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Remodelling of the palatal dome following rapid maxillary expansion (RME): laser scan-quantifications during a low growth period

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Structured Abstract

Objectives – To evaluate changes in the palatal vault after rapid maxillary expansion (RME) with bonded splint appliances.

Setting and Sample Population – The sample comprised 24 children (12 boys and 12 girls) with mixed dentition (mean age 8.3 years; range 6.4–10.4 years).

Materials and Methods – Following expansion, the splint appliance was used as a retainer for 6 months and then removed. Study casts were taken before RME (T_0) and when the appliance was removed (T_1). Then, 3D laser scans were taken to build complete 3D jaw models. Frontal cross sections were constructed at 53–63, 55–65 and 16–26, exported as coordinates, and finite element calculated to quantify their area, width and height. Maxillary length was also determined.

Results – Paired *t*-tests indicated statistically significant increases in the average palatal width (T_1–T_0 = 6.53–6.79 mm) and cross-sectional area (T_1–T_0 = 20.39–21.39 mm^2) after RME ($p < 0.001$). However, small but statistically significant reductions were observed in palatal height (T_1–T_0 = −0.49 mm, only at 55–65; $p < 0.001$) and length (T_1–T_0 = −0.54 mm; $p < 0.01$). Linear regression analysis showed statistically significant ($p < 0.001$) direct correlations between the widths and respective cross-sectional areas. Age did not influence any measurement. The reliability of the measurements was examined with an intraclass correlation coefficient (ICC). We found an ICC > 0.99 ($p < 0.001$) for all tested parameters.

Conclusions – Rapid maxillary expansion distinctly increased mean palatal widths and cross-sectional areas. However, palatal height (55–65) and maxillary length decreased to a small extent.

Key words: 3D laser scanning; palatal vault remodelling; rapid maxillary expansion

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Introduction

Rapid maxillary expansion, introduced in 1860 (1), is currently a proven method (2–5). Tooth- and bone- anchored treatment systems are used for this procedure, including Hyrax- and Haas-type devices and cemented splints (6). The characteristic working principle of rapid maxillary expansion (RME) is the application of strong forces over a short period of time (6). The ideal outcome is additional space created by widening the apical base and a transverse shift of the maxillary dental arch with minimal dentoalveolar tipping of the posterior teeth.

However, rapid expansion can produce other effects as well. Examination with the naked eye is sufficient to detect some differences in the configuration and dimensions of palatal cross-sectional images prepared before and after a rapid expansion. The relevance of these alterations lies in the fact that the palatal cross section and expansion determine the amount of space available for the tongue, which in turn impacts its physiological function. Fried (7) described an association between the anatomical changes to the palate incurred by RME and improved tongue activity during swallowing, chewing and speaking. Moreover, they observed a reduction in hyperkinesia associated with a narrow palatal dome. Oliver and Evans (8) reported that patients with pronounced articulation defects tended to have smaller oral dimensions than those of individuals with normal speech. Fymbo (9) and Lubit (10) found that, in those cases, the palatal dome tended to be higher and narrower than normal.

A number of authors have reported inconsistent results on the changes in palatal dome shape and dimensions that occur in the course of an RME. For instance, Cleall et al. (11) studied monkeys and reported a persistent flattening of the palatal dome following the expansion of the median palatal suture. In pigs and clinical studies, Haas (12, 13) described similar anatomical changes to the palatal shelves and alveolar processes in response to maxillary expansion. In contrast, Davis and Kronman (14) studied palatal structural changes in children in response to RME treatment; their results showed, on average, no vertical alterations in the palatal vault. In contrast, Fried (7) observed increases in palatal height at some measurement points in 9-year-olds treated with Haas devices for RME. Ladner and Muhl (15) also reported a distinct increase in palatal depth, conceding influences of growth and dental eruption. Recently, two studies that used cemented splints for RMEs in children with mixed dentition found opposite results. One study reported a less-deeply arched palatal dome (16), and the other recorded a small increase in palatal depth (17). This lack of a clear consensus suggested that subject age, the measuring methodology, or both may give rise to variability in the measurement of RME effects.

In the present retrospective study, we measured RME-induced changes in the palate, including cross-sectional area, width, height and sagittal length; we also investigated possible interactions between the measured parameters. Acrylic splint devices were used for expansion, and all treatments were conducted in subjects with similar dentition at an age of slow, steady growth (18). Upper jaw casts were prepared before and after active RME therapy with 6-month retention. The measurements were taken using 3D laser scanning.

Materials and methods

The present study was approved by the Ethics Commission of the Medical University of Graz/LKH, Austria. We included 24 subjects (12 girls and 12 boys) in the mixed dentition stage, with a mean age of 8 years 3 months (range 6.4–10.4 years). All children exhibited a narrow apical base associated with a cross bite. The cross bites were one-sided in 16 cases and double-sided in eight cases. All subjects exhibited some degree of malocclusion: class I (n = 12), class II (n = 8) and class III (n = 4).

Expansion procedure

All patients had the same maxillary dentition in the expansion area (16, 55, 54, 53, 63, 64, 65, 26). Initially, the subjects underwent a RME treatment with cemented (Ketac-Cem® 3M-Espe, 2380 Perchtoldsdorf, Austria) acrylic splints [Winsauer and Richter (6); Fig. 1].

In all cases, we used 12 + 12 Superscrew expansion screws produced by the Superscrew Superspring Company (Highwood, IL, USA). During the first 3 days, the device was activated at 0.5 mm (corresponding to 180° or 3 sixths rotation). This was followed each day by 0.33 mm (corresponding to 120° or/2 sixths rotation) until the palatal molar cusps of the maxilla contacted the buccal cusp tips of the mandibular molars. After completion of the active expansion, the device was left *in situ* for 6 months as a passive retainer; then, it was removed.

3D – image generation

The casts were made of modelling plaster (Plastodur; Henry Schein Company, Vienna, Austria). The initial casts (A) for the first measurement (T_0) were prepared immediately before treatment, and the final casts (E) for the second measurement (T_1) were prepared after expansion and 6-month retention. All 24 A and E casts were then positioned in a 3D laser scanner (Willytec Company, Munich, Germany) developed by Mehl et al. (19). Images were acquired at 0° and 180° positions to eliminate shadows produced by one-sided scans. Each A and E cast pair was incrementally scanned with a width of 60 μm in both positions. This process generated 5–6, partially overlapping, 11-mm-wide strips for each cast, which were subsequently stacked to create a 3D image. This produced a comprehensive picture of the upper teeth, the alveolar ridge and the palatal surface viewed from an occlusal perspective.

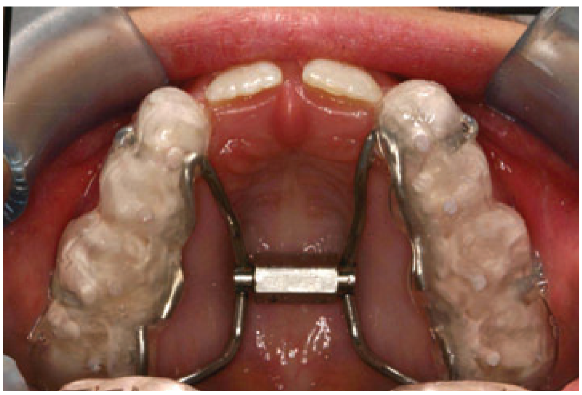

Fig. 1. Cemented arcrylic splint and expansion screw.

Measurement process

Now, the virtual casts were positioned in a metric *xyz*-coordinate system, where the *xy* plane is parallel to the occlusal plane and the *y*-axis runs with median sagittal direction.

In the next step, the origin of the 3D coordinate system was shifted to the tip of the papilla incisiva of the A cast to create a standard reference position. An identical reference point was placed on the E cast. To unify the coordinate systems (Fig. 2) of the two casts, the E cast was then rotated into the position of the A cast (Fig. 2) with the rotation function of the 3D software. With this standardization technique, it was possible to mark the reference points required for the measurement on the first permanent molars (16–26), the second deciduous molars (55–65) and the canines (53–63)

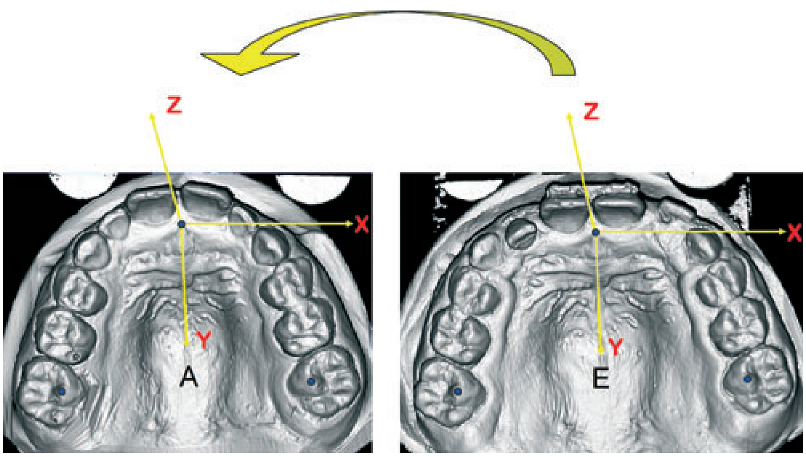

Fig. 2. Rotation of the E cast into the position of the A cast in order to unify the coordinate systems (blue dots mark the origin (0 points) of the 3D coordinate systems).

and on the papilla incisiva to determine their positions relative to one another.

To generate the palatal cross sections for each cast pair (A and E), three frontal cross sections were placed (Fig. 3) through the mesiopalatal cusp tips; the first at 16–26 (6), the second at 55–65 (V) and the third through the distal contact points at 53–63 (III). The section images ran perpendicular (in the *X–Z* plane; Fig. 2) to the palate surface and the cast base (in the *X–Y* plane; Fig. 2). The section images were exported as coordinate lists to Excel (Microsoft Office 2003 (11.8220.8221) SP3]. These were then used to generate graphical representations, and the reference points were placed at the respective crown-gingiva divisions on the right and left sides. For 16–26 and 55–65, the distance between the two reference points (base line) was defined as the palatal width (expansion widths w_6 and w_v, respectively). For 53 and 63, first a line was drawn that joined the most cranial crown points (54 to 53 on one side and 64 to 63 on the other side); then, a line running with cross section III was drawn from the junction between the adjacent teeth towards the palate surface. The intersection of these lines was used as the reference point (on each side; Fig. 2). The distance between the two reference points (base line) was defined as the palatal width, w_{III} (53–63).

The palatal cross-sectional area was defined as the space in the *X–Z* plane delimited by the entire respective base line and the palate contour (Fig. 2). The respective areas (a_6, a_v, a_{III}) enclosed by these two border lines were determined with the finite element method. Therefore, small cross-sectional units (60×60 μm), derived from the sampling rate of the laser scanner, were defined. Summarizing the units, which cover the desired area, its total extend could be calculated.

The palatal heights (h_6, h_v, h_{III}) were defined as the lengths of straight lines that connected the deepest point of the palatal dome and the middle of the base line (Fig. 2). Finally, the palatal length (L) was determined as the distance between a reference point at the tip of the papilla incisiva and the centre of the base line at 16–26 (w_6) (Fig. 4).

Statistical analysis

All measured values are expressed as the mean ± SD. Paired *t*-tests were used to compare all parameters measured before (T_0) and after (T_1) RME and to compare the measurements among individual sections (III, V and 6).

Linear regression analysis was used to examine associations between the palatal cross-sectional areas and expansion width, palatal height and subject age.

All reference points on the section images from the 3D scanner were assigned by a single inves-

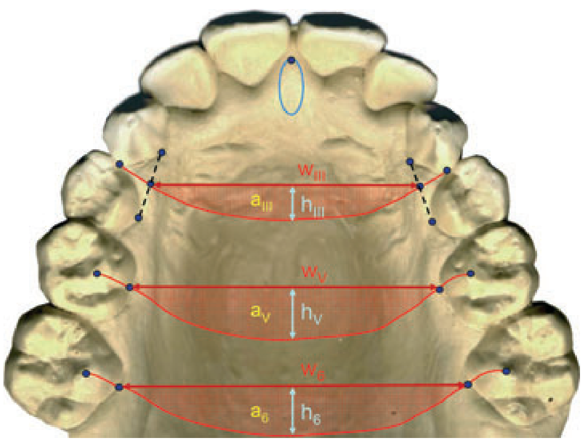

Fig. 3. Cross-sectional areas and measured parameters; blue dots indicate the reference points; double red arrows are the base lines, taken as the widths: w_{III}, w_V, and w_6; double white arrows between the middle of the base line and the deepest point on the palate are the heights: h_{III}, h_V, and h_6; red grid-lines indicate the areas: a_{III}, a_V, and a_6.

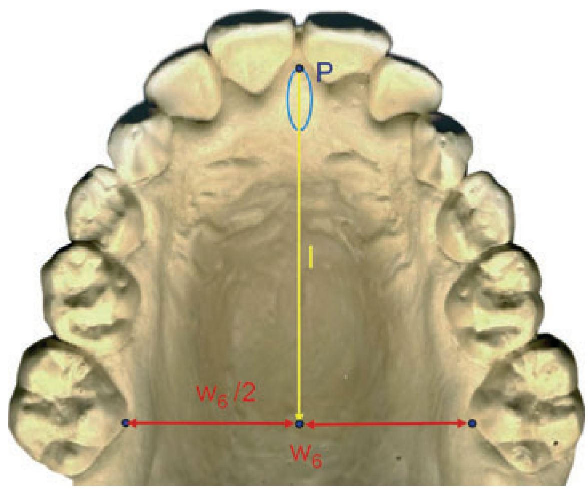

Fig. 4. Palatal length (yellow line, L) was defined as the distance between the tip (P_0, blue dot) of the papilla incisiva and the midpoint of the base line (w_6, 16–26).

tigator at three different times in at least 1-week intervals. The mean values of the three measurements were used for subsequent analyses.

Measurement errors in the linear and surface measurements resulted from the quantitation method used by the 3D scanner during the model capture. The error was ±0.06 mm for linear values and, derived from this, ±0.0036 mm^2 for surface areas.

The three measurement series were compared with a reliability analysis. Their consistency was assessed with the intraclass correlation coefficient (ICC). The reproducibility of the three measurements for all tested parameters was confirmed by a statistically significant ($p < 0.0001$) ICC > 0.99.

Results

The findings described in this section represent the differences between the measurements taken before and after expansion and retention (T_1–T_0).

Palatal width

The average post-expansion palatal widths (6.53–6.79 mm) revealed statistically significant increases ($p < 0.0001$) in all measured cross-sectional areas (Table 1). The percentage changes in the individual sections (Fig. 5, Table 2) showed that the increase in w_{III} (22.29%) was less than that in w_V (24.81%; $p < 0.001$). Moreover, w_V

Table 1. **Descriptive statistics: analysis of the mean changes ($T_1 - T_0$) in the average width (w), area (a), height (h), and length (L) in each section of the palate**

			Differences in values before and after rapid maxillary expansion and retention				
Parameter	Cross section	N	Minimum	Maximum	Mean	SD	*p*
Width [w_{III} (mm)]	53–63	24	2.64	11.27	6.53	2.39	0.0001
Width [w_V (mm)]	55–65	24	3.30	10.40	6.79	1.89	0.0001
Width [w_6 (mm)]	16–26	24	3.40	10.40	6.60	1.94	0.0001
Area [a_{III} (mm^2)]	53–63	24	−23.60	65.20	20.39	19.83	0.0001
Area [a_V (mm^2)]	55–65	23	−7.73	50.37	21.39	13.64	0.0001
Area [a_6 (mm^2)]	16–26	24	−18.90	48.83	20.46	15.42	0.0001
Height [h_{III} (mm)]	53–63	24	−1.43	1.57	0.04	0.80	0.8200
Height [h_V (mm)]	55–65	23	−1.37	0.37	−0.49	0.49	0.0001
Height [h_6 (mm)]	16–26	24	−1.17	1.26	−0.11	0.58	0.3700
Length [L_6 (mm)]	16–26	24	−2.60	1.63	−0.53	0.93	0.0100

N, number of subjects; SD, standard deviation; *p*, *p*-value.

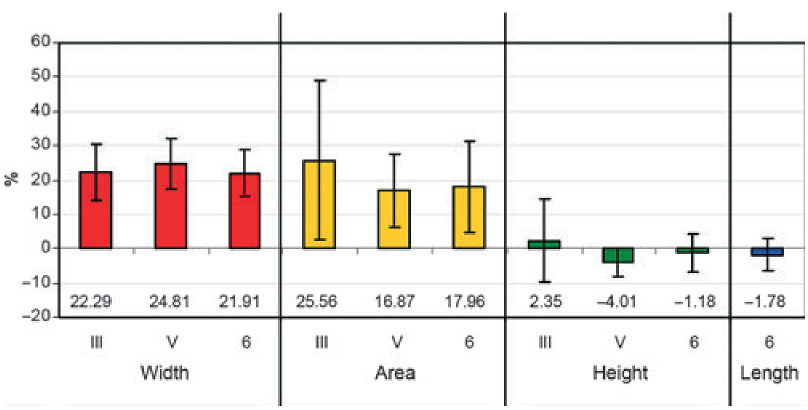

Fig. 5. Mean percent changes ([T_1–T_0]/T_0*100) in widths, heights, and areas of cross sections III (53–63), V (55–65), and 6 (16–26); change in length was measured from the papilla to the base line of section 6 (16–26).

Table 2. **Comparison of the mean percent changes [($T_1 - T_0$)/$T_0 \times 100$] in width, height, and area among cross sections III (53–63), V (55–65), and 6 (16–26)**

Parameter	Cross sections	Significance (p)
Width (increase)	III < V	< 0.0010
	V > 6	< 0.0001
	III > 6	0.6370
Height (reduction)	V > 6	0.017
Area (increase)	III > V	0.037
	V < 6	0.898
	III > 6	0.131

Table 3. **Linear regression analysis: the influence of width changes, height changes, and age on post expansion changes ($T_1 - T_0$) in the cross-sectional areas (III, V, and 6)**

Cross-section	III (p)	V (p)	6 (p)
Age	0.069	0.543	0.618
Width (change)	< 0.0001	< 0.001	< 0.0001
Height (change)	< 0.0001	< 0.0001	0.169

showed a larger increase than w_6 (21.91%; $p < 0.0001$). The difference between w_{III} and w_6 was not statistically significant ($p = 0.637$).

Cross-sectional area

The mean surface area of the palatal cross sections also exhibited a statistically significant increase with expansion (20.39–21.29 mm^2; $p < 0.0001$) for all measured sections (Table 1).

The percentage changes in the areas of the three sections (Fig. 5, Table 2) showed that the increase in a_{III} (25.56%) was statistically significantly larger ($p = 0.037$) than that observed in a_V (16.87%), but not statistically significantly different from that observed in a_6 (17.96%; $p = 0.131$). Also, there was no statistically significant difference in the increases observed in a_V and a_6 ($p = 0.898$).

The linear regression analysis revealed a statistically significant effect of palatal width on palatal cross-sectional area ($p < 0.0001$ for w_{III}, $p < 0.001$ for w_V, $p < 0.0001$ for w_6). The height only exerted an effect on a_{III} and a_V. Moreover, the age of the subjects exerted no influence on any changes in surface area ($p = 0.069$ for a_{III}, $p = 0.543$ for a_V, $p = 0.618$ for a_6; Table 3).

Palatal height

The expansion caused only minimal changes in the mean heights of the different areas of the palatal cross sections (Table 1). The only statistically significant height change was in the second deciduous molars (h_V) (−0.49 ± 0.49 mm; $p < 0.0001$). The deciduous canines (h_{III}) and the first permanent molars (h_6) showed insignificant changes (+0.04 ± 0.80 mm; $p = 0.820$ and −0.11 ± 0.58 mm; $p = 0.370$, respectively).

The percentage change in height between the start and end of expansion was larger on average in the V section (−4.01% reduction) than in the 6 section (−1.18% reduction) ($p < 0.017$). In area III, a small increase in height (2.35%) was apparent (Fig. 5, Table 2).

Palatal length

The mean absolute change in palatal length after expansion therapy (Table 1) was minimal, but statistically significant (−0.53 ± 0.93 mm; $p < 0.010$). The mean percentage change was −1.78% (Fig. 5).

Discussion

Palatal width

The increase in palatal width is often considered the most apparent measure of RME treatment outcome. In the present study, highly significant increases in the mean width were found after expansion and retention for all three cross-sectional areas (16–26 = 6.6 mm, 55–65 = 6.79 mm and 53–63 = 6.53 mm). This increase was consistent with previous reports. Phatouros and Goonewardene (17) applied splint devices for RME in children at an early stage of mixed dentition (mean age 9 years, 1 month); they found mean transverse width increases of 4.8 mm (16–26), 5.0 mm (54–64) and 3.9 mm (53–63). With comparable subject age and treatment, Geran et al. (20) documented transverse width increases of 3.4 mm (16–26), 2.8 mm (54–64) and 2.7 mm (53–63) with the Bioscan OPTIMAS digital imaging system. Sandikcioglu and Hazar (21) carried out RME on children with a transverse deficit at a mean age of 8.9 years with cemented bands of a Hyrax device. They found mean width increases of 5.5 mm (16–26), 6.0 mm (54–64) and 3.3 mm (54–63). da Silva Filho et al. (22) found an increase of 5.46 mm (16–26) in children at a mean age of 8 years that underwent RME with a modified Haas device.

In this study, the per cent increases in width at the deciduous canines (53–63) and the first permanent molars (54–64) were nearly the same (98.94%). This was a larger increase than those found in previous studies. For example, corresponding increases were 81.25% for Phatouros and Goonewardene (17), 79.42% for Geran et al. (20) and only 60% for Sandikcioglu and Hazar (21). The discrepancy might be explained by the fact that we used extended splints that included the deciduous canines; none of the other studies used this method.

Cross-sectional area

On average, all palatal cross sections in this study showed a significant ($p < 0.0001$) increase in surface area (a_6, a_V, a_{III}) after expansion. The respective increases were 20.46 ± 15.4 mm^2 (16–26), 21.39 ± 13.64 mm^2 (55–65) and 20.39 ± 19.83 mm^2 (53–63). These results were consistent with those reported by Phatouros and Goonewardene (17), who also reported a distinct increase of 15.3 ± 17.3 mm^2 at 16–26 ($p < 0.0001$) and an increase of 15.8 ± 23.0 mm^2 at 55–65, although the latter was not statistically significant. Both studies showed appreciable variability in the changes after expansion treatment, ranging from a clear increase to a clear reduction in cross-sectional area. The mean increases could be attributed to the opening of the medial palatal suture and dentoalveolar tipping in the expansion area.

In our study, the mean percentage increase in the cross-sectional area of 16–26 did not differ significantly from that of 53–63 after RME. This might also be explained, as for the similar changes in transverse widths, by the fact that we used extended splints that included the deciduous canines (53–63). The largest increases in the mean absolute values for transverse width and cross-sectional area occurred in the region of the second deciduous molars (55–65). This may have been due to the fact that the expansion screw was positioned in this region.

In the present study, the regression analysis indicated that age had no influence on any area changes. This finding was most likely related to the low growth rate of the young study subjects included in this study (17).

Palatal height

Palatal height constitutes an important parameter for tongue function. In our study, a significant ($p < 0.0001$) reduction of the mean palatal height (-0.49 ± 0.49 mm) only occurred in the region of the second deciduous molars (55–65), which may reflect the positioning of the expansion screws. The decrease observed at the first permanent molars (16–26) was minimal (-0.11 ± 0.58 mm) and significantly smaller than that observed at 55–65 (Table 2). In contrast, a small height increase (0.04 ± 0.80 mm) was observed in the area of the deciduous canines (53–63).

The literature contains variable information regarding changes in palatal height after RME. Haas (12, 13) reported a reduction in palatal height, in both humans and animals (see also Cleall et al.) (11). This reduction was caused by a lowering of the palatal shelves during RME. In their photogrammetric study, Marini et al. (16) also described a sinking of the palatal dome after expansion treatment with cemented splint devices.

Phatouros and Goonewardene in 2008 (17) found a slight increase in palatal height at 16–26 (0.09 ± 0.55 mm) and at 54–64 (0.15 ± 1.0 mm); however, these changes were not statistically significant when compared to an untreated control group. Ladner and Muhl (15) found a larger increase in palatal height at 54–64 (2.3 ± 1.6 mm) after RME with Haas devices. They ascribed this result to the increase in dentoalveolar height during tooth eruption and to the duration of the treatment, which commenced in adolescence (average age at the start of treatment was 11 years, 8 months ± 2 years). In contrast, Oliveira et al. (23) found no statistically significant changes ($p > 0.5$) at 16–26 after RME with Haas (0.33 ± 0.50 mm) and Hyrax (0.40 ± 0.52 mm) appliances in subjects at mean ages of 11.9 and 11.1 years, respectively.

Palatal length

In the present study, palatal length decreased after RME, on average, by a small, but significant amount (−0.53 ± 0.93 mm; $p < 0.01$). This decrease was slightly larger than that reported by Phatouros and Goonewardene (17) with 3D helical CT technology (−0.43 ± 0.9 mm). However, those results were not significantly different from results from an untreated control group. Adkins (24) showed similar findings (−0.4 ± 0.5 mm) in measurements of photographed plaster models of the jaws of adolescent subjects (11.6–17.0 years). However, growth may have influenced those results.

Limitations of the present study included the relatively small number of cases. On the other hand, a major strength of the study was the similar growth, stage and age of all subjects. Although the patients exhibited some degree of malocclusion, no muscular influence was to be expected, because the models were taken immediately after removing the retention appliance. As RME was the first and only orthodontic treatment patients underwent during the present investigation, also no other treatment effects had to be considered. Possible errors in measurement were mentioned in the Statistical analysis section.

Basically it can be said that further research is needed to determine the relationship between palatal morphology, tongue function and the extent of therapeutic palatal expansion.

Conclusions

1. For all three section positions (16–26, 55–65 and 53–63), RME with splint devices resulted in statistically significant enlargements of the mean palatal widths and cross-sectional areas.
2. RME caused small, but statistically significant reductions in mean palatal height (at 55–65) and palatal length.
3. Palatal width exerted a statistically significant influence on the palatal cross-sectional area in all three measured regions. Palatal height was only affected in 54–64 and 53–63.
4. There was no relationship between the observed changes in the palatal cross-sectional areas and the age of the study subjects.

Clinical relevance

Although remodelling of the palatal dome following RME has been investigated for decades, the results are frequently inconsistent. The clinical relevance of palatal changes stems from their influence on tongue housing and therefore, on the physiological function of the tongue. In this study, under standardized conditions, we conducted an evaluation of palatal changes after RME with identical devices, on a population largely similar in growth and age. The findings suggested that RMEs caused an increase in palatal widths and cross-sectional areas, but we also observed small reductions in maxillary length and palatal height (15–25).

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