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A photogrammetric technique for the analysis of palatal three-dimensional changes during rapid maxillary expansion

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SUMMARY The aim of this study was to assess, by a digital photogrammetric technique, the relative dimensional changes before and after rapid maxillary expansion (RME). The transverse diameters and volumetric variations of the palate were measured by photogrammetry on study casts taken at three different phases of therapy: at the beginning of treatment (T1), on removal of the rapid expander, after expansion and retention for three months (T2), and six months after appliance removal (T3).

The sample consisted of 30 children, (age range 7–8 years), all with a crossbite; 15 were angle Class I, six Class II and nine Class III. They were treated with an acrylic splint expander with two turns per day until the maxillary molar palatal cusps were in contact with the mandibular molar buccal cusps. The RME device was used as a passive retainer for three months, after which it was removed. During the following six months, no retention was used and no orthodontic treatment was undertaken.

The findings demonstrated a significant relapse ($P < 0.001$) in the dental transverse diameter in all patients six months after appliance removal, although the palatal volume remained stable.

Introduction

Rapid maxillary expansion (RME) as a means to correct a deficiency of the transverse dimension of the maxilla has recently become more routine (Haas, 1980; McNamara and Brudon, 2001).

Although the skeletal and dental effects of this therapy have been demonstrated (Haas, 1970; Isaacson *et al.*, 1964; Zimring and Isaacson, 1965; Wertz, 1970; Wertz and Dreskin, 1977; Melsen and Melsen, 1982) there seems to be no agreement among researchers on the real efficiency or long-term stability of RME (Haas, 1980; Stockfish, 1969; Timms, 1976; Brust and McNamara, 1995; Adkins *et al.*, 1990; Franchi *et al.*, 1998; Cameron *et al.*, 2002). The studies were limited by the difficulty in separating the effects of RME from those of subsequent orthodontic treatment; differences in time and the type of retention after RME removal must also be taken into account. Furthermore, treatment stability was evaluated with callipers and compasses, etc, which register measurements in only one plane and therefore do not provide precise three-dimensional (3D) measurements.

The aim of this study was to investigate the effect of RME on 3D change of the palatal vault by evaluating the changes in palatal shape and volume immediately after expansion and six months after completion and removal of the appliance.

Subjects and methods

The sample consisted of 30 Caucasian children in the mixed dentition stage, (14 boys, 16 girls; age range 7 to 8 years, mean 7.5 years). All subjects had crossbites (12 unilateral, 14 bilateral) due to a narrow maxilla; 15 were Angle Class I, six Class II and nine Class III. Sixteen had a normal anterior bite, three a deep bite, and 11 an open bite.

An acrylic splint expander was bonded in each patient. The Hyrax screw was activated one-quarter turn (0.25 mm) twice a day until the maxillary molar palatal cusps were in contact with the lower mandibular buccal cusps. After expansion, the appliance was left *in situ* for three months and then removed. During the following six months, no retention or additional orthodontic treatment was carried out.

Impressions were taken and casts were made at the start of the treatment (T1), immediately after RME removal (T2), and six months after RME removal, (nine months since the beginning of the study) (T3).

This study was based on biostereometric analysis of the casts at each of the phases using a digital photogrammetric technique (Krauss, 1993; Berkowitz and Pruzansky, 1968). This approach, based on the model creation of an object from two homologous photographic acquisitions, allowed 3D reproduction, accurate dimensional measurements, and a precise evaluation of shape. The operative phases of a digital photogrammetric survey are: (1) digital photographic acquisition, (2) optical 3D model creation, and (3) graphic rendering.

Digital photogrammetry acquisition of a dental cast allows the definition of a 3D model with the characteristics of the starting object, where the height differences among all visible points can be estimated. The resulting 3D digital cast is metrically accurate and allows measurement of areas, volumes and angles. The digital camera used was a Digital

Nikon DCS (Nikon Corporation, Tokyo, Japan), with a 29.5 mm focus at 700 mm distance. The image resolution was 1524 × 1012 pixel/cm with a 12-bit colour range.

The final part of the study was carried out using modified stereovision software (Stereo View 300, Leica Geosystems AG, Heerbrugg, Switzerland). Special glasses were connected to an infrared system to evaluate the Z dimension. The transverse diameter in the 30 subjects also evaluated, whereas the volumetric variations were computed for a subset of 15 subjects. The following transverse diameters were measured: the distances between the first permanent molars (16–26), the second primary molars (55–65), the first primary molars (54–64), and the primary canines (53–63).

The points selected to calculate the diameters on the plaster models were the upper part of the most lingual points at the gingival margins of the teeth (Adkins *et al*., 1990).

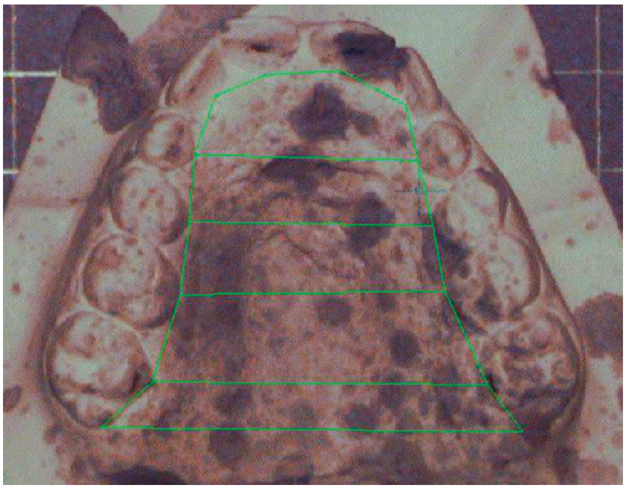

Figure 1 The reference surface of the palatal volume obtained by connecting the extremes of the transverse diameters, the rear distal of the permanent molars, and the upper part of the gingival margins of the incisors.

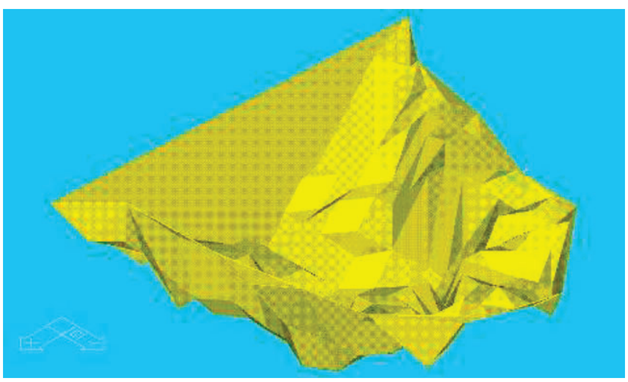

Figure 2 The palatal vault surface obtained using a Delaunay triangulation.

The contour of the reference surface for the palatal volume was obtained by connecting the extremes of the transversal diameters, the rear distal of the permanent molars, and the upper part of the gingival margins of the incisors (Figure 1).

The reference surface for evaluating the palatal volume was obtained by using a Delaunay triangulation scheme connecting the points. The base area was delineated by the

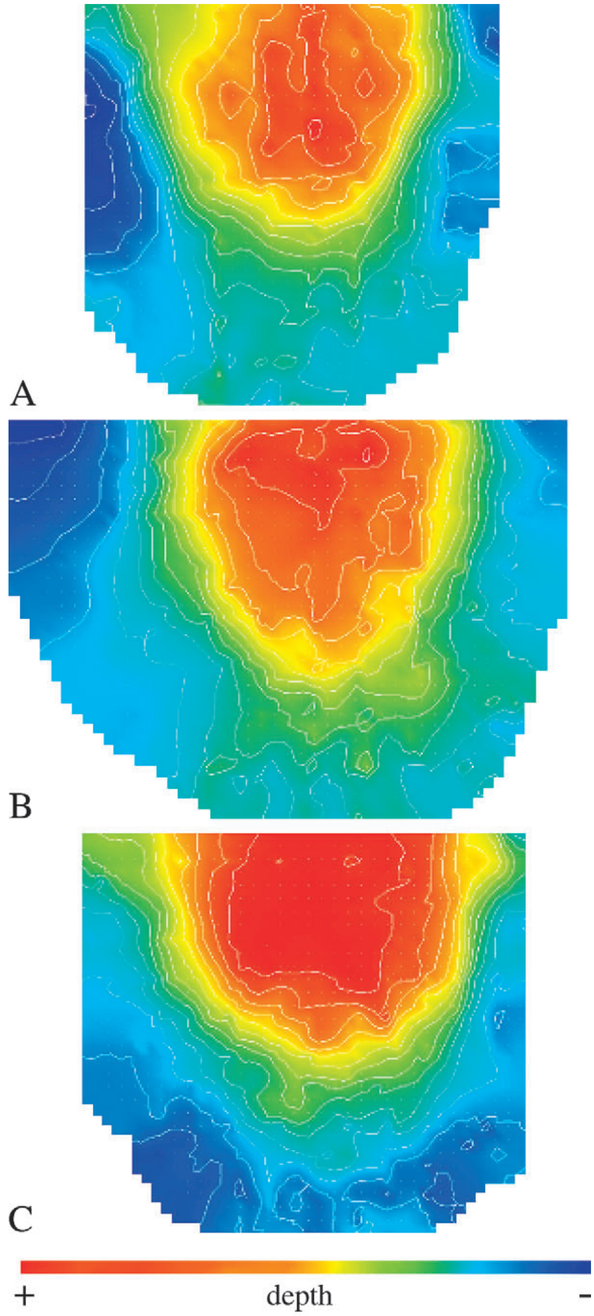

Figure 3 Depth of the palatal surface represented by false colour contour lines at (a) the beginning of treatment (T1), (b) the end of expansion (T2) and (c) six months after removal of the rapid maxillary expansion appliance (T3) shown at the same scale. Dark blue = 0 mm; red = 18 mm and upwards.

gingival margins and by the segment connecting the distal aspect of the last permanent molars. The palatal volume was then defined as the volume between the reference surface and the palatal surface and was calculated as the sum of small solid parallelepipeds, each having an area of 0.25 mm^2. The height was equal to the distance between the reference and palatal surfaces.

A regular grid of the palatal vault, with 1 mm steps, was then generated. The grid was automatically obtained by the software, using a matching function based on the break lines.

The palatal vault surface was obtained using a Delaunay triangulation, and the palatal volume computed (Figure 2). The base area was divided into 0.5 × 0.5 mm sub-areas and the distance between the reference and the palatal surfaces measured to determine the centre of each area. The absolute orientation of the model was metrically accurate to 0.5 mm, with respect to the selected fixed points on the grid.

Statistical analysis

Statistical analysis was carried out using F and ANOVA tests for each of the five variables. For each data series a sphericity test using the Mauchly criterion was also performed to check the appropriateness of an unadjusted univariate F test for the within-subject effects (Glantz, 2003). Furthermore, multiple comparisons were performed to evaluate the differences between T2 and T1, T3 and T1, and T3 and T2.

Results

The recordings at T1, T2 and T3 showed the variations in palatal transverse diameter and provide information relating to the palatal surface depth at those times (Figure 3).

The results concerning the transverse diameters are shown in Table 1 and the data from the descriptive statistics in Tables 2 and 3. All tests confirmed the hypothesis that the measurements at T2 and T3 were significantly different from those at the start of treatment. The confidence interval also appeared to be small, the narrowest interval of change being found for the second primary molars (between 2.8 and 7.3 per cent), and the largest interval for the variable volumes (between 2.2 and 12 per cent); in this case the omission

Table 1 Crossbite, Angle classification and transverse diameter for each patient.

Patients	Crossbite	Angle class	Transverse diameter (mm)							
			16–26		55–65		54–64		53–63	
			T2–T1	T3–T1	T2–T1	T3–T1	T2–T1	T3–T1	T2–T1	T3–T1
ORS	Bilateral	II	5.99	4.03	5.54	4.54	6.44	5.02	6.43	3.36
MAS	Unilateral	I	3.99	3.03	3.54	3.84	2.44	2.02	2.43	2.56
GAD	Unilateral	I	4.42	2.77	2.93	2.83	4.20	3.79	2.81	2.80
ACH	Bilateral	III	11.24	7.98	10.89	5.77	6.18	3.15	9.77	3.34
BAN	Unilateral	I			3.59	3.70	3.21	2.92	3.86	3.43
GADD	Unilateral	I	6.54	2.90	4.31	3.29	4.27	3.77	4.07	4.25
FER	Unilateral	I	7.14	3.17	5.98	3.39	5.39	2.43	6.46	3.41
FAN	Unilateral	III	5.92	3.13	4.98	2.81	4.98	1.66	2.55	3.36
DIA	Bilateral	I	4.47	2.28	4.77	2.70	4.79	2.44	3.30	1.66
COS	Bilateral	II			1.07	–0.41	3.35	1.38	1.90	0.21
CEL	Unilateral	II	5.41	2.97	5.72	1.46	5.26	0.14		
BEN	Bilateral	III	4.04	3.36	4.68	4.05	4.64	3.65	6.93	4.30
BAN	Bilateral	I	0.00	29.94	4.78	3.06	3.91	3.06	5.74	3.25
BAG	Unilateral	I	5.56	5.40	6.20	6.65	4.62	5.66	5.25	4.71
BLO	Bilateral	I	5.37	3.61	4.04	1.97	4.66			
BRI	Bilateral	II	4.39	–1.39	4.78	2.11	4.34	2.62	2.05	1.20
ORSI	Bilateral	III	7.29	3.35	6.73	4.43	7.59	4.46	4.48	1.68
PI1	Bilateral	III	4.84	6.27	4.07	5.33	4.35	5.85	4.91	5.63
PI2	Bilateral	II	6.27	4.84	5.33	4.07	5.85	4.35	5.63	4.91
SEF	Unilateral	I			3.98	1.93	4.34	2.39	3.73	2.51
SER	Bilateral	I	3.28	2.12	4.20	3.47	4.02	3.19	3.64	3.12
SEN	Bilateral	I	4.31	3.60	4.08	3.47	4.37	2.28	4.33	3.11
STAF	Unilateral	II	3.62	2.70	4.07	4.51	5.49		2.43	0.66
STO	Unilateral	III	4.29	3.71	4.17	2.67	3.73	2.09		
VEZ	Unilateral	III	5.73	1.65	5.64	2.36	6.26		5.95	1.90
LAG	Unilateral	I	5.18	4.26	4.36	3.31	5.13	3.69	5.16	4.66
LOL	Unilateral	I	1.86	2.32	1.77	1.04			1.62	1.01
MAT	Unilateral	I	3.32	3.40	3.20	3.26	2.95	2.91	2.57	2.06
ONO	Unilateral	III	5.02	2.40	4.93	3.53	5.46	3.39	5.60	3.74
RAV	Bilateral	III	3.21	3.40	2.36	2.85	2.73	2.90	1.87	2.56

T1, start of treatment; T2, immediately after rapid maxillary expansion; T3, six months after the end of rapid maxillary expansion.

Table 2 Multiple comparison between phases T2–T1, T3–T1, and T3–T2 for molars, canines and volume.

	t	DF	Probability > F
First permanent molars			
T2–T1	15.86	52	< 0.001
T3–T1	10.42	52	< 0.001
T3–T2	–5.44	52	< 0.001
Primary canines			
T2–T1	13.42	52	< 0.001
T3–T1	9.23	52	< 0.001
T3–T2	–4.19	52	< 0.001
First primary molars			
T2–T1	17.79	50	< 0.001
T3–T1	12.19	50	< 0.001
T3–T2	–5.60	50	< 0.001
Second primary molars			
T2–T1	16.29	58	< 0.001
T3–T1	11.68	58	< 0.001
T3–T2	–4.612	58	< 0.002
Volume			
T2–T1	9.721	34	< 0.001
T3–T1	6.77	34	< 0.001
T3–T2	–2.95	52	0.57

DF, degrees of freedom.

Table 3 Multiple comparison between F test results for molars, canines and volume.

	F	Degrees of freedom (numerator)	Degrees of freedom (denominator)	Probability > F
First permanent molars	129.9	2	52	< 0.001
First primary molars	165.5	2	50	< 0.001
Primary canines	94.3	2	52	< 0.001
Second primary molars	141.1	2	58	< 0.001
Volume	49.7	2	34	< 0.001

of one 'unusual' case lowered the interval to between 2.3 and 8.3 per cent. The same finding was confirmed for the variables second primary molars and volume.

The rapid expansion procedure had a percentage variation at the permanent molar, second primary molar, and first primary molar of between 10 and 20 per cent in 18 patients. In eight cases this was higher than 20 per cent, and in only one case was it lower than 10 per cent.

For the primary canine there was a low percentage variation of 10 per cent in all the patients.

Discussion

Although experimental research has been carried out to verify the long-term stability of RME (Haas, 1980; Stockfisch, 1969; Timms, 1976; Brust and McNamara, 1995; Cameron *et al.*, 2002) all the studies had limitations. Some of them were essentially case reports, while others included non-homogeneous samples and had significant differences in retention time. The main limitation was in the differentiation of the effects of RME from the differences in time and retention type after RME. Studies including long-term controls compared post-expansion parameters with those following the completion of orthodontic therapy; the data cannot therefore be considered as a reflection of the effects of expansion alone, but of the entire orthodontic therapy plus growth (Haas, 1980; Stockfisch, 1969; Timms, 1976; Brust and McNamara, 1995; Adkins *et al.*, 1990; Krebs, 1964).

Methodological errors were discussed by Brust and McNamara (1995) who compared data obtained from large homogeneous samples using RME with those of a control group. This evaluation was made on dental casts at the beginning of expansion, immediately after expansion, at the time of first premolar eruption, and immediately before final comprehensive orthodontic treatment. Unfortunately evaluation of relapse is difficult since retention (with a stabilization device) was used for a significant time after RME. In fact, after expansion, the device was left in place for five months, followed by the application of a palatal plate for an indefinite period of time and, furthermore, the insertion of a transpalatal bar before the loss of the primary second molars. In contrast, the subjects in the present study did not receive any additional orthodontic treatment after removal of the RME device. Palatal expansion was carried out as interceptive orthodontic therapy, hence it was possible to stop treatment and await exfoliation of the primary teeth before starting comprehensive orthodontic therapy. Although the sample was small it was homogeneous for age, dentition, type of appliance, clinical procedure and time of retention.

A standard control group was not used because in this age range there is no demonstrated change in transpalatal arch width (Spillane and McNamara, 1989; Ngan *et al.*, 1996; McNamara, 1999).

Analysis of data relative to palatal widths indicated a higher percentage of relapse in this preliminary study compared with that in the literature. The percentage relapse has been reported variously as 0 (Haas, 1980), 10–15 (Brust and McNamara, 1995), and 25–30 (Stockfish, 1969) per cent. Only Timms (1976) reported a percentage relapse similar to that found in the present study. All these investigations were limited because of the difficulty in separating the effects of the orthodontic treatment that all the patients underwent from the RME phase. In the present study patients were treated with RME only.

RME seems to be more stable in the anterior than in the posterior region. The greater increase in the transverse dimension of the anterior maxilla could be caused by the retention period of RME. Three months are necessary to allow normal histology of the suture to be re-established (Starnbach and Cleall, 1964; Cleall *et al*., 1965).

Analysis of the data relative to palatal volume showed a different trend to that of width. In fact, in all subjects there was some (non-significant) relapse in the post-retention phase. There may be a correlation between the differences in the post-retention phase.

Further research on a larger number of patients is in progress to validate the present findings.

Conclusion

The findings of this investigation show the effects of RME in patients who underwent treatment without any subsequent retention or fixed appliances. In all patients there was an increase in palatal volume and a change was observed in the morphology of the palate. The palatal vault became more symmetrically harmonious, wider, and less deeply arched in all subjects.

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