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Original article

Dento-skeletal response to three different protocols of rapid maxillary expansion in hyperdivergent growing subjects: a longitudinal retrospective study

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Summary

Background: The aim of this study was to evaluate the dento-skeletal response in hyperdivergent growing patients comparing Rapid Maxillary Expansion (RME) using three different protocols.

Materials and Methods: Three groups of hyperdivergent subjects treated with RME were analyzed. In 41 patients (23F, 18M) the RME was bonded on the maxillary deciduous second molars (E-RME group); in 40 patients (24F, 16M) the RME was bonded on the first permanent maxillary molars (6-RME group); in 45 patients (26F,19M) the RME was bonded on the first permanent maxillary molars with a removable mandibular Bite-Block (6-RME/BB group). Lateral cephalograms and dental casts were scanned and digitally measured before treatment (T1), at the appliance removal (T2) and at least 1 year after the appliance removal (T3). The comparison was made within the same group and between the groups. Statistical comparisons were assessed with analysis of variance multi-comparison test (*P = 0.05).

Results: A significant increase of upper molars buccal tipping was observed in 6-RME group when compared with E-RME and 6-RME/BB groups in the short-term (T2–T1) and long-term (T3–T1); a significant intercanine width increase was observed in E-RME group at the same times. No significant differences in dentoalveolar variables were observed comparing E-RME group versus 6-RME/BB group.

Conclusions: The E-RME protocol allows for a greater skeletal expansion and produces a lower buccal tipping of the first permanent upper molars. The use of the BB in 6-RME/BB group shows a similar attitude to the E-RME protocol then can be considered an effective therapeutic alternative.

Introduction

Maxillary constriction can be associated with several problems that include occlusal disharmony and aesthetics, such as functional difficulties as narrowing of the pharyngeal airway, increased nasal resistance, and alterations in tongue posture, resulting in retroglossal airway narrowing and mouth breathing. Therefore, early treatment of this malocclusion through palatal expansion is strongly recommended (1).

Rapid Maxillary Expansion (RME) is widely used to treat transverse deficiency by opening the mid-palatal suture, which has not yet completely ossified in growing individuals (2). According to Baccetti *et al.* (3), RME before the peak in skeletal growth velocity is able to induce more pronounced transverse craniofacial changes at the skeletal level. With increasing age, resistance originating from various structures of the craniofacial complex becomes greater (2). In order to reduce the risks of complications and to maximize the benefits on the transversal plane with a minimal dental compensation effect, RME treatment should be performed before the peak of pubertal growth (4).

In the active phase, heavy forces are exerted against the anchor teeth to open the mid-palatal suture (5) and these forces decrease slowly during the 5–7 weeks retention phase (6). Basal bones continue to relapse until 10 months after the expansion (7) and anchoring teeth are reported to suffer from the following changes: exostosis, pulp stones, and root resorption (8). Moreover, in patients with transverse deficiency, molars are often tilted buccally to compensate the narrow palate. Therefore, when the first permanent molars serve as anchor teeth, they will tilt buccally even more (9–11). Asanza *et al.* (12) reported that RME anchored on permanent molars produced a variation of the angulation of these teeth instead of a real skeletal expansion.

Transverse deficiency (e.g. posterior crossbite, anterior crowding, crowding, or arch length discrepancy due to narrow arches) may also be present in hyperdivergent patients. These patients are a particular challenge during orthodontic treatment and rapid palatal expansion is no exception.

Several studies documented that RME produces a vector of maxillary movement manifested in a downward and forward displacement of the maxilla (13). This change of maxillary posture invariably causes a downward and backward rotation of the mandible resulting in an increase in the vertical dimension of the lower face which is undesirable in patients with increased vertical pattern. Moreover, dental extrusion, lateral rotation of the maxillary segments, and cuspal interferences have also been attributed to this bite opening characteristic of RME (14). Therefore, the displacement of the maxilla

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during RME is not helpful if expansion must be performed in a patient with hyperdivergent pattern. This is particularly true if we consider that, traditionally, RME is anchored onto the first permanent molars and upon expansion, these teeth become buccally inclined (15).

To avoid any undesired side effects on permanent teeth, it might be prudent to utilize deciduous teeth to anchor the RME, especially during the mixed dentition stage (15). The effectiveness of RME anchored on deciduous teeth has been reported by some authors who have investigated the changes in molar dental tipping following maxillary expansion with RME bonded on first permanent molars or deciduous molars (15–18).

Ugolini *et al*. and Cerruto *et al*. suggested that E-RME reduced molar angulation increases when it was compared with RME anchored on permanent teeth (16, 17). The authors reported that RME anchored on deciduous teeth produced a net increase of maxillary intercanine distance, indicating a more stable expansion on the anterior region of the arch, resulting in a significant and spontaneous alignment of the upper central and lateral incisors (16, 17). Also, Mutinelli *et al*. stressed that the deciduous teeth can be used as anchoring for the application of heavy forces such as those produced during RME treatment and stated it as an effective type of treatment of the maxillary transverse deficit (16–18).

The RME bonded on deciduous molars might be also advantageous in hyperdivergent subjects to control vertical dimension and to counteract the changes in mandible posture during expansion when RME is anchored on permanent teeth. Sarver and Johnston suggested that the inferior displacement of the maxilla might be limited during treatment by the forces placed on the dentition by the elevator musculature and by the force associated with the stretch of the other soft tissues (19). Therefore, for hyperdivergent patients, one of the treatment strategies is based on the inhibition of vertical development by producing an anterior rotation of the mandible with reduction of facial skeletal divergence (20, 21). This effect can be possible using a Bite-Block (BB) in the mandibular arch that enables effective control of mandibular rotation (22, 23) and influences the development of the masseter muscles, perhaps due to the stretching effect of the muscles (20).

Akkaya *et al*. (24) found a positive correlation of the BB on masticatory muscles (e.g. masseter) and showed that muscle activities increased when this appliance was used, and this could positive affect the vertical pattern of long-faced subjects. Kuster and Ingervall (25) reported that the BB could have several beneficial therapeutic effects of both maxillary and mandibular arch, producing an intrusive action on the molars, and allowing the jaw to grow and to move forward and up.

The aim of this study is to evaluate the dento-skeletal response in hyperdivergent growing patients comparing a group of subjects with RME anchored on second deciduous molars (E-RME) and two groups of subjects with RME bonded on first permanent molars with (6-RME/BB) and without (6-RME) a BB on the mandibular arch.

Materials and methods

Three groups of subjects with hyperdivergent growing pattern treated with a rapid maxillary expander were selected from files of the Departments of Orthodontics of the University of Rome "Tor Vergata" in the period between 2006 and 2019. This project was approved by the ethical committee at the University of Rome "Tor Vergata" (protocol number 0015776/2019), and informed consent was obtained from patients' parents. The inclusion and exclusion criteria were shown in Table 1.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Class I–II	Caries, restored teeth
Mixed Dentition	Deciduous or permanent teeth extracted before or during treatment
Lack of anterior crossbite	Tooth agenesis
Subjects before the pubertal peak (CVM 1–2)	Craniofacial abnormalities or systemic disorders
Upper deciduous second molars available as RME anchoring teeth*	Skeletal asymmetries
Hyperdivergent skeletal pattern (FMA** > 26°, SN^GoGn*** > 37°)	Sucking habits
Full eruption of first permanent molars	Previous orthodontic treatment
	Lack of records
	Lack of compliance

*The deciduous molar was considered available as anchoring tooth when the root had the same length as the clinical crown at the orthopantomogram rx examination (12).
,*Refer to Figure 5 for the location of each landmark.

E-RME group consisted of 41 patients (23F, 18M) treated with RME soldered on the second deciduous molars (Figure 1a). 6-RME group consisted of 40 subjects (24F, 16M) treated only with RME soldered on the first permanent molars (Figure 1b). 6-RME/BB group consisted of 45 subjects (26F, 19M) treated with RME soldered on the first permanent molars and removable posterior BB in the lower arch (Figures 1b and 2) (22). The mean age of the patients at T1, T2, and T3 is reported in Table 2.

All the subjects included in the present study had the following complete records: three cephalograms, obtained using a modern cephalostat with 1.5 m of focus/film distance, and maxillary digital dental casts toke before treatment (T1), at the appliance removal (8 months, T2), and at least 1 year after the appliance removal (T3).

Each patient underwent at the same treatment protocol with 'Butterfly' expander (26) (Snap-lock expander screw, Leone, Pforzheim, Germany) bonded on first permanent molars or second deciduous molars. The expansion screw was activated twice a day (0.25 mm for activation) until overcorrection was achieved (i.e. the palatal cusps of the maxillary posterior teeth approximated the buccal cusps of the mandibular posterior teeth) in each group; the amount of the expansion was between 20 and 30 activations of the screw. At the end of the active phase, RME was left in place for at least 8 months as a passive retainer stabilizing the expansion reached during screw activation. After 8 months, the RME was removed, and no removable or cemented retention appliance was applied.

Patients of 6-RME/BB group received, during the active phase, a removable mandibular acrylic appliance (BB) constructed in the form of Schwarz plate with posterior occlusal resin splints of 5-mm thickness (20). The BB was used to control vertical dimension and permanent molars angulation during expansion. The patients were instructed to wear the

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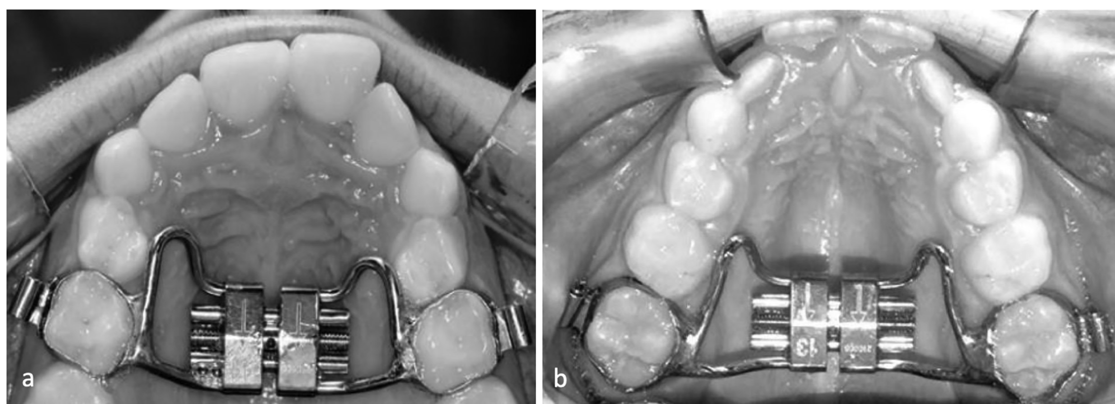

Figure 1. (a) RME bonded on second deciduous molars. (b) RME bonded on first permanent molars.

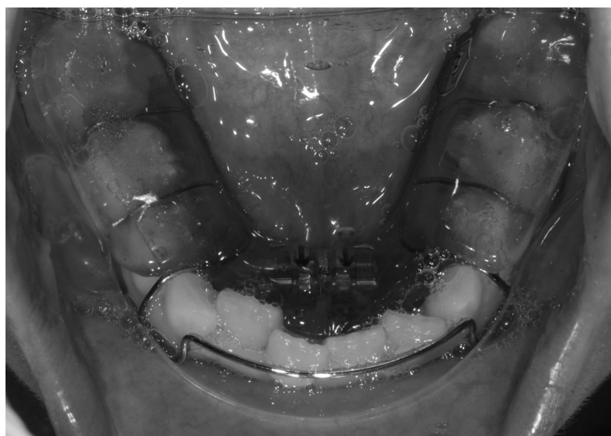

Figure 2. Mandibular Bite-Block.

BB 24 h a day. As in studies involving any removable device, compliance varied among patients. Therefore, a single investigator conducted a face-to-face interview with each patient to assess his or her cooperation. Compliance was appraised with a 3-point Likert-type scale (poor, moderate, good) (27,28): poor compliance was reported when the patient wore the BB at night only, moderate compliance occurred when the patient wore the BB at night and during the day at home, and good compliance was assessed when the patient wore the BB full time as suggested by the clinician. The mandibular BB was removed with RME after 8 months of active treatment (T2).

Measurements on digital dental casts

The maxillary dental casts were elaborated by a 3D scanner and reference points were plotted by 3D Software (Viewbox, version 4.0, dHAL Software, Kifissia, Greece). All measurements were calculated at T1, T2, and T3 on digital dental casts with a specific software by a single operator (X.X.) and then were checked by a second operator (X.X.). Each model has been subjected to the following measurements (Figures 3a, b and 4):

Intermolar width

The intermolar width (IMW) measured as the distance between mesiobuccal cusps tips of the first permanent maxillary molars bilaterally (16).

Intercanine width

The intercanine width (ICW) was measured as the distance between cusp tips of maxillary primary canine bilaterally (16).

Molar torque (Tor16; Tor26)

The molar torque was measured as the maxillary molar crown angulation. Two points per teeth were marked to trace the facial axis of the clinical crown (FACC) of the first permanent maxillary molars, according to the protocol by Ugolini *et al.* (16). A Triangular reference Plane through the detection of three palatal points (interincisal papilla; right and left molar points at the intersection of the tooth and gingival margin between the two cusps) was constructed (21). The angles between FACC and this reference plane were then measured. These angles corresponded to crown angulation on a reference plane and their clinical equivalent was the torque of the crown (29,30).

Measurements on cephalograms

All cephalometric measurements were taken on a lateral cephalogram at T1, T2, and T3 by a single operator (F.S.) and then were checked by a second operator (M.M.). All the reference points and anatomical structures were verified: any differences were resolved by retracing reference points or anatomical structures to satisfy both operators. A Cephalometric software (Viewbox, version 4.0, dHAL Software, Kifissia, Greece) was used for a customized digitization regimen used for the cephalometric evaluation. All lateral cephalograms were standardized with regard to magnification factor by setting this at 0%. The Hyperdivergent skeletal pattern was defined with a Frankfort horizontal plane to mandibular plane angle > 26° and with an SN^GoGn angle > 37° (Figure 5). The remaining cephalometric reference points, lines, and angles used in the analysis are shown in Figure 6 according to Steiner CC, Jacobson A, Ricketts RM, and Mc Namara JA, Jr analysis (31–34).

Statistical analysis

The sample size was calculated according to the previous literature (16); a statistical power of the study at 0.95 with an alpha of 0.05 was estimated. The calculated sample size for the multi-comparison analysis test was 28 subjects in each group. Data were analyzed with conventional descriptive statistics. The normal distribution of the data was tested with the Kolmogorov-Smirnov test. The hypothesis that the data were normally distributed could not be rejected for any variable. To standardize the method, measurements and landmark location were repeated 15 days after the first measurement on the 30% randomly selected casts and radiograph to determine the error of method. Dahlberg's values method error was performed and ranged from 0.24 to 0.65 mm for linear

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Table 2. Demographic of the groups

Group	Sample, *n* (Female, Male)	Mean (Years, Months)	SD (Years, Months)	Minimum (Years, Months)	Maximum (Years, Months)
E-RME					
T1	41 (23, 18)	8.2	1.3	6.8	9.4
T2	41 (23, 18)	8.8	1.1	7.6	9.7
T3	41 (23, 18)	10.1	1.5	8.5	11.4
6-RME					
T1	40 (24, 16)	8.6	1.2	7.5	9.9
T2	40 (24, 16)	9.2	1.3	6.9	11.7
T3	40 (24, 16)	10.4	1.7	7.7	13.5
6-RME/BB					
T1	45 (26, 19)	8.7	1.2	7.8	10.0
T2	45 (26, 19)	9.1	1.6	6.5	11.7
T3	45 (26, 19)	10.3	1.8	7.5	13.3

SD, standard deviations.

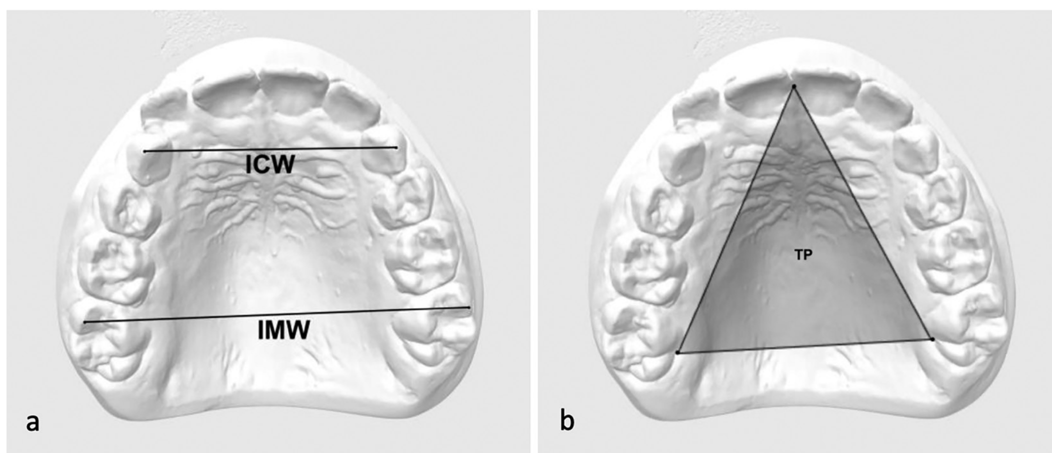

Figure 3. (a) ICW, intercanine width; IMW, intermolar width. (b) TP, triangular reference plane for crown angulation of 1.6 and 2.6.

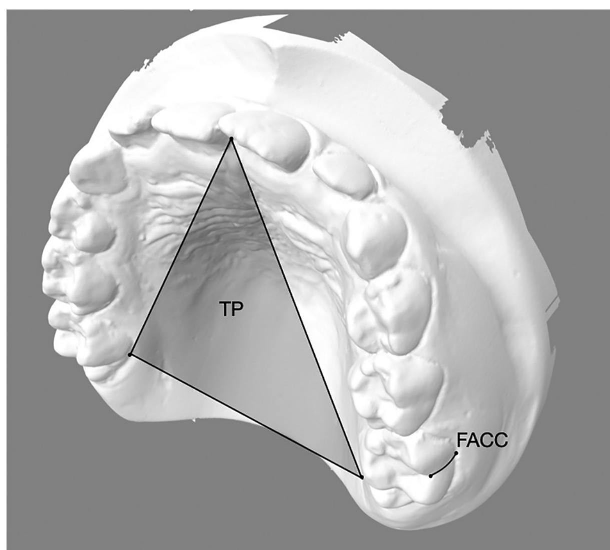

Figure 4. 3D view of measured Molar Torque. FACC, facial axis of the clinical crown; TP, triangular reference plane.

measurement and ranged from 0.7° and 1.0° for the angular measurement.

A one-way multi-comparison analysis of variance (ANOVA; T1, T2, and T3 were the independent variables) was used to find statistically significant differences for the variables analyzed in the same group (widths and angulations). In Table 3, the inter-group changes at T1, T2 and T3 were compared with a multi-comparison ANOVA and confirmed by *t*-tests. The level of significance was set at $P < 0.05$.

Results

Analysis of the starting forms (Table 4) showed that the three groups had no statistically significant differences in skeletal and dental characteristics at T1.

Intra-group comparisons

T2–T1

The statistical comparisons of T2–T1 changes (Tables 5–7) showed in all groups a statistically significant increase of ANB° angle. The 6-RME group exhibited a significant increase of Wits value ($P < 0.05$).

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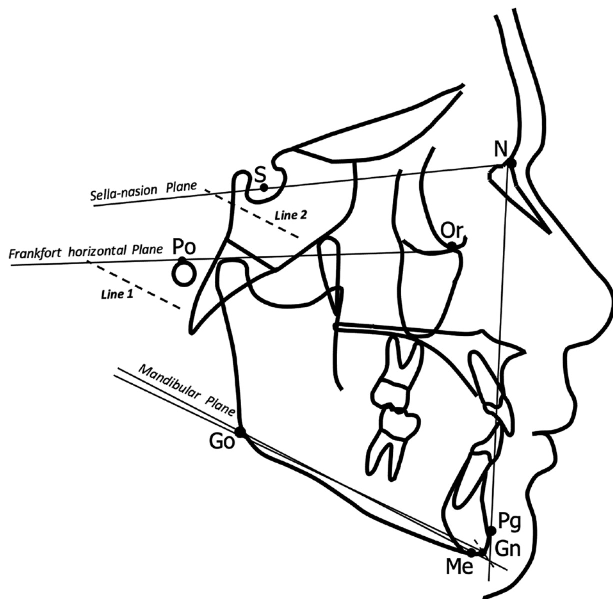

Figure 5. Cephalometric points, lines, planes, and angles used in analysis to determine the vertical Hyperdivergent skeletal pattern. S, sella; N, nasion; Po, porion; Or, orbitale; Me, menton; Go, gonion; Gn, gnation; Pg, pogonion; sella-nasion plane (SN), line from S to N; mandibular plane (MP) line from Go to Gn; Frankfort horizontal plane (FP), line from Po to Or; mandibular plane (MP) line from Go to Me; **Line 1**: Frankfort horizontal plane to mandibular plane angle (FMA), angle between Frankfort horizontal plane (Po-Or) to mandibular plane (Go-Me). **Line 2**: Sella Nasion plane to Mandibular plane angle (SN^GoGn), angle between the Sella Nasion plane (SN) to Mandibular plane (Go-Gn).

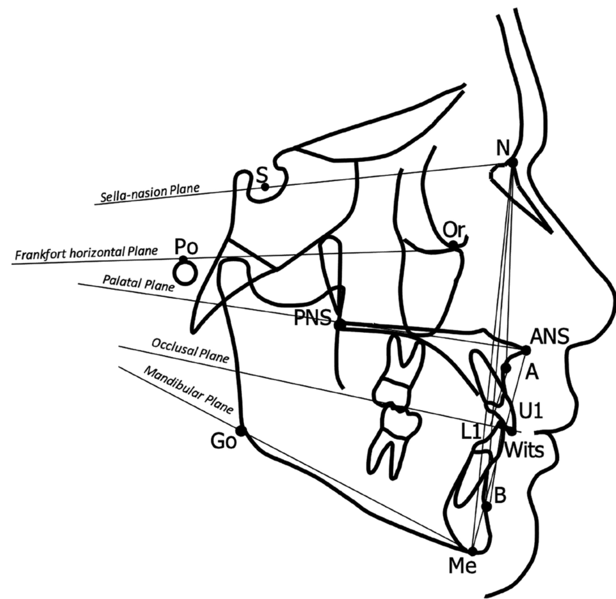

Figure 6. Cephalometric points, lines, planes and angles used in analysis: S, sella; N, nasion; Po, porion; Or, orbitale; ANS, anterior nasal spine; PNS, posterior nasal spine; A, point A; B, point B; Me, menton; Go, gonion; U1, incisal edge of the maxillary incisor; L1, incisal edge of the mandibular incisor; lower anterior facial height (ANS-Me), line from ANS to Me; sella-nasion plane (SN), line from S to N; Frankfort horizontal plane (FP), line from Po to Or; mandibular plane (MP) line from Go to Me; palatal plane (PP), line from PNS to ANS; occlusal plane (OP), line drawn along the maximum intercuspation of the posterior teeth; WITS value (WITS), perpendiculars from points A and B on the maxilla and mandible, respectively, onto the occlusal plane; overbite (OB) vertical linear distance from L1 to U1; sella-nasion-point A angle (SNA), angle between SN plane and NA plane; sella-nasion-point B angle (SNB), angle between SN plane and NB plane; point A-nasion-point B angle (ANB), difference between SNA and SNB; palatal plane to mandibular plane angle (PP^MP), angle between palatal plane and mandibular plane.

For the digital casts measurements, both ICW and IMW evidenced a significantly increase at T2 in all groups ($P < 0.05$).

The 6-RME group evidenced a significant increase of molars buccal tipping ($P < 0.05$) instead the Overbite value showed a significant reduction at T2 ($P < 0.05$).

T3–T2

During T3–T2 interval (Tables 5–7), the value of ANB° angle exhibited a statistically significant decrease for all groups ($P < 0.05$).

Those changes were also associated with a significant decrease of Wits value in 6-RME group ($P < 0.05$) while Overbite value resulted statistically increased in the same group (T2, 1.2 mm/T3, 2.6 mm).

For the dental relationship measurements, the 6-RME group showed a statistically significant decrease of IMW ($P < 0.05$).

T3–T1

The analysis of T3–T1 interval (Tables 5–7) showed in all groups no statistically significant changes for the sagittal and vertical skeletal measurements, while digital dental casts measurements showed a statistically significant increase of ICW and IMW at T3 ($P < 0.05$).

Inter-group comparisons

T2-T1

In the analysis of cephalometric values (Table 3, Supplementary Table 1), no differences among the groups were found in the comparison T2–T1 for the sagittal and vertical skeletal measurements. The 6-RME group showed in T2–T1 a statistically significant decrease of Overbite when compared with E-RME ($P < 0.43$) and 6-RME/BB ($P < 0.42$) groups and a statistically significant increase of molars buccal tipping and IMW respect to the other groups ($P < 0.05$). Moreover, a statistically significant increase of ICW was found in E-RME group than 6-RME ($P < 0.36$) and 6-RME/BB ($P < 0.34$) groups.

T3–T2

The statistical analysis of cephalometric values in T3–T2 interval (Table 3, Supplementary Table 2) showed no statistically significant differences between the groups for any skeletal cephalometric variable. For the dental cephalometric relationship measurements, a statistically significant increase of Overbite was evidenced in 6-RME group when compared with E-RME ($P < 0.46$) and 6-RME/BB ($P < 0.40$) groups.

Measurements on digital dental casts in 6-RME group showed a statistically significant decrease of molars buccal tipping ($P < 0.05$) and of IMW respect to E-RME ($P < 0.42$) and 6-RME/BB ($P < 0.47$) group.

T3–T1

The statistical comparisons of T3–T1 changes (Table 3, Supplementary Table 3) regarding cephalometric measurements showed no statistically significant difference between the groups. For the measurements on digital dental casts was found a statistically significant increase of molars buccal tipping in 6-RME group when compared to the other groups ($P < 0.05$). No

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Table 3. Intergroup comparison of P-values of mean differences in the three analyzed time points

	T2–T1			T3–T2			T3–T1		
	E-RME Versus 6-RME/BB	E-RME Versus 6-RME	6-RME/ BB Versus 6-RME	E-RME Versus 6-RME/BB	E-RME Versus 6-RME	6-RME/ BB Versus 6-RME	E-RME Versus 6-RME/BB	E-RME Versus 6-RME	6-RME/ BB Versus 6-RME
Lateral cephalogram	***P*-value**			***P*-value**			***P*-value**		
SNA (°)	0.094	0.086	0.092	0.089	0.090	0.087	0.096	0.093	0.094
SNB (°)	0.089	0.075	0.078	0.091	0.073	0.081	0.091	0.098	0.096
ANB (°)	0.091	0.082	0.086	0.091	0.084	0.078	0.096	0.091	0.087
Wits (mm)	0.087	0.084	0.088	0.092	0.086	0.083	0.092	0.082	0.089
PP^PM (°)	0.088	0.085	0.090	0.089	0.087	0.086	0.091	0.084	0.090
OB (mm)	0.086	0.043*	0.042*	0.091	0.046*	0.040*	0.094	0.079	0.082
Ans-Me (mm)	0.078	0.081	0.080	0.079	0.082	0.077	0.080	0.082	0.081
FMA (°)	0.085	0.087	0.088	0.084	0.085	0.087	0.088	0.086	0.089
Dental casts									
Torque 26 (°)	0.067	0.024*	0.029*	0.082	0.043*	0.047*	0.081	0.041*	0.047*
Torque 16 (°)	0.072	0.031*	0.037*	0.091	0.049*	0.042*	0.084	0.043*	0.046*
ICW (mm)	0.034*	0.036*	0.074	0.072	0.083	0.074	0.041*	0.043*	0.064
IMW (mm)	0.067	0.031*	0.035*	0.087	0.042*	0.047*	0.078	0.068	0.071

Refer to Figures 3a,b, 4–6 for the location of each landmark. Refer to Tables 5–7 for the mean values differences.
$^*P < 0.05$.

Table 4. Descriptive statistics and statistical comparisons on the starting forms (cephalometric, molars torque and dental arch distances values at T1)

	E-RME group ($N = 41$) (1)		6-RME/BB group ($N = 45$) (2)		6-RME group ($N = 40$) (3)		Statistical comparisons ($P < 0.05$)		
	Mean	SD	Mean	SD	Mean	SD	1 vs. 2	1 vs. 3	2 vs. 3
Lateral cephalogram									
SNA (°)	80.1	5.2	80.9	5.4	81.3	5.6	0.71	0.33	0.54
SNB (°)	75.1	4.8	74.9	4.6	76.7	4.5	0.84	0.14	0.08
ANB (°)	5.0	2.2	6	2.1	4.6	2.4	0.07	0.41	0.06
Wits (mm)	3.8	1.3	3.7	1.2	4.0	1.1	0.62	0.08	0.07
PP^PM (°)	33.4	4.1	33.6	4.4	32.6	4.0	0.25	0.13	0.06
OB (mm)	2.1	1.8	2.2	2.8	2.4	1.9	0.09	0.07	0.08
Ans-Me (mm)	60.3	4.1	59.7	4.3	59.3	3.9	0.13	0.09	0.15
FMA (°)	29.5	3.7	30.1	3.9	29.3	3.5	0.07	0.16	0.06
Dental casts									
Torque 26 (°)	−19.6	4.0	−18.9	4.0	−18.9	4.6	0.07	0.07	1.00
Torque 16 (°)	−18.5	4.9	−18.5	4.9	−19.4	5.6	1.00	0.08	0.08
ICW (mm)	28.3	4.4	29.1	4.4	28.2	4.3	0.08	0.92	0.09
IMW (mm)	47.9	2.9	48.3	2.9	48.3	5.2	0.25	0.24	1.00

Refer to Figures 3a, b, 4–6 for the location of each landmark.
SD, standard deviations.
$^*P < 0.05$.

significant differences of the same values were found comparing E-RME vs 6-RME/BB group.

A statistically significant increase of ICW was found in E-RME group when compared with 6-RME and 6-RME/BB groups ($P < 0.05$).

Discussion

All patients examined in this study had a narrow palate as a common characteristic; this last was matched by an hyperdivergent pattern. All the subjects included in this

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Table 5. Cephalometric values, molars torque and dental arch distances in E-RME patients

	T1			T2			T3			Comparisons					
E-RME	Mean	SD	CI	Mean	SD	CI	Mean	SD	CI	T2–T1		T3–T2		T3–T1	
Lateral cephalogram										**Diff**	***P***	**Diff**	***P***	**Diff**	***P***
SNA (°)	80.1	5.2	±1.59	81.4	5.7	±1.74	80.3	5.5	±1.68	1.3	0.81	−1.1	0.86	0.2	0.93
SNB (°)	75.1	4.8	±1.47	73.2	4.9	±1.50	75.0	4.6	±1.40	−1.9	0.84	1.8	0.81	−0.1	0.95
ANB (°)	5.0	2.2	±0.67	8.2	1.9	±0.58	5.3	2.1	±0.64	3.2*	0.04*	−2.9*	0.04*	0.3	0.12
Wits (mm)	3.8	1.3	±0.39	4.3	0.9	±0.27	3.9	1.1	±0.33	0.5	0.07	−0.4	0.07	0.1	0.24
PP^PM (°)	33.4	4.1	±1.25	33.8	4.2	±1.28	33.6	3.9	±1.19	0.4	0.93	−0.2	0.96	0.2	0.96
OB (mm)	2.1	1.8	±0.55	1.9	2.0	±0,61	2.2	1.9	±0.58	−0.2	0.61	0.3	0.56	0.1	0.83
Ans-Me (mm)	60.3	4.1	±1.25	61.6	3.9	±1.19	60.5	4.3	±1.31	1.3	0.27	−1.1	0.25	0.2	0.72
FMA (°)	29.5	3.7	±1.13	30.4	4.0	±1.19	29.7	3.9	±1.19	0.9	0.45	−0.7	0.42	0.2	0.83
Dental casts															
Torque 26 (°)	−19.6	4.0	±1.22	−16.5	6.9	±2.11	−16.3	10.6	±3.24	3.1	0.07	0.2	0.42	3.3	0.07
Torque 16 (°)	−18.5	4.9	±1.50	−15.8	6.5	±1.99	−15.6	7.6	±2.32	2.7	0.08	0.2	0.36	2.9	0.07
ICW (mm)	28.3	4.4	±1.34	34.6	2.6	±0.79	34.1	2.7	±0.82	6.3*	0.03*	−0.5	0.35	5.8*	0.04*
IMW (mm)	47.9	2.9	±0.88	51.7	3.6	±1.10	51.2	3.2	±0.98	3.8*	0.04*	−0.5	0.51	3.3*	0.04*

Refer to Figures 3a, b, 4–6 for the location of each landmark.
SD, standard deviations; CI, confidence interval.
$^{*}P < 0.05$.

Table 6. Cephalometric values, molars torque and dental arch distances in 6-RME/BB patients

	T1			T2			T3			Comparisons					
6-RME/BB	Mean	SD	CI	Mean	SD	CI	Mean	SD	CI	T2–T1		T3–T2		T3–T1	
Lateral cephalogram										**Diff**	***P***	**Diff**	***P***	**Diff**	***P***
SNA (°)	80.9	5.4	±1.57	82.2	5.3	±1.55	81.7	5.1	±1,49	1.3	0.82	−0.5	0.88	0.8	0.91
SNB (°)	74.9	4.6	±1.34	73.1	4.8	±1.40	75.0	4.5	±1,31	−1.8	0.76	1.9	0.74	0.1	0.97
ANB (°)	6	2.1	±0.61	9.1	1.8	±0.52	6.7	1.9	±0,55	3.1*	0.03*	−2.4*	0.04*	0.7	0.14
Wits (mm)	3.7	1.2	±0.35	4.1	1.4	±0,40	3.8	1.3	±0,38	0.4	0.07	−0.3	0.07	0.1	0.09
PP^MP (°)	33.6	4.4	±1,28	34.1	4.7	±1,37	33.8	4.5	±1,31	0.5	0.75	−0.3	0.71	0.2	0.85
OB (mm)	2.2	2.8	±0,81	2.0	3.0	±0,87	2.1	2.7	±0,78	−0.2	0.64	0.1	0.82	−0.1	0.83
Ans-Me (mm)	59.7	4.3	±1,25	61.2	4.6	±1,34	59.9	4.5	±1,31	1.5	0.23	−1.3	0.27	0.2	0.52
FMA (°)	30.1	3.9	±1,14	31.2	4.3	±1,25	30.3	4.1	±1,19	1.1	0.41	−0.9	0.46	0.2	0.58
Dental casts															
Torque 26 (°)	−18.9	4.0	±1,17	−16.7	6.9	±2,01	−16.2	10.6	±3,10	2.2	0.09	0.5	0.27	2.7	0.07
Torque 16 (°)	−18.5	4.9	±1,43	−16.9	6.5	±1,90	−16.4	7.6	±2,22	1.6	0.15	0.5	0.32	2.1	0.08
ICW (mm)	29.1	4.4	±1,28	34.2	2.6	±0,76	33.8	2.7	±0,78	5.1*	0.03*	−0.4	0.28	4.7*	0.03*
IMW (mm)	48.3	2.9	±0,84	52.9	3.6	±1,05	52.3	3.2	±0,93	4.6*	0.04*	−0.6	0.25	4*	0.04*

Refer to Figures 3a, b, 4–6 for the location of each landmark.
SD, standard deviations; CI, confidence interval.
$^{*}P < 0.05$.

investigation were at the same stages of cervical vertebral maturation (CS1–2). The aim of this study was to evaluate the dento-skeletal response in these patients by using three different protocols of RME.

The use of deciduous teeth as anchoring teeth could be particularly advantageous if a patient with hyperdivergent growing pattern must be treated; this because in these patients the vertical control is necessary.

During RME, changes in sagittal and vertical development are common. According to the literature, in this investigation the sagittal effects of expansion in the short-term (T2–T1 interval) showed a reduction of SNB° in 6-RME group, probably due to a clockwise rotation of the mandible (of point B) with an increasing of ANB°. As previously suggested by Broddsman *et al.*, the mandibular rotation that occurs with the expansion is the result of the molar extrusion that generates a posterior dental precontact (14).

Despite an increase of vertical values, our results did not evidence significant effects on the vertical plane after RME: only 6-RME group showed vertical values increased but not

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Table 7. Cephalometric values, molars torque and dental arch distances in 6-RME patients

6-RME	T1			T2			T3			Comparisons					
	Mean	SD	CI	Mean	SD	CI	Mean	SD	CI	T2–T1		T3–T2		T3–T1	
Lateral cephalogram										Diff	*P*	Diff	*P*	Diff	*P*
SNA (°)	81.3	5.6	±1.74	82.5	5.4	±1.68	81.4	5.7	±1.77	1.2	0.83	−1.1	0.84	0.1	0.96
SNB (°)	76.7	4.5	±1.43	74.6	4.7	±1.46	76.5	5.3	±1.64	−2.1	0.75	1.9	0.71	−0.2	0.93
ANB (°)	4.6	2.4	±0.74	7.9	2.1	±0.65	4.9	2.3	±0.71	3.3*	0.02*	−3*	0.03*	0.3	0.12
Wits (mm)	4.0	1.1	±0.34	5.0	1.4	±0.43	3.9	1.3	±0.40	1.0*	0.04*	−1.1*	0.04*	−0.1	0.23
PP^MP (°)	32.6	4.0	±1.24	33.2	4.4	±1.36	31.8	4.2	±1.30	0.6	0.72	−1.4	0.86	−0.8	0.79
OB (mm)	2.4	1.9	±0.59	1.2	1.8	±0.56	2.6	2.0	±0.62	−1.2*	0.03*	1.4*	0.03*	0.2	0.65
Ans-Me (mm)	59.3	3.9	±1.21	60.9	4.2	±1.30	59.6	4.4	±1.36	1.6	0.21	−1.3	0.24	0.3	0.54
FMA (°)	29.3	3.5	±1.08	30.6	4.0	±1.24	29.5	3.9	±1.21	1.3	0.23	−1.1	0.32	0.2	0.74
Dental casts															
Torque 26 (°)	−18.9	4.6	±1.43	−10.5	7.9	±2.45	−13.6	12.4	±3.85	8.4*	0.01*	−3.1	0.07	5.3	0.06
Torque 16 (°)	−19.4	5.6	±1.74	−11.8	7.6	±2.36	−14.1	13.2	±4.10	7.6*	0.02*	−2.3	0.08	5.3	0.06
ICW (mm)	28.2	4.3	±1.33	32.0	2.9	±0.90	31.5	3.6	±1.12	3.8*	0.04*	−0.5	0.24	3.3*	0.04*
IMW (mm)	48.3	5.2	±1.61	54.9	6.1	±1.89	51.6	6.4	±1.99	6.6*	0.02*	−3.3*	0.04*	3.3*	0.04*

Refer to Figures 3a, b, 4–6 for the location of each landmark.
SD, standard deviations; CI, confidence interval.
$^{*}P < 0.05$.

significantly. Similar observations were reported in literature (7, 8) and it was conceivable that these results, unobservable in E-RME and 6-RME/BB group, could be due to the different anchoring teeth in E-RME subjects, resulting in a less molar extrusion that limited the jaw to move backwards and the opening of the mandibular angle. In 6-RME/BB group the movement of the jaw was controlled by using the BB that favoured the anterotation of the jaw (25). The BB allowed to counteract any tendency to clockwise mandibular rotation and the splints had the goal to control for molar eruption and limit intermaxillary divergency (23). The lack of the BB in 6-RME group allowed molars extrusion and prevented mandibular control.

According to the literature, our results stressed how the BB in 6-RME/BB group was effective in controlling molars teeth during expansion (less precontact, less extrusion) possibly also through the increase of muscle strength with several beneficial therapeutic effect (24, 25). Vice-versa, occlusal changes (dental contacts) following the increase of molars buccal tipping in 6-RME group, were probably responsible for the mandible rotation. All this confirms that the BB is a useful device that can be associated with RME treatment if deciduous teeth are not available for expansion.

Further changes during maxilla expansion occur in dental structures. The amount of IMW and of molars buccal tipping were higher in 6-RME group when compared to E-RME and 6-RME/BB groups. Measurements of the T2–T1 interval, showed a statistically significant increase of IMW in 6-RME group when compared to E-RME group. Variations of the molars buccal tipping followed similar results: an increasing of Tor16 and Tor26 values in 6-RME group was verified during T2–T1 interval with a relapse of these values in T3–T2 interval in the same group.

Probably, as suggested by previous literature (13, 16), anchoring the RME on permanent teeth the expansion that occurs is more dental than skeletal. Some authors observed that the increasing of molars buccal tipping during RME can be considered a dentoalveolar compensation towards maxillary expansion (14, 29). As a confirmation of this, the results of this investigation stressed how by anchoring RME on deciduous teeth in E-RME group or by using a BB to control molars buccal tipping in 6-RME/BB group allow to get more control in dental and skeletal structures. In fact, 1 year after the appliance removal, E-RME and 6-RME/BB groups show IMW values that can be superimposed to those of the 6-RME group but lower values of molars buccal tipping, confirming a lower dental compensation and more stable skeletal expansion over time. So, the amount of skeletal expansion will probably be greater in E-RME and 6-RME/BB groups.

In this study, the analysis of RME effects in the short and long-term shows a statistically significant increase of ICW in E-RME group when compared with 6-RME and 6-RME/BB groups. These results were similar to those found by Mutinelli *et al.* (18) and Ugolini *et al.* (16), which reported a reduction of ICW after maxillary expansion when the RME was anchored on the first permanent molars compared to when the appliance was anchored on the second deciduous molars. Ugolini *et al.* (16) reported similar results and suggested a more stable expansion in the anterior area of the maxilla when RME is anchored onto deciduous teeth.

Anchoring the RME on deciduous teeth, all heavy forces produced during expansion can be expressed without any compensatory effects, damage or suffering to the permanent teeth, and also promote the displacement of the action force of the screw in the anterior region of the arch.

E-RME protocol produces a more skeletal and stable expansion and allows a better control of molars buccal tipping if compared with 6-RME protocol and this is evidenced by the fact that ICW values are greater and there is a less relapse of molars buccal tipping at T3–T2 interval in E-RME group.

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The clinical implications derived from this investigation, in conjunction with the literature, suggest that RME is a goal in presence of a narrow palate and that second deciduous molars could be taken as a reference in the evaluation of anchoring the RME on deciduous teeth for an RME treatment. This is true as well in presence of patient with hyperdivergent growing pattern where expansion is needed. However, in these patients, if palatal expansion on deciduous teeth is not possible, RME anchored on permanent molars combined with a BB in the lower arch is an effective treatment.

Conclusions

This comparison of three different treatment protocols of expansion with RME in vertically growing patients with mixed dentition resulted in the following at the long-term:

1. E-RME protocol allows a greater expansion in the intercanine area if compared with 6-RME and 6-RME/BB protocol.
2. The 6-RME/BB and E-RME protocol showed a better control of the buccal tipping of the permanent molars.

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None to declare.

Conflicts of interest

None to declare.

Data availability

Data are available on request.

Ethical committee approval

University of Rome "Tor Vergata" (protocol number 0015776/2019).

Supplementary material

Supplementary material is available at *European Journal of Orthodontics* online.

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