary teeth could achieve the normal eruption of first molars, avoiding the excessive buccal tipping that occurred when RME was performed using these teeth as anchorage; an improvement in the rotation of the first permanent molar is also achievable promoting a potential and spontaneous correction of the Class II molar relationship.

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References

1. Martina, R.; Cioffi, I.; Farella, M.; Leone, P.; Manzo, P.; Matarese, G.; Portelli, M.; Nucera, R.; Cordasco, G. Transverse changes determined by rapid and slow maxillary expansion—A low-dose CT-based randomized controlled trial. *Orthod. Craniofac. Res.* **2012**, *15*, 159–168.
2. Oliveira, N.L.; Da Silveira, A.C.; Kusnoto, B.; Viana, G. Three-dimensional assessment of morphologic changes of the maxilla: A comparison of 2 kinds of palatal expanders. *Am. J. Orthod. Dentofac. Orthop.* **2004**, *126*, 354–362.
3. Lamparski, D.G., Jr.; Rinchuse, D.J.; Close, J.M.; Sciote, J.J. Comparison of skeletal and dental changes between 2-point and 4-point rapid palatal expanders. *Am. J. Orthod. Dentofac. Orthop.* **2003**, *123*, 321–328.
4. Costa, J.G.; Galindo, T.M.; Mattos, C.T.; Cury-Saramago, A.A. Retention period after treatment of posterior crossbite with maxillary expansion: A systematic review. *Dent. Press J. Orthod.* **2017**, *22*, 35–44.
5. Lanteri, V.; Cavagnetto, D.; Abate, A.; Mainardi, E.; Gaffuri, F.; Ugolini, A.; Maspero, C. Buccal Bone Changes Around First Permanent Molars and Second Primary Molars after Maxillary Expansion with a Low Compliance Ni-Ti Leaf Spring Expander. *Int. J. Environ. Res. Public Health* **2020**, *17*, 9104.
6. Cozzani, M.; Rosa, M.; Cozzani, P.; Siciliani, G. Deciduous dentition-anchored rapid maxillary expansion in crossbite and non-crossbite mixed dentition patients: Reaction of the permanent first molar. *Prog. Orthod.* **2003**, *4*, 15–22.
7. Cozzani, M.; Guiducci, A.; Mirenghi, S.; Mutinelli, S.; Siciliani, G. Arch width changes with a rapid maxillary expansion appliance anchored to the primary teeth. *Angle Orthod.* **2007**, *77*, 296–302.
8. Quinzi, V.; Federici Canova, F.; Rizzo, F.A.; Marzo, G.; Rosa, M.; Primozic, J. Factors related to maxillary expander loss due to anchoring deciduous molars exfoliation during treatment in the mixed dentition phase. *Eur. J. Orthod.* **2021**, *43*, 332–337.
9. Garib, D.G.; Henriques, J.F.; Janson, G.; Freitas, M.R.; Coelho, R.A. Rapid maxillary expansion—Tooth tissue-borne versus tooth-borne expanders: A computed tomography evaluation of dentoskeletal effects. *Angle Orthod.* **2005**, *75*, 548–557.
10. Fernandes, L.C.; Farinazzo Vitral, R.W.; Noritomi, P.Y.; Schmitberger, C.A.; Jose da Silva Campos, M., Influence of the hyrax expander screw position on stress distribution in the maxilla: A study with finite elements. *Am. J. Orthod. Dentofac. Orthop.* **2019**, *155*, 80–87.
11. Garib, D.G.; Henriques, J.F.; Carvalho, P.E.; Gomes, S.C. Longitudinal effects of rapid maxillary expansion. *Angle Orthod.* **2007**, *77*, 442–448.
12. Bazargani, F.; Feldmann, I.; Bondemark, L. Three-dimensional analysis of effects of rapid maxillary expansion on facial sutures and bones. *Angle Orthod.* **2013**, *83*, 1074–1082.
13. Weissheimer, A.; de Menezes, L.M.; Mezomo, M.; Dias, D.M.; de Lima, E.M.; Rizzatto, S.M. Immediate effects of rapid maxillary expansion with Haas-type and hyrax-type expanders: A randomized clinical trial. *Am. J. Orthod. Dentofac. Orthop.* **2011**, *140*, 366–376.
14. Araújo, M.C.; Bocato, J.R.; Oltramari, P.V.; de Almeida, M.R.; Conti, A.C.; Fernandes, T.M., Tomographic evaluation of dentoskeletal effects of rapid maxillary expansion using Haas and Hyrax palatal expanders in children: A randomized clinical trial. *J. Clin. Exp. Dent.* **2020,** 12, e922–e930.
15. Fastuca, R.; Lorusso, P.; Lagravère, M.O.; Michelotti, A.; Portelli, M.; Zecca, P.A.; D'Antò, V.; Militi, A.; Nucera, R.; Caprioglio, A. Digital evaluation of nasal changes induced by rapid maxillary expansion with different anchorage and appliance design. *BMC Oral Health* **2017**, *17*, 113.
16. Lagravere, M.O.; Major, P.W.; Carey, J. Sensitivity analysis for plane orientation in three-dimensional cephalometric analysis based on superimposition of serial cone beam computed tomography images. *Dentomaxillofacial Radiol.* **2010**, *39*, 400–408.
17. Lagravere, M.O.; Carey, J.; Heo, G.; Toogood, R.W.; Major, P.W. Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: A randomized clinical trial. *Am. J. Orthod. Dentofac. Orthop.* **2010**, *137*, 304 e1–304.e12; discussion 304–305.

18. Mutinelli, S.; Manfredi, M.; Guiducci, A.; Denotti, G.; Cozzani, M. Anchorage onto deciduous teeth: Effectiveness of early rapid maxillary expansion in increasing dental arch dimension and improving anterior crowding. *Prog. Orthod.* **2015**, *16*, 22.
19. Luca, L.; Enrico, A.; Angela, A.; Chiara, D.A.A.; Giuseppe, S. Rapid maxillary expansion on the permanent teeth versus the deciduous teeth: Comparison of skeletal and dentoalveolar effects by volumetric tomography. *J. World Fed. Orthod.* **2015**, *4*, 2–7.
20. Caroccia, F.; Moscagiuri, F.; Falconio, L.; Festa, F.; D'Attilio, M. Early Orthodontic Treatments of Unilateral Posterior Crossbite: A Systematic Review. *J. Clin. Med.* **2020**, *10*, 33.
21. Garrett, B.J.; Caruso, J.M.; Rungcharassaeng, K.; Farrage, J.R.; Kim, J.S.; Taylor, G.D. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. *Am. J. Orthod. Dentofac. Orthop.* **2008**, *134*, 8–9.
22. Kartalian, A.; Gohl, E.; Adamian, M.; Enciso, R. Cone-beam computerized tomography evaluation of the maxillary dentoskeletal complex after rapid palatal expansion. *Am. J. Orthod. Dentofac. Orthop.* **2010**, *138*, 486–492.
23. Rosa, M.; Lucchi, P.; Manti, G.; Caprioglio, A. Rapid Palatal Expansion in the absence of posterior cross-bite to intercept maxillary incisor crowding in the mixed dentition: A CBCT evaluation of spontaneous changes of untouched permanent molars. *Eur. J. Paediatr. Dent.* **2016**, *17*, 286–294.
24. Sari, Z.; Uysal, T.; Usumez, S.; Basciftci, F.A. Rapid maxillary expansion. Is it better in the mixed or in the permanent dentition? *Angle Orthod.* **2003**, *73*, 654–661.
25. Cerruto, C.; Ugolini, A.; Di Vece, L.; Doldo, T.; Caprioglio, A.; Silvestrini-Biavati, A. Cephalometric and dental arch changes to Haas-type rapid maxillary expander anchored to deciduous vs permanent molars: A multicenter, randomized controlled trial. *J. Orofac. Orthop.* **2017**, *78*, 385–393.
26. Ugolini, A.; Cerruto, C.; Di Vece, L.; Ghislanzoni, L.H.; Sforza, C.; Doldo, T.; Silvestrini-Biavati, A.; Caprioglio, A. Dental arch response to Haas-type rapid maxillary expansion anchored to deciduous vs permanent molars: A multicentric randomized controlled trial. *Angle Orthod.* **2015**, *85*, 570–576.
27. Mutinelli, S.; Cozzani, M.; Manfredi, M.; Bee, M.; Siciliani, G. Dental arch changes following rapid maxillary expansion. *Eur. J. Orthod.* **2008**, *30*, 469–476.
28. Guest, S.S.; McNamara, J.A., Jr.; Baccetti, T.; Franchi, L. Improving Class II malocclusion as a side-effect of rapid maxillary expansion: A prospective clinical study. *Am. J. Orthod. Dentofac. Orthop.* **2010**, *138*, 582–591.
29. Abate, A.; Cavagnetto, D.; Rusconi, F.M.E.; Cressoni, P.; Esposito, L. Safety and Effects of the Rapid Maxillary Expander on Temporomandibular Joint in Subjects Affected by Juvenile Idiopathic Arthritis: A Retrospective Study. *Children* **2021**, *8*, 33.
30. Lo Giudice, A.; Fastuca, R.; Portelli, M.; Militi, A.; Bellocchio, M.; Spinuzza, P.; Briguglio, F.; Caprioglio, A.; Nucera, R. Effects of rapid vs slow maxillary expansion on nasal cavity dimensions in growing subjects: A methodological and reproducibility study. *Eur. J. Paediatr. Dent.* **2017**, *18*, 299–304.
31. Lione, R.; Ballanti, F.; Franchi, L.; Baccetti, T.; Cozza, P., Treatment and posttreatment skeletal effects of rapid maxillary expansion studied with low-dose computed tomography in growing subjects. *Am. J. Orthod. Dentofac. Orthop.* **2008**, *134*, 389–392.
32. Braun, S.; Bottrel, J.A.; Lee, K.G.; Lunazzi, J.J.; Legan, H.L. The biomechanics of rapid maxillary sutural expansion. *Am. J. Orthod. Dentofac. Orthop.* **2000**, *118*, 257–261.
33. Halıcıoğlu, K.; Yavuz, I. Comparison of the effects of rapid maxillary expansion caused by treatment with either a memory screw or a Hyrax screw on the dentofacial structures—Transversal effects. *Eur J. Orthod.* **2014**, *36*, 140–149.