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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

ABSTRACT

Aim *The aim of this study was to investigate the reaction of untouched permanent molars following RPE, anchored on deciduous teeth in the early mixed dentition, aimed to solve maxillary anterior crowding in the absence of posterior cross-bite.*

Method *A prospective clinical trial comprised 35 consecutive patients (20 males and 15 females) treated by the same orthodontist (MR). All patients showed crowding of the upper permanent incisors in the early mixed dentition in the absence of posterior cross-bite. RPE was anchored on second deciduous molars and on the deciduous canines. CBCT was taken before and after the removal of the RPE appliance. The transverse linear changes in width and the variation in the torque of the permanent molars were measured in the coronal plane.*

Results *Relief of incisor crowding was found in all patients. The transverse width between permanent molars increased significantly. The apices of the upper permanent molars spontaneously expanded more than the crowns, while the opposite happened on the lower permanent molars. Moreover, the untouched upper permanent molars spontaneously uprighted palatally, while the lower permanent molars spontaneously uprighted buccally. The variation in the torque of the permanent molars mirrored transverse normal growth.*

Conclusions *In the early mixed dentition and in the absence of posterior cross-bite, it is possible to expand transversally the palate while uprighting the upper permanent molars in the opposite direction. RPE anchored on the deciduous teeth in the early mixed dentition, in the absence of posterior cross-bite, provides an "anticipation of transverse growth" and could be indicated to expand the anterior portion of the maxillary arch perimeter to solve upper incisor crowding.*

Keywords *CBCT analysis; Early treatment; Maxillary incisors crowding; Mixed dentition; Rapid Palatal Expansion.*

Introduction

Rapid Palatal Expansion (RPE) in the absence of posterior crossbite (PXB) remains a controversial method for increasing upper arch perimeter and resolving anterior crowding [Giannelly, 2003; Canuto et al, 2010; Marshall et al, 2005; Brust and McNama-ra, 1995; Spillane and McNamara, 1995]. Crowding of the permanent incisors, with associated rotations and/or anterior crossbite, is commonly observed during eruption of the permanent lateral incisors. The rationale of interceptive treatment in the early mixed dentition is to generate adequate space for the spontaneous alignment of the permanent upper lateral incisors prior to complete eruption. When crowding is limited to few millimeters, normal growth could provide adequate space, but when the palate is narrow and the crowding exceeds this amount, RPE could represent an effective procedure. Space would be gained not only at the level of the alveolar bone, but also in the basal bone where canines and premolars are crowded too. However, RPE in the absence of posterior crossbite presents three major drawbacks when the first permanent molars serve as anchor teeth.

a) Molars which are often tilted buccally to compensate the narrow palate [Marshall et al., 2005], will tilt buccally even more [Cameron et al., 2002; Haas, 1961; Wertz, 1970; Adkins et al., 1990; Garrett et al., 2008; Lagravère et al., 2010], with potential periodontal damage [Vanarsdall, 1994; Greenbaum and Zachrisson, 1982; Garib et al., 2006]. Moreover the resulting deepening of the Wilson Curve will create posterior occlusal interferences.
b) The amount of anterior expansion needed to correct the incisor crowding is often insufficient, if a scissor

FIG. 1 Young boy, 8y/5m of age before RPE. Normal transverse occlusal relationship in the absence of posterior cross-bite (a/c) with crowded permanent incisors (b).

bite is to be avoided.

c) To increase the arch perimeter posterior expansion is ineffective, while increase in the anterior area provides the most space to resolve maxillary incisor crowding [Germane et al., 1991]. Thus, RPE performed in the absence of a posterior crossbite, could be very effective in resolving anterior crowding and simultaneously increasing the arch perimeter, but ideally the expansion should be limited to the anterior region of the arch, while the permanent molars should move in a palatal (opposite) direction.

To counteract these drawbacks several solutions have been proposed [Marshall et al., 2005; Schepp, 2010; McNamara, 2006]. To prevent excessive buccal inclination of the upper permanent first molars during RPE, some authors proposed to create a posterior cross-bite with a transpalatal bar before RPE [Schepp, 2010]. Others proposed to use criss-cross elastics [Marshall, 2005], or expansion plates [McNamara, 2006], to upright buccally the lower permanent molars and to avoid scissor bite. This approach could be correct in the permanent dentition, but it represents an over-treatment in the mixed dentition, when all those ideal conditions can be fulfilled, by anchoring the expander on the second deciduous molars and on the deciduous canines. The benefits and results of this type of RPE have been extensively reported [Rosa, 1994; Silva et al., 1995; Cozzani P et al., 1999; Cozzani M et al., 2003; Cozzani M et al., 2003; Lima et al., 2005; Cozzani M et al., 2007; Mutinelli et al., 2015; Rosa et al., 2012; Ballanti et al., 2009].

1) Correct the maxillary transverse deficiency and posterior cross-bite on permanent molars [Rosa, 1994; Silva et al., 1995; Cozzani P et al., 1999; Cozzani M et al., 2003; Cozzani M et al., 2003; Lima et al., 2005].
2) Improve maxillary incisor crowding [Cozzani P et al., 1999; Cozzani M et al., 2003; Cozzani M et al., 2003].
3) Expand the arch form [Cozzani M et al., 2007; Mutinelli et al, 2015].
4) Induce spontaneous correction of the anterior cross-bite of permanent incisors [Rosa et al., 2012].
5) Intercept maxillary impacted canines [Ballanti et al, 2009].

The purpose of the present study was to investigate, using CBCT, the effect of RPE anchored on deciduous teeth in the early mixed dentition on:

1. the spontaneous bucco-lingual modifications of the upper and lower, fully erupted first permanent molars;
2. the transverse change in width between the apices and the crowns of first permanent molars;
3. the transverse change of the maxillary basal bone.

Materials and methods

Patient selection and method

the present study is a prospective clinical trial, conduced on consecutive patients treated by the same orthodontist (MR) in his private practice.

All subjects were recruited from June 2011 to January 2012. All subjects were in the early stage of the mixed dentition with crowding of the upper permanent incisors without posterior crossbite (Fig. 1). Two patients showed anterior crossbite of the permanent incisors too.

Thirty five consecutive "crowded" patients (20 males, 15 females) with a mean age of 8y10m (SD 1y/1m) were included in the final study group fulfilling all the following inclusion criteria:

- permanent maxillary central incisors and first permanent molars fully erupted;
- normal lower arch (no crowding, nor lower incisors' protrusion), i.e. patients to be treated with "non-extraction" approach;
- absence of posterior crossbite;
- normal and stable transverse occlusion on deciduous and first permanent molars;
- crowding of maxillary incisors in the first stage of the mixed dentition, with maxillary lateral incisors just erupted or not yet emerged in the alveolar crest;
- upper second deciduous molars and upper deciduous canines stable with minimal apical root resorption;
- RPE equal or greater than 8 mm (i.e. 40 activations);
- CBCT taken within six months before RPE;
- no previous orthodontic treatment;
- no active orthodontic forces applied on the permanent molars during and after RPE;
- intact dentition (absence of restorations, caries, or tooth loss).
- absence of skeletal asymmetries;
- absence of skeletal anomalies and syndromes.

Crowding was defined when one or more of the following conditions existed.

1. Crowding and/or Irregularity Index greater than 6 mm on all erupted maxillary permanent incisors. Crowding was measured comparing the available

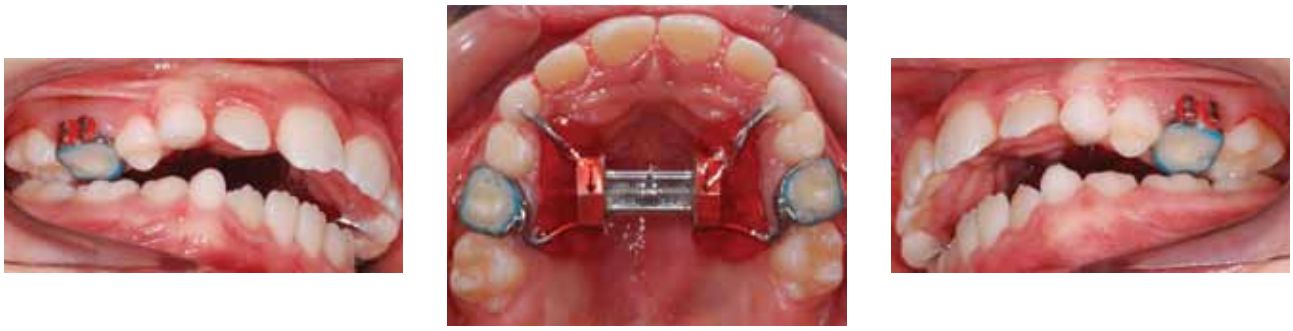

FIG. 2 At the end of the active transverse expansion (56 activations performed progressively in 10 weeks), transverse overcorrection is evident on both deciduous and permanent molars (a/c). Deciduous molars were ground on the occlusal surface in order to let the permanent molars touch in occlusion. The buccal crest of the palatal cusps of the upper permanent molars are touching in occlusion with the lingual crest of the buccal cusps of the lower permanent molars. Crowding on the permanent incisors improved spontaneously (b).

space between the deciduous canines on the ideal arch form with the sum of the mesiodistal width of the four incisors [Nance, 1947]. Irregularity Index was assessed, modifying the Little method [Little, 1975], on the CBCT as the sum of the linear distance between the connector areas of the upper incisors.

2. Lack of space for the not yet emerged upper lateral incisors in presence of fully erupted upper central permanent incisors. Space was measured on the CBCT comparing the mesiodistal width of the not yet emerged permanent lateral incisors with the available space on the ideal arch perimeter between upper deciduous canines and the erupted central incisors. The upper lateral incisors were considered "crowded" when the sum of their R/L (right and left) mesiodistal width was greater than or equal to 6 mm, with respect to the sum of the available R/L spaces and the diastema between the central incisors. Six mm was considered the "critical threshold" of crowding, in accordance with the expected normal changes of the intercanine width during growth between 7 and 10 years of age [Bishara et al., 1998; Thilander, 2009].
3. Protrusion of the maxillary permanent incisors (inclination of the upper central incisors on SNA-SNP greater than or equal to 115° and/or overjet greater than 5 mm).

All patients were treated with a modified Haas RPE [Rosa, 1994; Cozzani P et al., 1999; Cozzani M et al., 2003; Cozzani M et al., 2003; Cozzani M et al., 2007; Mutinelli et al., 2015; Rosa et al., 2012], banded on second upper deciduous molars and bonded on deciduous canines (Fig. 2B).

Each subject had a CBCT taken before treatment (T0) at mean age 8y/8m (SD 1y/1m), and after appliance removal (T1) at mean age 11y9m (SD 1y/5m). The total observation time was 3y/1m (SD 10m). The RPE appliance was cemented and expansion started at a mean age of 8y/10m (SD 1y/1m). In Table 1 the sample distribution is reported. The CBCT exams were indicated to investigate one or more of the following possible clinical features: impacted or absent teeth, airways obstruction, severe transverse skeletal discrepancy. All the parents, after being informed about the indication and con-traindication of the CBCT, agreed and signed an informed consent regarding the complete procedures.

RPE treatment protocol

The maxillary expander used for all subjects was a Haas-type RPE appliance modified to be anchored on the upper second deciduous molars and bonded on upper deciduous canines (Fig. 2B). All the appliances were manufactured by the same lab (Orthocheck, Trento, Italy) using a 13 mm screw (Leone® A0620-13, Florence, Italy) performing 0,2 mm expansion by each activation (1/4 of a turn). The RPE were cemented us-ing Transbond Plus (3M Unitek, Monrovia, CA, USA) in accordance with the manufacturer's instructions. The anterior arms of the screw were bonded with light-cured composite on the palatal surface of the upper deciduous canines (Synergy D6, Coltene, Switzerland). Before the placement of the appliance, deciduous canines were ground on the palatal surface, in order to facilitate the best possible adaptation of the screw's anterior arms to the dental surface.

The screw was activated once daily (1/4 turn) in the first 2–3 weeks and then once every second day for a mean active treatment time of 51 days (SD 11d). Of the 35 patients enrolled in the study, 14 were expanded in a single phase, whereas 21 were activated in two active phases with a 7–8 months suspension between the two phases (Table 1). This group of patients had 39.6 activation turns (SD 10.8) in the first stage and 18.2 turns (SD 8.9) in the second stage of active treatment. There are two reasons to perform a two-step active expansion: the upper lateral incisors still to emerge in the dental arch; and to prevent a posterior scissor-bite, while keeping the buccal ridges of the palatal cusps of the upper permanent molars in occlusion with the lingual ridges of the buccal cusp of the lower permanent molar.

The mean of total activations was 50.5 (SD 7.4). The active expansion was continued until adequate space for the lateral incisors correction was achieved transversally on deciduous canines. At the end of the active expansion, deciduous canines and molars were over-expanded showing a scissor bite. The untouched first permanent molars did also expand showing a partial scissor bite: the buccal ridges of the upper palatal cusps always were kept in contact with the lingual ridges of the lower buccal cusp (Fig. 2a,c). Occlusal selective grinding was performed on the deciduous molars, to facilitate the occlusal contacts only on permanent molars. At the end of the active expansion, the screw was locked with a

FIG. 3 Day of the Rapid Palatal Expander removal (b) 14 months after the end of the active ex-pansion. The transverse occlusal relationship is now correct on the permanent molars (a/c), due to their spontaneous uprighting. Upper permanent incisors self aligned during the retention time.

stainless steel metal ligature and the expander was kept in place as a passive retainer until upper lateral incisors were fully emerged in the dental arch and spontaneous adjustment in occlusion of the first permanent molars was achieved (Fig. 3).

The mean age of the patients was 8y/10m (SD1y/1m) the day when RPE was cemented and active expansion started, and 11y/2m (SD1y/3m) the day when the RPE appliance was removed. The total treatment time, including active expansion and retention, was 2y/3m (SD 9m4d). During this period, no appliances nor active forces were applied to the first permanent molars. No retention device was applied or used after removal of the RPE until the end of the transition (Fig. 4). First permanent molars have not been touched at all before, during and after treatment.

Image recording and post-processing

The CBCT scans (KaVo 3D eXam) were performed in the seated position and was set at 120 KV, 3.8 mA, 4.8 s ("Half Scan" setting). A vertical and horizontal sighting beam to ensure accurate and repeatable head positioning was used. The DICOM files were processed using the OsiriX software (Open-Source, OsiriX Medical Imaging Software, Switzerland). Multi-planar reconstructions (MPR) (thickness slice 0.3 mm) were used to measure the posterior teeth inclination.

The images were initially viewed using the 3D (MPR) mode. In this way there are 3 windows corresponding to 3 planes of space (sagittal, axial and coronal) and 3 color lines (orange, blue and purple) (Fig. 5, 6).

The first step to assess the measurements of the upper molars, consists in scrolling the tomographic cuts on the axial plane up to the palatal roots' level (Fig. 5a). After, the blue line in the axial image was rotated so as to pass through the center of palatal roots (Fig. 5b). In the next step the blue line was adjusted on the sagittal plane and rotated so as to pass along the long axis (Fig. 5a). Finally the coronal section of upper molars was ob-tained (Fig. 5c).

For the lower molars, the first step consists in scrolling the tomographic cuts in the axial plane on the distal roots of mandibular first permanent molar (Fig. 6b). After, the blue line was rotated on the sagittal and axial images so as to pass through the center of the distal roots along the long axis (Fig. 6a). Finally the coronal section of lower molars was obtained (Fig. 6c).

The palatine foramen was also identified on both sides to assess the transverse skeletal change. The first step consisted in scrolling the axial and coronal cuts until the right and left palatinal foramen palatally to the upper second molars. Finally the axial image of the center of the palatal foramen was obtained (Fig. 7b).

Measurements

On upper permanent molars two vertical and two horizontal lines were drawn and four angles for each tooth were therefore obtained (Fig. 8a):

- Line A: from the apex (UAp point) to the top of the palatal cusp (UCu point).
- Line B: from the center of fossa (UFo point) to root furcation (UFu point).
- Line C: through the Right and Left upper palatal cemento-enamel (R/L UPCEJ points) junctions.
- Line D: through the Right and Left upper buccal cemento-enamel (R/L UBCEJ points) junctions.

The measurements of the upper internal angles between vertical and horizontal lines were measured for each patients. Mean value of the 4 angles, both in the right and in the left side, was assumed as expression of upper molar bucco-palatal inclination. Any increase of angles indicates palatal tip of the crown (Upper Molar

	T0		T1		T1-T0	
	Mean	SD	Mean	SD	Mean	SD
Age of subjects at CBCT	8y8m	1y1m	11y9m	1y5m	3y1m	10m
	Total Activation		1st Activation		2nd Activation	
	Mean	SD	Mean	SD	Mean	SD
RPE Activation	50,48	7,4	39,57	10,84	18,19	8,89

TABLE 1 Mean age the day when CBCT was taken: before expansion (T0) and at the time of the expander removal (T1).
RPE Activation: 14 patients were expanded in one stage, while 21 were expanded in two stages, the second of which after a 7-8 months interval.

FIG. 4 At the end of the transition 20 months after the removal of the appliance and without any retention, the occlusal relationships are within the normal range (a/c). The permanent incisors still are well aligned (c).

Decompensation). Any decrease of the angles indicates buccal tip of the crown (Upper Molar Compensation).

On the lower permanent molars two vertical and two horizontal lines were identified in the same way (Fig. 8b):

- Line E: from the apex of the distal root (LAp point) to center of the fossa (LFo point).
- Line F: from lingual cusp (LCu point) to lingual cementoenamel junction (LLCEJ points).
- Line G: a horizontal line passing through the Right and Left lower lingual cementoenamel junctions (R/L LLCEJ points).
- Line H: a horizontal line passing through the Right and Left lower buccal cementoenamel (R/L LBCEJ points) junctions.

The measurements of lower internal angles between vertical and horizontal lines were recorded for each patients. Mean value of the 4 angles, both in the right and left side, was assumed as representative of lower molar bucco-lingual inclination. Any decrease of this angles indicate a buccal tip of the crown, which is expression of the molar decompensation. Any increase of this angle indicates a lingual tip of the crown.

The angular expression of the upper and lower Wilson curve were measured on the intersection of two lines tangent the buccal and palatal cusps of the first permanent molars (Fig. 8a, b).

- Line I: tangent the buccal and palatal cusps of upper first permanent molars.
- Line L: tangent the buccal and palatal cusps of the lower first permanent molars.

On the same scanned coronal planes, the transverse linear changes were meas-ured between the permanent molars on this points (Fig. 8c,d).

1. R/L Palatal roots apex of upper first permanent molars (R/L UAp points).
2. R/L Fossa of upper first permanent molars (R/L Fo points).
3. R/L Distal roots apex of lower first permanent molars (R/L LAp points).
4. R/L Fossa of lower first permanent molars (R/L Fo points).
5. R/L F points.

The transverse skeletal expansion was measured on the axial plane between Right and Left most medial point of the palatinal foramen (Fig. 8e). To obtain reliable/reproducible R/L Ap points at T0 and T1 and overcome measurement errors related to the possible

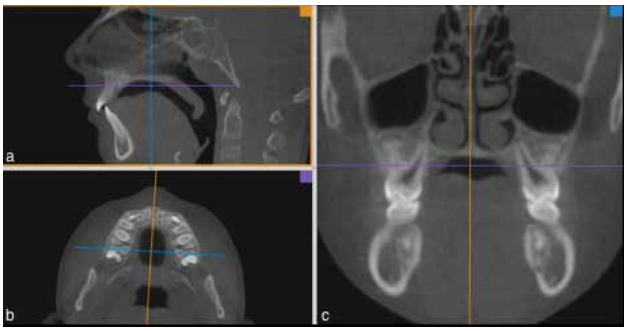

FIG. 5 Upper arch: the blue line was rotated in the sagittal (a) and in the axial image (b) to obtain the coronal section (c) through the long axis of the R/L palatal root of the upper molars.

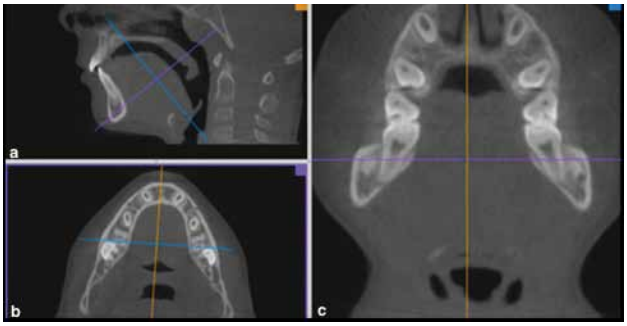

FIG. 6 Lower arch: the blue line was rotated in the sagittal (a) and in the axial image (b) to obtain the coronal section (c) through the long axis of the R/L distal root of the lower molars.

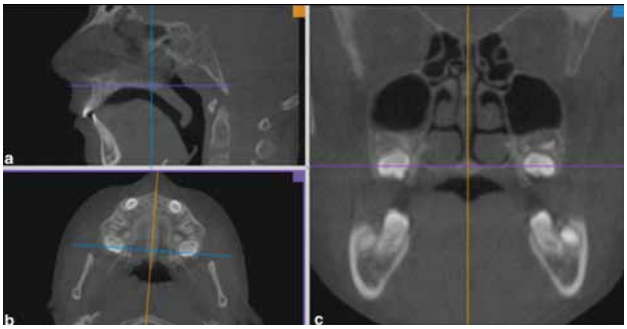

FIG. 7 The palatal plane was identified on the sagittal and coronal cuts (a / c). The R/L palatinal foramens were identified on the coronal and axial planes (b / c).

late development of the root and changes in the apex anatomy, the R/L Ap point at T1 was reproduced at the same height of T0. For each patient, 18 angular and 5 linear measurements were taken, resulting in a total of 805 measurements.

As described above, for upper and lower molars a mean value of internal angles was calculated and assumed as representative of their inclination. This means that, for every subject, 11 measurements were investigated, 6 angular measurements, to assess the bucco-lingual inclination of the first permanent molars:

1. UR6 (bucco-lingual inclination of the upper right molar);
2. UL6 (bucco-lingual inclination of the upper left molar);
3. LR6 (bucco-lingual inclination of the lower right molar);
4. LL6 (bucco-lingual inclination of the lower left molar);

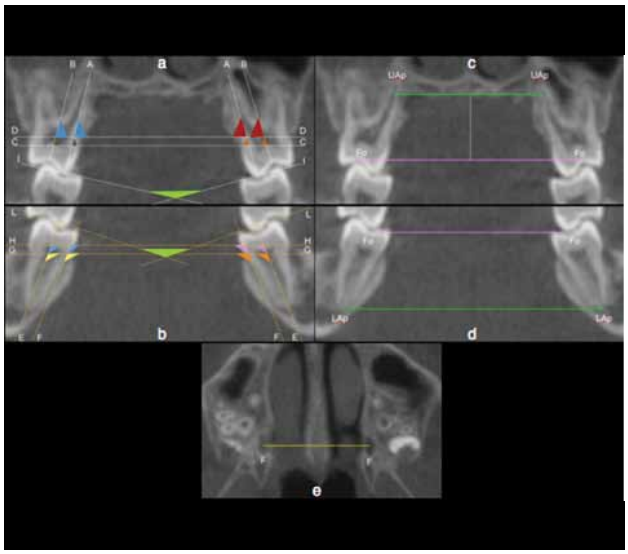

FIG. 8 Measurements of UR6, UL6, and upper Wilson curve (a). Measurement of LR6, LL6, lower Wilson curve (b). Transverse measurements of R/L UAp and Fo points (c). Transverse measurements of R/L LAp and Fo points (d). Transverse measurements of R/L pa-latinal foramina (e).

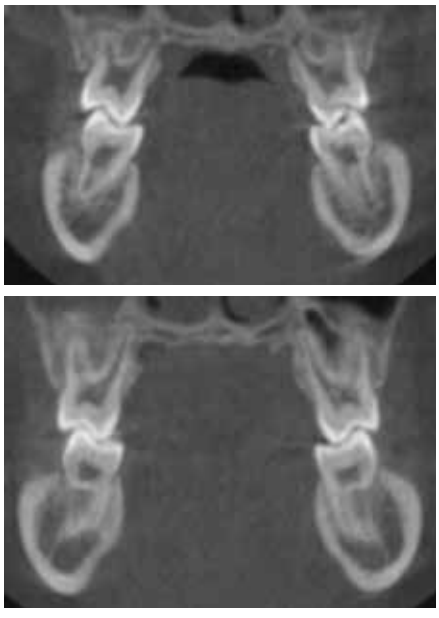

FIG. 9 Coronal view of the first permanent molars bucco-lingual inclination before treatment (a) and at the end of the observation period, 14 months after the active expansion (b).

5. Upper Wilson (Intersection U6);
6. Lower Wilson (Intersection L6);

and 5 linear measurements to assess the transverse changes:

1. 6+6 Apex (transverse dimension between upper palatal root apex);
2. 6+6 Fossa (transverse dimension between upper crowns);
3. 6-6 Apex (transverse dimension between lower distal root apex);
4. 6-6 Fossa (transverse dimension between lower crowns);
5. Palatinal Foramen (transverse skeletal dimension).

Statistical analysis

Descriptive statistics was conducted to summarise percentage and distributions of measurements. A normal distribution for the values of all variables was verified for the study group with the Shapiro-Wilk test. For all measurements means and standard deviations were calculated at T0, T1, and for the T1-T0 differences. Paired T test was performed in order to detect any significant changes between data at T0 and T1. Statistical significance was set at $p<.05$. A power analysis was carried out for an alpha-level at 0.05. All tests gave a power over 83%. The inter-observer error of the method used to measure each variable was calculated by double measurements in 20% of the sample randomly selected, using the Dahlberg's formula. The obtained value was 0.075 considerably lower than the maximum limit of 0.25 [Kirkwood and Sterne, 2003]. All data were analysed with STATA12 (StataCorp LP, College Station, TX, USA).

Results

All measurements showed statistically significant T1-T0 differences.

Crowding on maxillary permanent incisors self-corrected, being the mean dentoalveolar discrepancy of -6.81 mm (SD 1.21) before treatment (T0) and 0.79 mm (SD 0.46) at T1, when the appliance was removed. Anterior crossbite self-corrected in all patients during the active expansion.

Table 2 shows the averages and standard deviations for all angular and transverse linear changes at T0, T1, the T1-T0 differences with all their significance values.

- Six angular measurements of the changes in bucco-lingual inclination of the permanent molars and of the Wilson curve.
- Four transverse linear changes between upper and lower permanent molars.
- One measurement of the skeletal transverse expansion.

The upper first permanent molars uprighted palatally, namely in the direction opposite to that of the transverse expansion. They showed an average increase of their palatal-crown inclination of 3.6° (SD 2.2°) on the right side and of 3.7° (SD 2.4°) on the left side. The lower first permanent molars uprighted in a buccal direction and showed an average decrease of their lingual-crown inclination of -5.7° (SD 3.8°) for the right side and of -6.1° (SD 3.6°) for the left side.

The angle of intersection (expression of the Wilson curve) of the upper and lower permanent molars increased by 7.7° (SD 3.8°) and by 10.9° (SD 6.1°) respectively.

	T0		T1		t1-to			
Variables	Mean	SD	Mean	SD	Mean	SD	T.TEST	P
UR6°	74,6	4,18	78,24	4,37	3,63	2,23	***	0,0001
UL6°	72,31	4,18	76,05	4,47	3,74	2,4	***	0,0001
LR6°	113,47	5,39	107,61	5,98	-5,69	3,8	***	0,0001
LL6°	114,16	5,46	108,09	6,46	-6,08	3,65	***	0,0001
Upper CW°	143,46	9,03	151,2	10,31	7,73	3,83	***	0,0001
Lower CW°	136,58	7,03	147,83	7,65	10,94	6,06	***	0,0001
6+6 Apex (mm)	28,79	2,47	33,74	2,86	4,94	1,14	***	0,0001
6+6 Fossa (mm)	45,29	2,41	48,75	2,77	3,46	1,16	***	0,0001
6-6 Apex (mm)	54,88	3,83	53,85	3,78	-1,03	0,81	***	0,0001
6-6 Fossa (mm)	40,75	2,42	42,82	2,95	2,05	1,03	***	0,0001
Palatinal Foramen (mm)	26,24	1,84	28,81	1,99	2,55	0,66	***	0,0001

TABLE 2 Six angular measurements of the changes in bucco-lingual inclination of the permanent molars and of the Wilson curve.
Four transverse linear changes between upper and lower permanent molars
One measure of the skeletal transverse expansion.

The transverse linear change between the upper palatal root apices showed a mean increase of 4.9 mm (SD 1.1). The transverse linear mean increase between the fossae of right and left upper first permanent molars was 3.46 mm (SD 1.16).

After RPE anchored on the deciduous teeth in the mixed dentition, the skeletal transverse increase, measured in correspondence of palatal foramen, was 2.5 mm (SD 0.7).

Even in the absence of posterior crossbite before the RPE, none of the patients showed a scissor bite (reverse cross-bite) at T1. On the contrary, all patients showed a correct transverse occlusal relationship at the end of the observation period.

Discussion

The principal finding of this study was that interceptive relief of maxillary incisor crowding in the early mixed dentition was provided with RPE anchored to deciduous teeth in the absence of a posterior crossbite. It was also possible to expand the maxilla and to increase the upper arch perimeter, while tipping the upper first permanent molars in the opposite direction (Fig. 9). The early orthopaedic maxillary expansion of the maxilla seems to be an anticipation of the transverse maxillary growth, which will normally occur in a longer time period [Marshall et al. 2003; Hesby et al., 2006].

Furthermore and to our knowledge, this is the first study that used CBCT to evaluate spontaneous changes of the permanent first molars following RPE anchored on deciduous teeth in the mixed dentition.

The rationale of RPE in the absence of posterior crossbite is to increase the perimeter of the maxillary arch and provide space to correct upper incisor crowding in cases where the lower arch is within the normal range and premolar extractions are not indicated. Actually the transverse expansion of the first permanent molars is debatable for at least two reasons. Firstly, it has been demonstrated that 5 mm of transverse expansion of the molars increases the arch perimeter by just 1.5 mm, which is not clinically relevant, while the expansion in the anterior area is much more effective [Germane et al., 1991]. Thus, using the upper permanent molars as anchor teeth, only a minor crowding can be corrected, because, after having expanded few millimeters and having provided 3–4 mm increase of the arch perimeter [Giannelly, 2003; Canuto et al., 2010; Marshall et al., 2005; Brust and McNamara, 1995; Spillane and McNamara, 1995], the permanent molars will be in a scissor bite occlusion and the expansion must be suspended. Secondly, in cases where the palate is narrow and the crowding of the upper incisors is greater than 5–6 mm, in the absence of posterior crossbite, the permanent molars are tilted buccally, while the lower molars are tilted lingually. This scenario is what Marshall et al. [2005] defined a "posterior dental compensations which can mask severe skeletal transverse discrepan-cies even when no posterior teeth are in crossbite". In these cases RPE could be the best indication but, being anchored on the permanent molars, dentoalveolar compensation will worsen [Wertz, 1970; Adkins et al., 1990; Garrett et al., 2008; Lagravère et al., 2010], with the inherent risk of attachment loss and periodontal damage [Vanarsdall, 1994; Greenbaum and Zachrisson, 1982; Garib et al, 2006]. Besides, it will increase the Wilson Curve, create posterior occlusal interference and bite opening. Actually, the results of this study show that RPE anchored on the deciduous teeth in the early mixed dentition is also more effective, because it enables the orthodontist to increase the upper arch perime-ter beyond 5–6 mm, so that the severe crowding on the maxillary incisors can be solved. All the patients involved in this investigation showed a severe incisor crowding and a mean of 50.5 (SD 7.4) RPE's activations (i.e. 10 mm) was necessary to gain adequate space. If the RPE appliance had been anchored on the permanent molars, it would conceivably have been impossible to achieve the same increase in arch perimeter without producing a posterior scissor bite and occlusal disorder. Besides, if RPE anchored on permanent molars can increase the perimeter of the maxillary arch and provide space to correct only moderate crowding (3–4 mm) [Giannelly, 2003; Canuto et al., 2010; Marshall et al., 2005; Brust and McNamara, 1995; Spillane and McNamara, 1995], this procedure makes no sense in the mixed dentition, because 4–5 mm could be provided by normal growth and arch development [Bishara et al., 1998; Thilander, 2009].

Timing is another crucial issue to be discussed. The goal is to expand the maxilla, increase the arch perimeter, and fix anterior crowding as well as posterior dentoalveolar compensation of the permanent molars. The best timing

is during the early mixed dentition, just before eruption of the upper permanent lateral incisors and after the permanent molars are fully erupted and coupled in occlusion. The occlusal contacts between the buccal crests of the upper palatal cusps on the lingual crests of the buccal cusps will push the upper permanent molars palatally and the lower molars buccally (permanent molar decompensation). To allow occlusal forces work at the best only on the permanent molars, the occlusal contacts of the deciduous molars can be removed by grinding. It is also possible that the lower permanent molars are pushed buccally by the posture of the tongue, which is kept down by the palatal screw. Orthodontic movement and occlusal adjustment of the permanent molars could take from 5 to 12 months or more, based on the the occlusal forces. The RPE appliance is to be removed after the complete eruption of the permanent lateral incisors, thus in most patients the RPE appliance was kept in the mouth more than two years.

For the deciduous teeth, overcorrection is necessary. Expansion should be continued until adequate space to align permanent incisors is obtained, so that, when incisors' crowding is severe, deciduous molars are often over-expanded into a full scissor bite transverse occlusion at the end of the active phase of treatment (Fig. 2 a,c). The screw must be activated once a day or once every other day in order to prevent the posterior scissor bite to occur on the permanent molars too. If RPE starts before the eruption of the lateral incisors, active expansion can be performed in two phases. In the first stage 25-30 activations take place followed by a second active expansion phase after six-ten months during the emergence of the lateral incisors. The crowns of the untouched upper permanent molars spontaneously expand and follow 60% the deciduous molars (and screw) expansion during the weeks of the active phase [Rosa, 1994; Cozzani P et al., 1999; Cozzani M et al., 2003]. Spontaneous molar decompensation will take place in the following months because of the occlusal forces. Time of the de-compensation is different and could be correlated to the amount of the biting forces and occlusal function.

In the present study the width between the maxillary permanent molar crowns in-creased by 3.5 mm (SD 1.2) from 8.8y (SD 1.1y) of age to 11.3y (SD 1.3) of age, while normal growth was measured varying from 2.4 mm [Bishara et al.,1998], to 2.8 mm (males) and 1.0 mm (females) [Snodell et al.,1993; Nanda et al., 2012]. In other studies normal transverse growth of the upper permanent molars was measured from 1 mm (males) and 0.3 mm (females) [Thilander, 2009; Korn and Baumrind, 1990], to 2.8 mm [Marshall et al., 2003]. Lower molars crowns self-expanded in our patients by 2.0 mm (SD 1.0 mm), much more than 0.8 mm, which is what was measured by Marshall et al. [2003] during normal growth in the same observation timeframe.

The apices of the upper molars self-expanded more than the crowns in the upper arch: 4.9 mm (SD 1.1) and 3.5 (SD 1.2), respectively. The transverse width between the lower molars increased on their crowns by 2.0 mm (SD 1.0), while decreased between apices by 1,0 mm (SD 0.8). The difference in the transverse expansion between the apices and the crowns describe the angular changes measured in the coronal plane.

The spontaneous angular changes are significant for the bucco-lingual inclination of the permanent molars in the coronal plane: 3.6° (SD 2.2°) and 3.7° (SD 2.4°), for the upper right and left permanent molars respectively, while -5.7° (SD 3.8°) and -6.1° (SD 3.6°) for the lower right and left permanent molars respectively). As a consequence the Wilson Curve flattened significantly by 7.7° (SD 3,8°) in the upper arch and by 10,9° (SD 6,1°) in the lower one. The spontaneous transverse uprighting of the first permanent molars after RPE anchored on deciduous teeth in the mixed dentition mirrors the transverse physiologic/normal growth, as described by Marshall [2003] and Hesby [2006], even if a difference is noticeable in the amount of change. During normal growth, between 9 and 11 years of age, the torque change was 2.5° for the upper molars in the lingual direction and 3.0° for the lower permanent molars in the buccal direction, while in our group of patients the spontaneous variations in torque was greater especially for the lower molars.

The "orthopaedic effect" of the RPE in the patient of the present study is evident. The interincisal diastema opened in all patients after 12–15 activations and, being the mid-palatal suture in the early mixed dentition more immature [Melsen, 1975], it is possible to speculate that the skeletal change is greater than in the adolescents. A common objection to our clinical approach is that "orthopaedics could be too much". Actually the residual transverse expansion produced by RPE at the level of the basal bone, measured between the R/L palatinal foramen, increased 2.5 mm (SD 0.7) in the 2.2 years from T0 to T1. It is difficult to compare the data of this study with the data available in the literature about normal transverse growth of the maxilla, because all those studies used different methods and study groups. Nevertheless the transverse changes found in our re-search look similar to the normal transverse growth of the maxilla reported in the literature, being 2 mm from 9 to 11 years of age [Hesby et al., 2006], varying from 0.5 to 1,7 mm per year, and most rapidly between 7 and 11 years of age [Snodell et al., 1993; Nanda et al., 2012; Korn and Baumrind, 1990; Marshall et al., 2003; Hesby et al., 2006]. The net increase in the residual skeletal transverse dimension of the maxilla is much less than the inter-apices increase. This could be explained by two reasons: first, considering the skeletal relapse of the basal bone, which always takes place after the active expansion [Krebs, 1974; Lagravère et al., 2005]. Second, the landmarks of palatal foramen are located in most posterior and superior position than upper palatal root apex, therefore the net increase in width of the basal bone could be less significant than the dentoalveolar expansion.

As an overall main finding to be underlined in this discussion, the RPE in the early mixed dentition aimed to solve upper incisors' severe crowding in the absence of posterior cross-bite is not an excess of orthopedic expansion, but provides mostly an orthodontic effect on permanent molars, which could be defined a mere "anticipation of growth".

The occlusal stability of the transverse changes and the fact that the permanent molars move spontaneously into the periodontal envelope let us suppose that the final torque of the permanent molars could be considered "ideal" from both occlusal and periodontal point of view.

Last, but not least important, the anchorage onto the deciduous teeth means absolute prevention of the possible side effects produced by RPE anchored on permanent molars: periodontal damage and attachment loss [Greenbaum and Zachrisson, 1982; Garib et al., 2006], demineralisation and external root resorption [Barber and Simms, 1981; Langsford and Simms, 1982; Vardimon et al., 1991; Vardimon et al., 1993].

The limitation of this study is that we are missing a control group of non-treated patients studied with CBCT during growth at the same age in the mixed dentition. Right now a similar group does not exist and it is very likely that it will never be collected for ethical reasons. On the other hand, comparing the results of this study to a matched group of similar patients treated with different procedures and/or appliances would not provide any relevant information in order to answer the hypothesis and the specific purposes of the present study.

Conclusions

- Interceptive relief of maxillary incisor crowding in the early mixed dentition with RPE anchored to deciduous teeth in the absence of a posterior cross-bite provides an efficient treatment modality.
- Favourable spontaneous changes were observed of the permanent first molars, with buccal uprighting of the lower molars, palatal uprighting of the upper permanent molars (in the opposite direction of the expansion) and the potential to emulate anticipated natural transverse growth.
- RPE anchorage onto the deciduous molars with untouched permanent molars implies prevention of periodontal damage, attachment loss, demineralisation and external root resorption of the permanent molars.

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