Original Article

Three-dimensional assessment of palatal area changes after posterior crossbite correction with tooth-borne and tooth bone–borne rapid maxillary expansion: *A randomized controlled trial with 5-year follow-up*

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ABSTRACT

Objectives: To assess and compare the three-dimensional treatment changes in palatal surface area and volume using either tooth-borne (TB) or tooth bone–borne (TBB) rapid maxillary expanders and to evaluate the long-term effects of the two devices and the incidence of the relapse between the groups.

Materials and Methods: A total of 52 consecutive patients who met the eligibility criteria were recruited and allocated to either the TB group, mean age 9.3 years (standard deviation [SD], 1.3), or the TBB group, mean age 9.5 years (SD, 1.2). Study casts were taken before, directly after, 1 year after, and 5 years after expansion. Study casts were digitized, superimposed, and evaluated. Participants were randomly allocated in blocks of different sizes using the concealed allocation principle in a 1:1 ratio.

Results: Changes in palatal volume, palatal surface area, and palatal projection area within and between the groups up to 5 years after expansion followed the same pattern and did not show any statistically significant differences between the groups. Relapse was seen in 15% of the patients. It seemed that open-bite and a Class III growth pattern could be assumed as prognosis-deteriorating factors in regard to stability of the treatment.

Conclusions: There were no significant differences between the TB and TBB groups in palatal volume, palatal shell area, or palatal projection area directly after expansion or at 1 year and 5 years after expansion, which implies that the two devices gave rise to the same immediate and long-term outcomes. (*Angle Orthod.* 2022;92:589–597.)

KEY WORDS: Palatal expansion technique; 3D imaging; Crossbite

INTRODUCTION

Posterior functional crossbite is one of the most prevalent malocclusions in young adolescents, with a reported prevalence in the literature from 8% to 22%.[1,2] The underlying reason is considered to be a constricted maxilla that, as a result of occlusal interferences, forces the mandible to be displaced laterally upon closure, giving rise to hindered growth and development on the constricted side if left untreated.[3,4]

When a maxillary constriction with posterior crossbite is diagnosed in adolescents, the treatment goal is maxillary expansion to alleviate the skeletal discrepancy and restore normalized growth and development.[5,6] Several different treatment modalities and appliances have been described. The most common appliance is the rapid maxillary expander (RME) as first described by Angell in 1860 and later repopularized by Haas in the 1960s.[7,8]

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The principle of rapid maxillary expansion is that heavy forces enable skeletal maxillary expansion by opening the midpalatal suture while causing hyalinization around the supporting teeth to minimize tooth movement. However, tooth-borne (TB) devices may lack the anchorage to retain long-term sutural expansion, and adverse effects such as dental tipping and thinning of the buccal bone plate of supporting teeth have been reported in the literature.[9–12] In recent years, an alternative to TB-RME has been introduced. The new hybrid design anchors the RME appliance both to the posterior teeth and, also, by means of two mini-implants, directly to the palatal surfaces of the maxilla. Bone-anchored expanders are intended to apply the expansion forces directly to the maxilla and the midpalatal suture.[13] The use of skeletal anchorage in maxillary expansion could possibly improve skeletal expansion and reduce the risk of dental adverse effects, although further studies have not shown conclusive results of the effectiveness.[10–15]

Treatment outcome after maxillary expansion is often assessed mainly by the elimination of dental crossbite and linear two-dimensional measurement of dental expansion. In growing children, the successful treatment of maxillary constriction should also involve the re-establishment of normal growth and occlusal development.[6] Dental measurements may not accurately represent the underlying skeletal changes, and dental tipping may cause bias in the assessment of treatment success.

A three-dimensional (3D) evaluation can describe the palatal morphology and treatment changes in all three planes. Some studies have used cone-beam computed tomography to accurately describe skeletal and dental changes. However, in growing children, it would be preferable to avoid repeated exposure to ionizing radiation.[16] Recently, several methods of 3D analysis based on digital dental casts have been developed. Primožič et al. proposed a method using palatal volume and area to evaluate maxillary expansion and re-establishment of a normalized growth pattern in growing children.[6,17] The method has also been used to compare treatment outcome after maxillary expansion with different treatment modalities and has been compared with untreated controls.[18]

No previous study has compared long-term 3D changes in palatal morphology after the treatment of posterior crossbite in young adolescents. The aim of this study was, therefore, to assess 3D changes of the palatal vault following treatment of functional posterior crossbite in the mixed dentition with the following two different treatment modalities: a group treated with conventional TB-RME and a group with a hybrid tooth bone–borne (TBB) RME with a long-term follow-up of up to 5 years.

MATERIALS AND METHODS

Trial Design

The study was a follow-up analysis to a two-arm, parallel-group, randomized controlled trial (RCT) performed at a single center.[13] The regional ethical review board in Uppsala, Sweden, which follows the guidelines of the Declaration of Helsinki, and the regional radiation protection committee approved the study protocol (Dossier number: 2009/334).

Participants, Eligibility, and Settings

A total of 54 consecutive patients examined at the Department of Orthodontics, Postgraduate Dental Education Center, Örebro, Sweden, who met the eligibility criteria were recruited from September 2010 to December 2015. Two declined participation and were excluded. After receiving oral and written information about the clinical trial, the included patients and their parents/guardians signed the consent forms. The following inclusion criteria had to be fulfilled by all participants enrolled in the study:

- unilateral or bilateral crossbite with constricted maxilla
- age at diagnosis of 8–13 years, with a dental stage in the early or late mixed dentition.

Patients with previous or ongoing orthodontic treatment, craniofacial syndromes, or cleft lip or palate were considered ineligible for the study.

Randomization

All 52 participants were randomly allocated in blocks of different sizes using the concealed allocation principle in a 1:1 ratio to two groups: a TB group and a TBB group. The randomization procedure was as follows: a computer-generated randomization list was created using SPSS software (version 17.0; SPSS, Chicago, Ill) and stored with a research secretary. Each time a patient gave his/her consent, the secretary was contacted by e-mail to provide the information about which type of expander the patient should receive. The randomization list was also stratified by sex, ensuring the inclusion of equal numbers of boys and girls in each group.

Interventions

After informed consent was obtained from both patients and their parents/guardians, the patients were randomly assigned into two groups: group A was treated with a TB expander (Figure 1A), and group B with a TBB expander with two 1.7 × 8-mm miniscrew implants (Orthoeasy; Forestadent, Pforzheim, Ger-

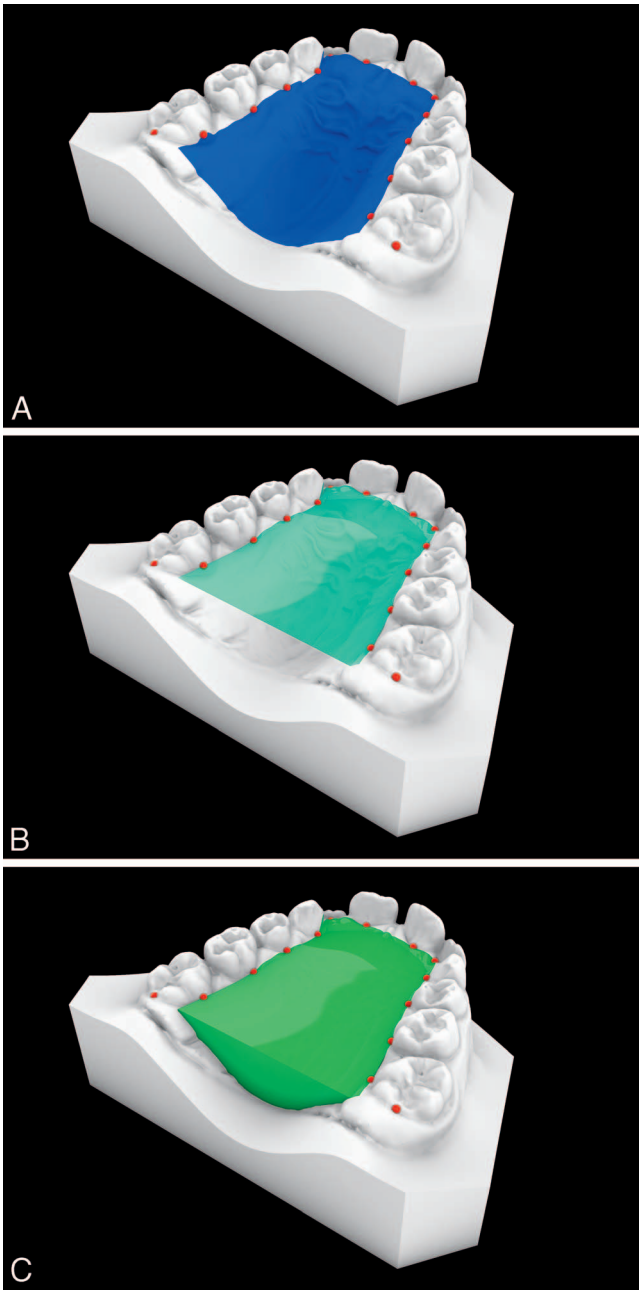

Figure 1. (A) Palatal surface area. (B) Palatal projection plane. (C) Palatal volume.

many), attaching the expander to the palate surface (Figure 1B). No predrilling was undertaken. Both expanders were activated two quarter turns per day (0.5 mm) until the palatal cusps of the maxillary first molars contacted the buccal cusps of the mandibular first molars. Hence, both groups were overexpanded and had the same end point. All expanders were removed after a retention period of 6 months. All patients in both groups were treated by the same orthodontist (Dr Bazargani). Study casts were taken for all patients at pretreatment (T0); directly after removal of the RME 6 months after the desired overexpansion was achieved (T1); 1 year after expansion, which coincided with 6 months after removal of the expanders (T2); and 5 years after expansion (T3). Between the time points T0 and T3, no additional orthodontic treatment was carried out on the patients. In addition, no retention schemes were undertaken between time points T1 and T3.

Assessment of Palatal Surface Area, Projection Area, and Shell Volume

Study casts were digitized using a Planmeca PlanScan Lab 5.0 desktop 3D scanner and software (Planmeca OY, Helsinki, Finland). To obtain 3D measurements of jaw morphology, the reverse modeling software Rapidform was used (Rapidform, INUS Technology Inc., Seoul, South Korea). Analysis protocol was as described by Primožič et al.[6] and was previously used in several other studies.[18–20]

To obtain measurements and calculate the palatal surface (Figure 1A), palatal projection plane surface (Figure 1B), and volume of the palate (Figure 1C), the palatal boundaries in all three dimensions had to be defined. In the vertical direction, the gingival plane was used as a delimitation; it was defined as a best-fit plane through the midpoints of the dentogingival junctions of all the teeth between the first permanent molars. Posteriorly, a distal plane was created perpendicular to the gingival plane through two points behind the first permanent molars. After the morphological boundaries were set, the program calculated the palatal surface, gingival projection plane surface, and palatal surface. All measurements were performed and analyzed by one of us (Dr Golež) who was experienced in the analysis method and blinded to group allocation.

Primary Outcome

Changes in palatal volume, palatal shell area, and palatal projection area within and between the groups up to 5 years after expansion were the primary outcomes.

Secondary Outcome

Incidence of long-term relapse between the groups was a secondary outcome.

Blinding

Because of the clinical limitations, only the outcome assessors were blinded to the groups to which the patients were allocated.

Sample Size Calculation

The calculated sample size for each group was based on a significance level of .05 and 90% power to detect a difference of 1.5 mm (standard deviation [SD], ±1.5) of the midpalatal suture expansion between the groups. The SD was adapted from earlier studies.[8,9] The sample size calculation indicated that 22 patients would be required in each group. To compensate for dropouts, it was determined to include at least 26 patients in each group (an addition of 15% per group).

Statistical Analysis

The changes in outcome (at T1/T2/T3 minus T0) between groups (TBB vs TB) were evaluated with a random intercept linear mixed model with first-order autoregressive correlation structure between time points. Study groups and times (T1, T2, T3) and the interaction (group × time) were used as fixed factors and the baseline outcome variable at T0 as covariate. The same type of analysis, but with T0 as the outcome, was used to compare the outcomes within the study groups. The outcomes transformed to $\log_{10}$ scale were used to estimate the mean percentage change from T1 to T3. The marginal mean differences of outcomes in the mixed models were reported with 95% confidence intervals (CIs). A *P* value below .05 was considered statistically significant, and the analyses were performed with SPSS Statistics 25 (IBM, Armonk, N.Y.) and Stata release 17 (StataCorp, College Station, TX).

Error of Method

To evaluate the reliability of the outcomes, 23 randomly selected digital casts at T0, T1, and T2 were measured twice on two separate occasions at an interval of 8 weeks. The intraclass correlation coefficient (ICC) was used for evaluating the error of method. The ICCs of palatal parameters with 95% CIs were the following: palatal surface, 0.99 (95% CI, 0.98–0.99); gingival projection plane area, 0.98 (95% CI, 0.95–0.99); and palatal volume, 0.99 (95% CI, 0.99–0.99). An ICC >0.9 indicates excellent reliability, 0.75–0.9 good, 0.5–0.75 moderate, and <0.5 poor.[21]

RESULTS

A total of 54 patients, mean age 9.8 years (SD, 1.28), were assessed for eligibility. Two patients declined to participate in the trial and were therefore excluded. A total of 52 patients were included in the trial (Table 1). All patients were followed for 1 year and 5 years after expansion (Figure 2). One study cast in the TB group was defective and could not be analyzed.

Changes in palatal volume, palatal surface area, and palatal projection area within and between the groups

Table 1. Patient Characteristics

	TBB, n = 26	TB, n = 26
Age, mean (SD), y	9.5 (1.2)	9.3 (1.3)
Minimum–maximum	(7.6–13.8)	(7.4–12.7)
Girls, n (%)	13 (50)	13 (50)

up to 5 years after expansion followed the same pattern and did not show any statistically significant differences between the groups. Within groups, there were significant changes between the different time points. Palatal surface area and projection area showed a constant decrease between the time points in both groups. Palatal surface volume increased up to 5 years after expansion in both groups (Table 2).

Palatal surface area decreased by 5.4% in both groups during the 5-year follow-up. Palatal surface volume increased by 6.2% and 6.6% in the TBB and TB groups, respectively. Projection surface area also showed a decrease of approximately 13% in both groups during the 5-year follow-up (Table 3). Changes during the observation periods (T0 to T3) are also shown in Figures 3, 4, and 5 for palatal area, volume, and projection area between the TB and TBB groups.

At 5 years after expansion, relapse was observed in eight children (15.4%): two patients in the TB group and six in the TBB group. The reason for relapse was either a Class III growth pattern between T1 and T3 (four patients) or open-bite tendency with insufficient occlusal contacts (two patients) between the maxilla and mandible at the end of the treatment (at T1, which also persisted at T3). For the remaining two patients (one in each group), the relapse was not related to the aforementioned reasons.

DISCUSSION

Most previous studies evaluated the immediate effects of different RME devices and seldom assessed the long-term effects and stability of the treatments. Findings of this longitudinal RCT showed that the palatal volume, palatal surface area, and palatal projection area within and between the groups up to 5 years after expansion followed the same pattern and did not show any statistically significant differences between the groups. The decrease in both palatal surface and projection area in both groups during the 5-year follow-up went hand in hand and could coincide with some moderate relapse by a magnitude of approximately 5% and 13%, respectively. The increase of palatal volume by approximately 6% in both groups during the 5-year follow-up period could, logically, have been attributed to the slight growth and enlargement of palatal volume in patients between the ages of 9 and 14 years in both groups.

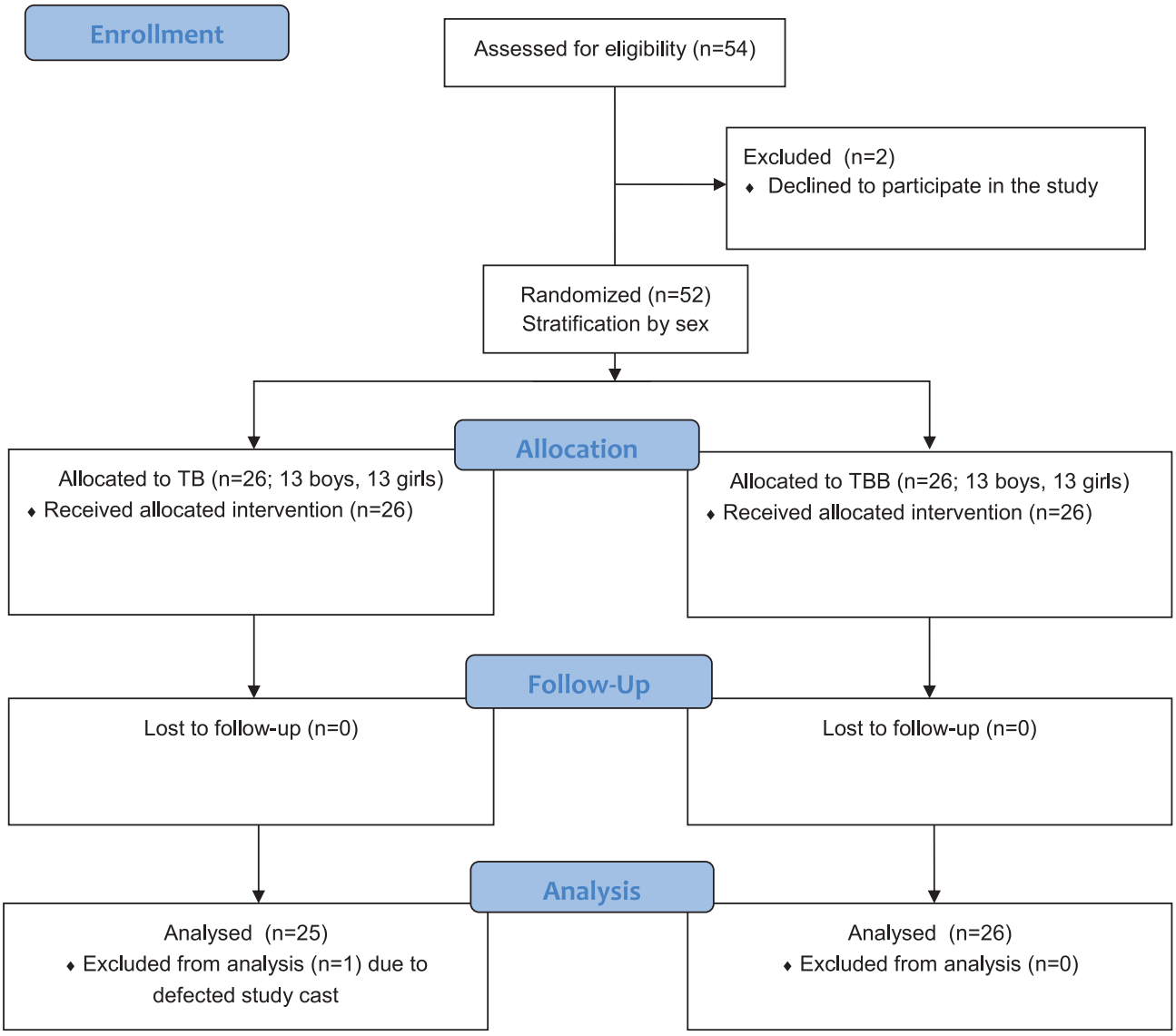

Figure 2. Flow diagram.

Relapse occurred in approximately 15% of the patients and was not associated with the design of the RME device. It seemed to be that open-bite and a Class III growth pattern could be assumed as prognosis-deteriorating factors with regard to the stability of the treatment. Five patients with either open-bite tendency or a Class III growth pattern were, by chance, allocated to the TBB group.

This could happen even with a rigorous randomization procedure. Excluding these five patients with an abnormal growth pattern, the incidence of relapse was very low and equal between the groups. Two patients, one in each group, relapsed despite adequate occlusal outcomes after expansion. The reasons for relapse in these two patients were not obvious. An earlier study[22] with a somewhat older study population (mean age 12.7 years) reported an approximately 20% relapse in patients with posterior crossbite treated with RME after long-term follow-up, which was somewhat higher than the results from the current study. This could be explained by the age differences between the study groups. The older the patients, the more fusion of the midpalatal suture and maxillary complex could be expected. Angelieri et al.[23] concluded that fusion of the midpalatal suture in girls was completed earlier than in boys and, up to 13 years of age, the midpalatal suture was usually in stages A and B (in other words, not completely fused). This might indicate that in older adolescents (14–17 years of age), the use of mini-screw-anchored RME devices could be considered an option. However, the evidence in this matter is deficient, and more RCTs with adequate follow-up

Table 2. Comparing the Outcomes Between the Study Groups Adjusted for Baseline and Within the Study Groups With Linear Mixed Models for Repeated Measurements

	T0	T1	T2	T3
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
TBB group, n = 26				
Palatal surface area	1226 (143)	1404 (158)	1356 (161)	1332 (177)
Palatal surface volume	5250 (1001)	6325 (1206)	6397 (1167)	6720 (1287)
Projection surface area	859 (95)	1006 (105)	953 (108)	872 (109)
TB group, n = 25				
Palatal surface area	1209 (104)	1362 (120)	1317 (111)	1291 (129)
Palatal surface volume	4944 (859)	5903 (986)	5895 (942)	6297 (1043)
Projection surface area	838 (89)	978 (102)	927 (98)	853 (97)
TBB vs TB group				
Palatal surface area				
Palatal surface volume				
Projection surface area				

Table 3. Comparing the Mean Percentage Difference in Outcomes Between T1 and T3 With Linear Mixed Models for Repeated Measurements With Outcomes on a $\log_{10}$ Scale

	T1	T3	T3 vs T1	T3 vs T1
	Mean	Mean	Mean Difference (95% CI)	Mean Percentage (95% CI)
TBB group, n = 26				
Palatal surface area	3.145	3.121	0.946 (0.927 to 0.966)	−5.4 (−7.3 to −3.4)
Palatal surface volume	3.794	3.820	1.062 (1.020 to 1.105)	+6.2 (+2.0 to +10.5)
Projection surface area	3.000	2.938	0.865 (0.845 to 0.886)	−13.5 (−15.5 to −11.4)
TB group, n = 25				
Palatal surface area	3.133	3.109	0.946 (0.926 to 0.966)	−5.4 (−7.4 to −3.4)
Palatal surface volume	3.765	3.793	1.066 (1.023 to 1.110)	+6.6 (+2.3 to +11.0)
Projection surface area	2.988	2.928	0.870 (0.850 to 0.892)	−13.0 (−15.0 to −10.8)

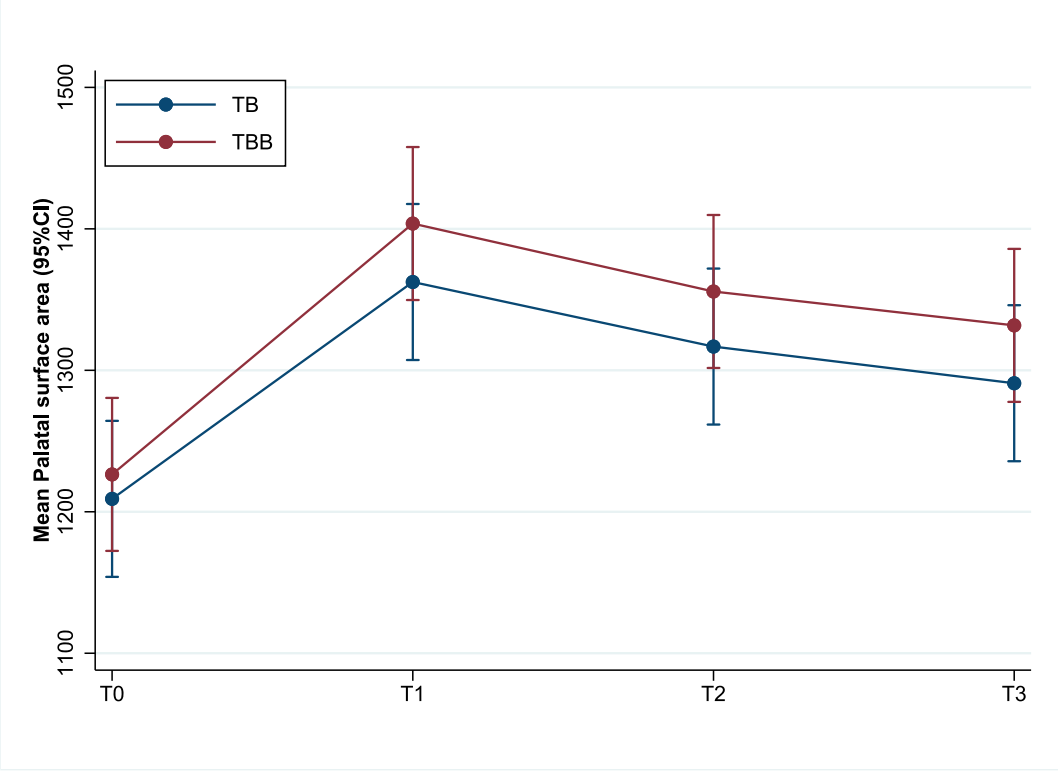

Figure 3. Palatal surface area changes between T0 and T3.

Table 2. Extended

T1 vs T0		T2 vs T1		T3 vs T2	
Mean Difference (95% CI)	*P* Value	Mean Difference (95% CI)	*P* Value	Mean Difference (95% CI)	*P* Value
177 (155 to 199)	<.01	−48 (−70 to −26)	<.01	−24 (−46 to −2)	.03
1075 (882 to 1267)	<.01	72 (−120 to 264)	.46	324 (131 to 516)	<.01
147 (130 to 163)	<.01	−53 (−70 to −36)	<.01	−80 (−97 to −63)	<.01
153 (131 to 176)	<.01	−46 (−68 to −23)	<.01	−26 (−48 to −4)	.02
959 (763 to 1155)	<.01	−8 (−204 to 188)	.93	402 (206 to 599)	<.01
140 (123 to 157)	<.01	−51 (−68 to −33)	<.01	−75 (−92 to −57)	<.01
Change T1 to T0		Change T2 to T0		Change T3 to T0	
23 (−12 to 58)	.20	21 (−14 to 56)	.24	23 (−12 to 58)	.20
101 (−205 to 408)	.51	181 (−126 to 488)	.24	102 (−204 to 409)	.51
7 (−21 to 36)	.62	5 (−24 to 33)	.74	−1 (−29 to 28)	.97

periods are required to confirm the efficiency of miniscrew-anchored RME devices in older adolescents.

In an earlier study[13] with the same population as the current report, it was concluded that, with regard to skeletal and dental expansion, alveolar bending, and tipping of the molars, there were no clinically significant differences between the patients treated with TB-RME and TBB-RME designs in the early mixed dentition. The midpalatal suture in these young patients was not fused, and the expansion of the maxillary complex seemed to respond equally well in both groups. Hence, the use of a hybrid RME in children at approximately 10 years of age might not be justified. The hybrid design is also somewhat more expensive than the conventional TB design[13] and, in a cost–benefit context, it seems to also be wiser to use the TB device because of the similar immediate and long-term outcomes between the groups.

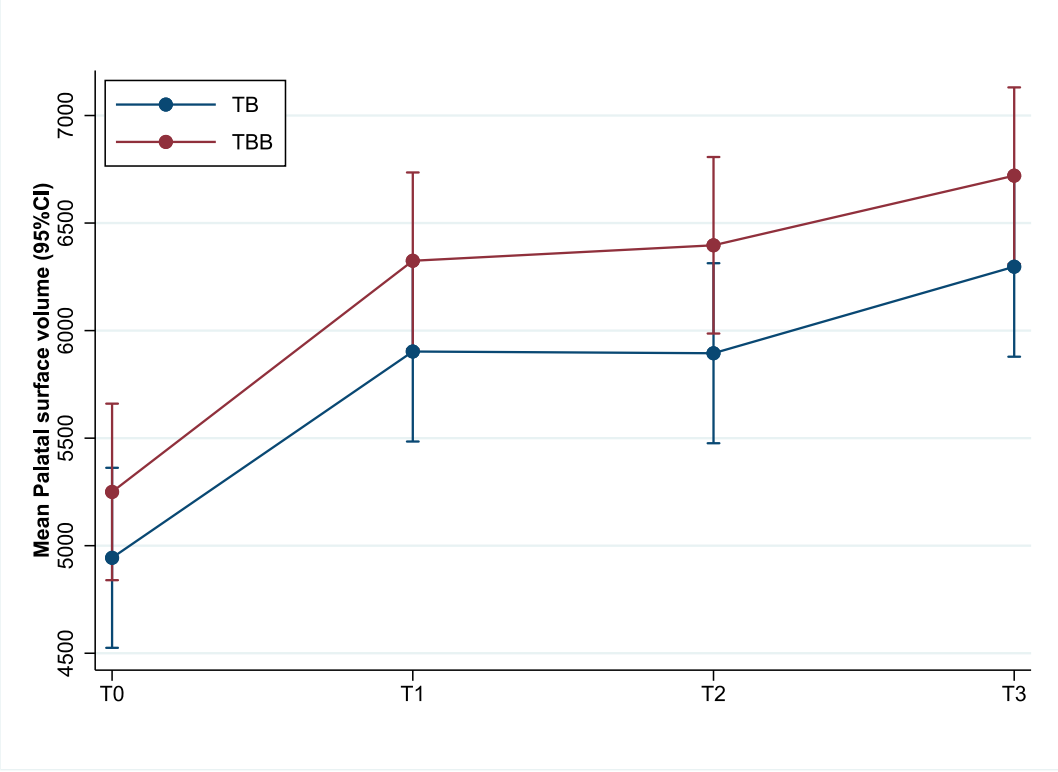

Figure 4. Palatal volume changes between T0 and T3.

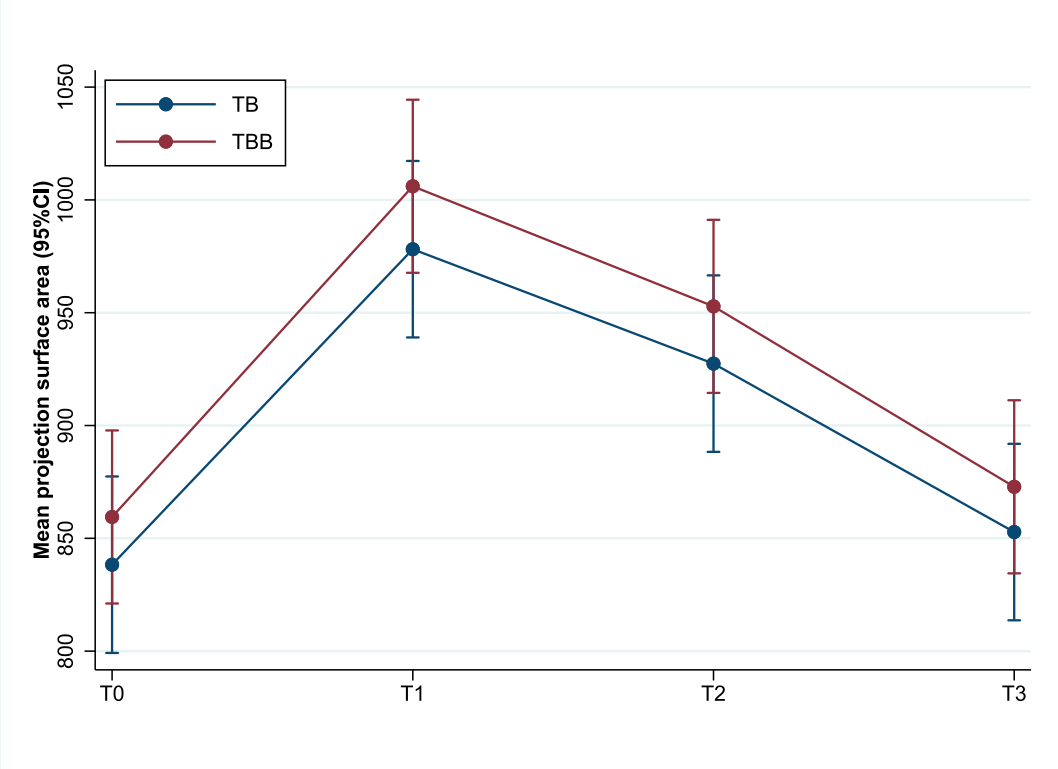

Figure 5. Palatal projection area changes between T0 and T3.

CONCLUSIONS

- Changes in palatal volume, palatal surface area, and palatal projection area within and between the groups up to 5 years after expansion followed the same pattern and did not show any statistically significant differences between the groups.
- Relapse occurred in approximately 15% of the patients and was not associated with the design of the RME device. It seems to be that open-bite and a Class III growth pattern could be assumed as prognosis-deteriorating factors with regard to the stability of the treatment.
- It seems to also be wiser to use the TB device in children with posterior crossbite in the early mixed dentition because of the similar immediate and long-term outcomes between the groups.

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