

# Antero-posterior and transverse changes in the positions of palatal rugae after rapid maxillary expansion

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**SUMMARY** The purpose of this study was to investigate the stability of the medial aspects of the rugae in patients where rapid maxillary expansion (RME) was performed in addition to fixed appliance therapy. Nineteen subjects that met the inclusion criteria for each group were randomly selected from the archive of one orthodontist office. The RME/fixed appliances group consisted of 8 males and 11 females (mean age pre-treatment  $12.4 \pm 2.0$  years). The control group treated with fixed appliances only, consisted of 6 males and 13 females (mean pre-treatment age of  $12.5 \pm 2.1$  years). The medial aspects of the rugae were recorded on the pre- and post-treatment dental models by means of a standardized photographic set-up. The transverse and antero-posterior positional rugae changes were measured. Kolmogorov–Smirnov normality tests were performed and paired *t*-tests were used to determine differences between and within the groups.

The addition of RME to fixed appliance therapy caused a change in transverse measurements between the medial aspects of the bilateral rugae. There was no change in antero-posterior measurements (APM). The transverse changes were more marked for the third, less for the second rugae, and the least for the first rugae. The medial aspects of the third rugae cannot be considered as stable reference landmarks for dental cast analysis when RME is performed in addition to fixed appliance therapy.

## Introduction

Disadvantages and limitations exist in superimposition of cephalometric radiographs, which is used to evaluate orthodontic treatment outcome. Patients need to be exposed to radiation, tracing and superimposing are time consuming and technique sensitive, and radiographic landmarks are difficult to locate. The use of study models to evaluate tooth movement is just as accurate as cephalometric superimposition (Hoggan and Sadowsky, 2001). Other advantages of using study models are that the technique is simpler and no additional radiation is required.

However, to accurately evaluate tooth movement on serial dental casts, it is necessary to identify stable soft tissue landmarks. Previous studies suggest that the medial ends of the rugae are soft tissue landmarks which remain stable during orthodontic treatment and can be used as stable reference points for quantitative analysis of tooth movement (Van der Linden, 1978; Almeida *et al.*, 1995; Bailey *et al.*, 1996; Hoggan and Sadowsky, 2001). Whether these points remain stable after rapid maxillary expansion (RME) has been performed in addition to fixed appliance therapy has yet to be determined.

The effects of RME on the dentition and maxillary complex have been well documented (Haas, 1961, 1965; Wertz, 1968, 1970; Bishara and Staley, 1987; Davidovitch *et al.*, 2005; Ren, 2005). However, very little has been published about the effects of RME on the palatal mucoperiosteum. It is suggested that post-expansion angular relapse of the maxillary teeth may be related to the stretched

fibres of the attached palatal mucosa (Cotton, 1978; Muguerza and Shapiro, 1980). Mesial tipping of maxillary incisor crowns after RME was thought to result from the recoil of the transseptal fibres (Haas, 1965). Since the palatal mucosa containing the rugae is tightly fixed to the underlying periosteum, it is likely that the rugae will follow the separation of the underlying palatal shelves during RME. This would mean that the medial aspects of the rugae may not be stable during RME because transverse expansion of the rugae is likely to occur. The medial aspects of the palatal rugae will then not be suitable landmarks for serial cast superimposition when RME and full fixed appliance therapy have been performed.

The aim of the present study was to investigate the stability of the medial aspects of the palatal rugae in subjects treated with RME followed by fixed appliance therapy. The null hypothesis tested is that the medial aspects of the palatal rugae will remain stable in the transverse and antero-posterior dimensions when RME and fixed orthodontic appliance therapy are carried out.

## Subjects and methods

A power analysis was undertaken to determine the sample size to detect a 0.75 mm difference. This analysis was based on a previous pilot study by the authors where the standard deviation of the response variables was not more than 1.00 mm. A sample of 19 subjects would be needed to detect such a difference. Two treatment groups, a RME/

fixed appliances group and a control group (with fixed appliance therapy only), were compared to determine the effect of RME on the rugae. The inclusion criteria for the RME/fixed appliances and the control group are shown in Table 1. All malocclusions were considered in the present study provided they met the inclusion criteria. Patients with a cleft lip and/or palate were excluded. The mean pre-treatment age and duration of treatment are summarized in Table 2. In the RME/fixed appliances group, the Hyrax appliance was activated an average of  $7.70 \pm 1.18$  mm. Nineteen subjects per group that met the inclusion criteria for each group were randomly selected from the archive of the orthodontic office of Dr 'Wick' Alexander. The complete sample included the pre- and post-treatment dental casts of 38 subjects.

#### Standardized capturing of images

According to the classification method of Lysell (1955), the primary rugae were numbered from first to third, with the first primary rugae being the most anterior. The palatal rugae outlines were marked with a 0.3 mm pencil. The outlines were confirmed by another observer (Arash Jafari)

**Table 1** Inclusion criteria for the two groups.

Rapid maxillary expansion (RME) group	Control group
Initial treatment by a Hyrax appliance (four-banded in the permanent dentition, two-banded with anterior extensions in the mixed dentition)	No treatment with any expansion type appliance (hyrax, quadhelix, headgear, or transpalatal arch)
A minimum of 12 months of pre-adjusted full fixed appliance treatment following RME	A minimum of 12 months of pre-adjusted full fixed appliance treatment
No extraction of maxillary premolars	No extraction of maxillary premolars
Clear and identifiable rugae points on the dental casts	Clear and identifiable rugae points on the dental casts
Standardized Hyrax activation protocol (one activation of the screw per day)	
A minimum of 5 mm palatal screw activation	

**Table 2** Chronological age before treatment and the duration of treatment for both groups.

Group	N	Mean chronological age (year) and SD	95% Confidence interval	Minimum	Maximum	Treatment duration		
						x	SD	P
Rapid maxillary expansion	19	12.4 ± 2.0	11.6, 13.3	8.3	15.4	2.7	0.6	NS
Control	19	12.5 ± 2.1	11.6, 13.5	11.0	14.0	2.2	1.0	

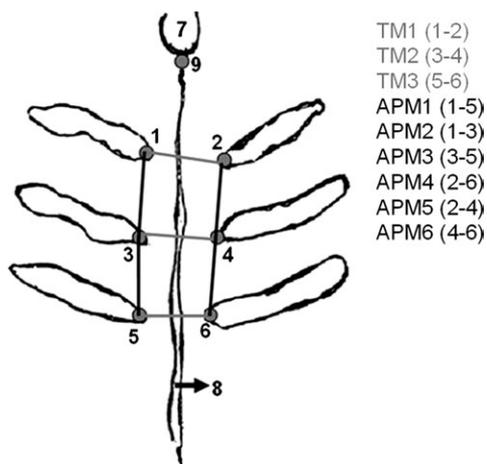
SD, standard deviation; NS, not significant.

after a consensus meeting. The pre- and post-treatment maxillary dental casts of each patient were kept side by side when the landmarks were identified to avoid confusion. The palatal reference points used for this study are illustrated in Figure 1. A digital camera and a metric ruler were fixed on a piece of black card and their positions were clearly marked. They were placed at a fixed distance of 16 cm from each other at the same height. The camera was also levelled in the horizontal plane with a spirit level (Figure 2a). The metric millimetre ruler enabled precise calibration of the photographs during electronic measurement and standardized placement of the dental casts.

A simple levelling device was made by joining two spirit levels (Stanley Works, New Britain, Connecticut, USA) together horizontally and vertically. The anterior end of the horizontal level was marked 'A' and the posterior end 'P'. The vertical level of this device was placed on the anterior wall of the palatal vault, with the distal end 15 mm from the anterior raphe point with Scotch™ Adhesive Putty (3M, St Paul, Minnesota, USA). The horizontal spirit level was used to level the dental cast, producing a constant vertical orientation of the palatal vault. The model was placed with the T-shaped levelling device parallel to the metric ruler. This was done by lining up the anterior wall of the vertical level of the levelling device with the fixed metric ruler (Figure 2b). The levelling device was then gently removed without moving the dental cast. The photographs were taken with a Fuji FinePix S5100 (Fujifilm Corporation, Tokyo, Japan) digital camera. One operator (JD) performed all evaluations and focussed on the palatal tissue at the level of the medial ends of the second palatal rugae. The aperture on the digital camera was set at maximum to achieve the best field of depth and the picture quality set at 4.0 megapixels.

#### Computerized analysis of the images

All images were imported into CoralDraw® Graphics Suite (Corel Corporation, New York City, USA). A standard millimetric ruler was superimposed over the images for precise calibration. The image was resized so that the ruler on the image coincided exactly with the superimposed ruler. Each calibration was double checked at a magnification of



**Figure 1** Landmarks marked on the dental cast. 1 and 2, most medial points on the first rugae; 3 and 4, most medial points on the second rugae; 5 and 6, most medial points on the third rugae; 7, the incisive papilla; 8, the palatal raphe; and 9, the anterior raphe point where the palatal raphe and incisive papilla intersect. The transverse measurements (TM 1–3) and antero-posterior (APM 1–6) measurements are illustrated.

300 per cent. The measurements were made to the nearest one hundredth of a millimetre. Figure 1 illustrates the transverse linear distances that were measured between bilateral rugae points in each group (Almeida *et al.*, 1995; Bailey *et al.*, 1996). The antero-posterior measurements (APM) were made directly in relation to each other (Simmons *et al.*, 1987).

*Error study*

Two days after initial digitization and measurement, the dental casts of 15 subjects were randomly selected to test the methodology and intra-examiner reliability. The method was repeated by the same operator (JD) for the 15 dental casts and the images were recaptured and remeasured. A total of seven (3 transverse and 4 antero-posterior) variables were remeasured. Paired *t*-tests were used to determine the differences between the two measurements. Pearson correlation coefficients and the error of the method by means of Dahlberg’s formula (Houston, 1983) were determined. The method error includes possible errors of landmark identification, distortion of the impression material and impression trays, errors that can occur during the casting technique, and possible expansion of the dental stone (Lysell, 1955; Peutzfeldt and Asmussen, 1989; Millstein *et al.*, 1998; Jagger *et al.*, 2004). *P* values of less than 0.05 were considered to be statistically significant.

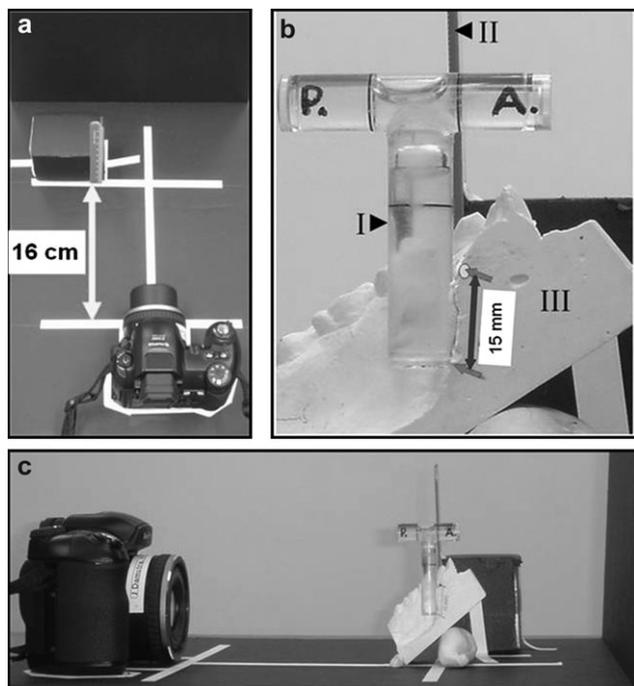
*Statistical analysis*

Kolmogorov–Smirnov normality tests were performed. The values ( $P > 0.05$ ) indicated that the data was normally distributed. Therefore, paired *t*-tests were performed within the groups to determine whether the average change was different from zero and to evaluate whether the average changes in positions of the rugae during the treatment period were the same for the two groups. *P* values of less than 0.05 were considered to be statistically significant. All the statistical analyses were performed using the Statistical Package for Social Sciences Version 14.0 (SPSS Inc., Chicago, Illinois, USA).

**Results**

The mean age at the start of treatment ( $12.5 \pm 2.0$  and  $12.5 \pm 2.1$  years) was the same for both groups (Table 2). The addition of RME to the fixed appliance therapy increased the mean treatment time but this increase was not significant ( $P > 0.05$ ). The results of the error study are shown in Table 3. The observed difference in the mean values was not significant ( $P > 0.05$ ). Pearson correlation coefficients (*r*) between the two sets of measurements were high, showing sufficient reproducibility of the measurements. The error of the method ranged between 0.16 and 0.40 mm ( $0.25 \pm 0.07$  mm).

Descriptive statistics for the rugae changes within and between the two groups are summarized in Table 4. The



**Figure 2** (a) Aerial view showing the position of the digital camera and the metric ruler before placement of a dental cast. The camera and metric ruler were fixed at a distance of 16 cm. (b) Photograph showing the placement of the T-shaped levelling device (I) in the dental cast and placement of the dental cast with regard to the fixed metric ruler (II). The T-shaped levelling device (I) was positioned parallel to the metric ruler, resulting in a reproducible angle of the anterior palatal vault. The maxillary cast (III) was trimmed in half to illustrate the relationship of the ruler and the anterior palatal vault placement. (c) Side view of the photographic set-up before removal of the T-shaped levelling device. The model was trimmed in half to illustrate the placement.

mean changes for the transverse measurements (TM) during the observation time in the RME group were statistically significant ( $P < 0.001$ ). The mean change between the medial aspects of the third rugae was 1.15 mm. The mean changes for all APM between the medial aspects of the rugae were not significant ( $P > 0.05$ ). Within the control group, TM did not change significantly ( $P > 0.05$ ). Antero-posteriorly, although statistically significant ( $P < 0.05$ ), the mean changes of APM2 was less than 0.29 mm. This value was less than the measured method error of APM2 (Table 3). The average changes in the positions of the rugae during the treatment period were the same for APM but not for TM.

## Discussion

Many studies have reported on the stability of the palatal rugae as reference points for pre- and post-treatment dental cast comparison (Peavy and Kendrick, 1967; Van der Linden, 1978; Simmons *et al.*, 1987; Almeida *et al.*, 1995;

**Table 3** Results of the error study. Pearson correlation coefficients, paired *t*-tests and the error of the method.

Measurements (mm)	Pearson ( <i>r</i> )	Paired <i>t</i> -tests ( <i>P</i> )	Error of the method (mm)
Transverse measurement (TM)			
TM1	0.98	NS	0.22
TM2	0.99	NS	0.24
TM3	0.99	NS	0.16
Antero-posterior measurement (APM)			
APM1	0.98	NS	0.23
APM2	0.93	NS	0.40
APM3	0.99	NS	0.25
APM4	0.97	NS	0.24

NS, not significant.

**Table 4** Descriptive statistics [mean and standard deviation (SD), 95 percent confidence interval (CI) and probability (P)] for the changes in the rapid maxillary expansion (RME) and control groups.

Measurements (mm)	RME group ( <i>n</i> = 19)			Control group ( <i>n</i> = 19)			<i>P</i> †
	Mean and SD	95% CI	<i>P</i>	Mean and SD	95% CI	<i>P</i>	<i>P</i>
Transverse							
TM1	0.34 ± 0.43	-0.15, 0.53	***	0.01 ± 0.57	-0.25, 0.28	NS	*
TM2	0.79 ± 0.71	0.51, 1.07	***	0.30 ± 0.66	0.00, 0.58	NS	*
TM3	1.15 ± 0.92	0.81, 1.49	***	0.22 ± 0.49	0.00, 0.44	NS	***
Antero-posterior							
APM1	-0.24 ± 0.94	-0.52, 0.04	NS	0.04 ± 0.65	-0.25, 0.33	NS	NS
APM2	-0.08 ± 0.85	-0.32, 0.16	NS	0.29 ± 0.57	0.04, 0.55	*	NS
APM3	-0.03 ± 0.54	-0.24, 0.18	NS	-0.10 ± 0.41	-0.28, 0.09	NS	NS
APM4	-0.12 ± 0.99	-0.47, 0.23	NS	-0.14 ± 0.51	-0.37, 0.09	NS	NS
APM5	-0.30 ± 0.82	-0.57, 0.02	NS	-0.06 ± 0.36	-0.22, 0.10	NS	NS
APM6	0.15 ± 0.92	-0.14, 0.44	NS	-0.16 ± 0.43	-0.35, 0.03	NS	NS

NS, not significant. \* $P < 0.05$ ; \*\*\* $P < 0.001$ .

Bailey *et al.*, 1996; Hoggan and Sadowsky, 2001; Christou and Kiliaridis, 2008). Although the findings differ regarding the stability of the rugae during longer periods of growth, previous studies have shown that the medial aspects of the palatal rugae can be used as reference marks to assess tooth movement after orthodontic treatment (Van der Linden, 1978; Almeida *et al.*, 1995; Bailey *et al.*, 1996; Hoggan and Sadowsky, 2001). The reasoning is that the medial rugae growth changes taking place during the short period of orthodontic treatment are very small and neither statistically nor clinically significant. Several studies have subsequently used the palatal rugae as stable reference points for assessment of orthodontic tooth movements (Rajcich and Sadowsky, 1997; Ashmore *et al.*, 2002; Mavropoulos *et al.*, 2005).

The results from the control group in the present research confirm the findings of previous studies that there were no changes in transverse and APM between the medial aspects of the rugae during non-extraction orthodontic treatment (Almeida *et al.*, 1995; Bailey *et al.*, 1996).

Recently, Christou and Kiliaridis (2008) evaluated the vertical changes of the medial aspects of the rugae. They concluded that the medial aspects change over time in the vertical direction and that these changes are more marked for the first and second rugae. The medial aspect of the third ruga is less affected by vertical changes and is therefore the most reliable reference mark for short-term observations. The medial first and second rugae are less reliable due to the vertical changes which are associated with the changes in the vertical position of the maxillary incisors and the increase of the lower face height.

The addition of RME to fixed appliance therapy resulted in a significant increase between TM but had no effect on APM. However, care should be taken when interpreting the data from the present study. A statistically significant result

may not indicate clinical significance. The power in the present study was sufficient to detect a 0.75 mm difference. The method error was 0.25 mm. Therefore, a mean change of more than 1.00 mm was considered to be of clinical significance. The RME/fixed appliances group showed mean transverse changes of the first and second rugae of 0.34 and 0.79 mm, respectively. Although these results were statistically significant, clinical relevance is questionable. It has to be acknowledged that based on the present results, no conclusion can be made regarding the stability of the first and second rugae because the vertical changes of these points were not evaluated. These points have been shown to be affected by vertical changes associated with the vertical position of the upper incisor (Christou and Kiliaridis, 2008).

The mean transverse change between the third rugae (1.15 mm) exceeds the 1.00 mm value considered to be statistically and clinically significant. The medial aspects of the third rugae therefore cannot be regarded as stable reference marks when RME is undertaken.

The palate separates in a V pattern when RME is performed due to the increased resistance to separation in the posterior aspect of the palate (Haas, 1965; Wertz, 1968, 1970; Bishara and Staley, 1987; Davidovitch *et al.*, 2005). If the palatal mucosa follows the underlying separating palatal shelves, a V-shape expansion of the medial aspects of the rugae would be expected. Interestingly, the opposite occurred in the present study. The transverse changes were more marked for the third, less for the second, and least for the first rugae. The medial aspects of the rugae expanded in a 'Λ'-shape pattern when RME was performed in addition to fixed appliance therapy. These results suggest that the palatal mucosa may not follow the underlying separation of the palatal shelves and that the stretched fibres in the hard palate may have an effect on rugae movement. The stretched fibres of the palatal mucoperiosteum can be a factor for the tendency of maxillary teeth to return to their original position after RME (Cotton, 1978; Muguerza and Shapiro, 1980). A strong relationship might exist between the stretched fibres of the hard palate and the rugae when RME is performed. The rugae might yet prove to be a stable reference but may need sufficient time to re-establish their original position after RME due to constriction of the stretched fibres in the palatal mucoperiosteum. This hypothesis needs to be tested in order to confirm the relationship between the stretched fibres of the hard palate and rugae movement and to clarify the relapse tendency after expansion.

Dental changes are often measured on two-dimensional (2D) photocopies or scanned images of dental casts (Rajcich and Sadowsky, 1997; Hoggan and Sadowsky, 2001). These methods use the occlusal plane of the dental cast as a reference plane. However, the occlusal plane decreases from 14 to 8 degrees from ages 6 to 16 years (Riolo *et al.*, 1974) and may change considerably during orthodontic

treatment (Van der Linden, 1978). Therefore, using the occlusal plane as the reference plane to measure changes in the palate would result in inaccuracies.

Measuring three-dimensional (3D) structures on 2D images fails to take the surface morphology into account. The present study describe a new 2D method of rugae assessment using standardized digital photographs. It eliminates problems such as rotation of the occlusal plane and magnification errors associated with traditional 2D methods. The linear measurements between the medial rugae points are accurate because this area is generally unaffected by the palatal curvature. The present study did not intend to develop a 2D alternative for 3D analysis and the method described is only suitable to assess rugae changes. To determine the amount of tooth movement or treatment outcome on dental casts, the focus of future research will be 3D analysis. However, the method provides a simple, cost-effective yet accurate alternative to investigate the medial rugae movement when a 3D set-up is not available.

The results of the present study raise some interesting questions. Future research should investigate the vertical changes of the medial rugae points when RME is performed and clarify the effects of RME on the palatal mucoperiosteum and the role of the collagen fibres during expansion.

## Conclusion

The addition of RME to fixed appliance therapy caused a change in TM between the medial aspects of the bilateral rugae. There was no change in APM. The transverse changes were more marked for the third, less for the second, and least for the first rugae and resembled a Λ-shape pattern. Due to the transverse changes, the third ruga should not be considered as stable reference mark for short-term observations when RME is performed.

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