Evaluation of the effects of rapid maxillary expansion in growing children using computer tomography scanning: a pilot study

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SUMMARY The principle of rapid maxillary expansion (RME) as a method to expand the transverse dimension of the palate and maxillary dental arch is by no means new, and previous studies have reported the effects of the method using a variety of radiographic methods. In the present study, the effect of a Hyrax splint appliance was studied in a group of nine growing children (six females, three males; mean age 8 years 1 month) undergoing orthodontic treatment. The changes were evaluated on pre- and post-treatment computer tomographic scans taken using a low-dosage protocol.

The results demonstrated a clear appliance-induced effect in all patients, although the relative contribution of dental, alveolar, and skeletal changes varied from subject to subject. The average expansion, measured at the molar crowns, was 3.6 mm, whereas the actual sutural opening, the main aim of RME, was as low as 1.6 mm.

The findings of this study raise doubts as to the efficiency of the Hyrax appliance and further comparative studies are recommended to evaluate other methods of maxillary expansion.

Introduction

Even though transverse discrepancies, including their aetiology, diagnosis, and treatment, have been described as the 'forgotten dimension' (Vanarsdall and White, 1992), a review of the literature reveals a great deal of interest in this subject. Clinically the relevance of the topic is clear, since transverse occlusal discrepancies are relatively common, with uni- or bilateral crossbites, occurring in 9.4 per cent of boys and 14.1 per cent of girls (Helm, 1968).

The transverse dimension represents the sum of the skeletal maxillary base and the inclination of the buccal segment teeth and surrounding alveolar bone (Solow, 1980). Discrepancies involving the skeletal base should be treated by skeletal expansion, whereas dentoalveolar discrepancies should be corrected by tooth movement.

The increase in palatal width is the result of growth in the midpalatal suture, which itself undergoes a continual morphological change at the histological level, becoming successively more complicated from birth to the cessation of development (Melsen, 1975). As a result of this maturation process, treatment of transverse discrepancies depends both on the nature of the malocclusion and, to a large extent, on the age of the patient. The clinical implications of the histological findings are that it is generally accepted that the simple methods for palatal expansion used in young children, e.g. removable appliance expansion, are likely to be unsuitable for the treatment of the more complicated suture seen in more mature patients. The indications for rapid maxillary expansion (RME) are therefore clear and are based not only on the differential diagnosis of the malocclusion itself but also on the skeletal (sutural) maturity of the individual patient.

The possibility of separating the two halves of the maxilla using orthopaedic appliances was originally reported by Goddard (1893) but further developed by Haas (1961, 1965, 1970), Wertz and Dreskin (1977) and Timms et al. (1982). These studies, as well as a more recent report (Cross and McDonald, 2000) which describe changes in facial morphology, were generally based on conventional cephalometric analysis using anteroposterior views and described the changes observed as angular parameters. An early report on RME by Krebs (1958) is noteworthy since it utilized metallic implants in the palate and other relevant structures. Information was revealed regarding linear parameters, and longitudinal development of the palate and dental arches during and after RME could be illustrated. In a later study, Timms et al. (1982) used computed tomography (CT) to observe the changes taking place in the palatal plane and recommended this type of investigation as worthy of elaboration.

Over the years, several different appliances have been developed for RME:

- 1. Removable plates
- 2. Fixed wire spring to create gradual expansion of the palate
 - a. Transpalatal bar
 - b. Quadhelix
- 3. RME devices
 - a. Haas appliance
 - b. Hyrax
 - c. Cemented splint expander (Figure 1)

Treatment with the RME devices can also be supplemented by surgical corticotomy (Byloff and Mossaz, 2004).

Assuming continuity between the diagnosis and treatment method, it is logical to assume that the treatment of a malocclusion involving a skeletally narrow maxilla should involve orthopaedic/surgical expansion in that region. It is therefore important to evaluate the relative contribution of skeletal–palatal expansion in relation to the total expansion observed, as measured by the increase in distance between the buccal segment teeth either directly or on study casts.

Podesser *et al.* (2004) presented a methodological study based on CT scanning. The parameters created were intended to express the skeletal, dental, and alveolar components of the transverse occlusion, thus facilitating differentiation between the effects of the expansion at different levels. The method was shown to exhibit good reproducibility and was therefore utilized in this study.

The aim of the present study was to quantify and evaluate the changes occurring as a result of RME at both the skeletal and dentoalveolar level in a group of young patients, and to answer the following questions:

- 1. What dimensional changes occur in the midpalatal suture following RME when evaluated by a method involving CT scanning and direct measurement?
- 2. What proportion of the change, as measured at the molars and canines, is the result of skeletal change, i.e. expansion of the palate itself?
- 3. What relationship exists between expansion at the palatal level and the transverse dimension of the nose?

Since the radiation dose is not negligible, it was felt that it would be advisable to perform a preliminary study to gain information before enrolling a larger number of patients. The research was therefore performed as a pilot study and was approved by the ethical committee of the University of Vienna (approval number 047/02).

Material and method

The study comprised CT scans of nine growing children (six females and three males) in the mixed dentition stage (average age: 8 years 1 month, minimum: 6 years 1 month, maximum: 9 years 9 months.). All were treated using a cemented splint



Figure 1 Splint expansion device.

RME device (Figure 1) as the initial part of comprehensive orthodontic therapy. The appliance screw was activated two quarter turns (0.25 mm per turn) per day for 2 weeks until the opening of the screw reached 7.0 mm. Subsequent to the active phase, the appliance was left *in situ* as a passive retainer for a further 3–5 months, after which it was removed.

Records were obtained immediately pre-treatment (T1) and after active expansion (T2) when the expander was removed for registration and later replaced. The records at each stage comprised study casts, full-face photographs and low-dose standardized CT scans (Podesser et al., 2004). A Tomoscan 7000SR® (Philips, Eindhoven, The Netherlands) was used to obtain the scans. The tomograms were obtained using frontal plane orientation, with the patient positioned face downwards with the neck hyperextended, with a resulting scanning plane 90 degrees to the plane of the hard palate. Distortion due to poor orientation of the subject was minimized by supporting the head on a contoured pillow. In order to reduce radiation, a low-dosage CT scan protocol was used. The slice thickness was set at 1.5 mm with a table feed of 1.5 mm, the scanning time being 1.0 second, resulting in a high-resolution bone algorithm.

Evaluation was performed on two slices: the canine slice (Figure 2), defined as the first anterior slice on which the crown and root of the permanent canine could be seen in its entirety. The canine slice was only used for evaluation of the sutural opening in this region, since in many of the subjects the maxillary canines were not sufficiently erupted to make evaluation of the inclination possible. In three subjects, the incisor canal obscured the suture thus making evaluation impossible. The molar slice (Figure 3a) showed the entire palatal root and crown of the first maxillary molar and, as this second slice was available for all patients, the majority of the quantitation was based on this slice.

Numerical evaluation of the various parameters was based on the identification and registration of a number of



Figure 2 Computer tomographic scan at the canine level.

reference points, identified directly on the CT images, using a computer 'Easy Vision' facility® (Philips Easy Vision), Software Release 2.1, Level 5, Dental Software Package (Philips Medical System, Best, The Netherlands). For parameters involving geometric construction, the reference points were transferred to acetate paper and measured using a ruler, accurate to 0.5 mm. Angular parameters were measured using a protractor accurate to 0.5 degrees.

The material was measured twice, by one author (BP) with at least a 1-week interval between the first and second recordings. The average value of the first and second readings was used, as recommended by Baumrind and Frantz (1971).

The registration points are shown in Figures 4 and 5. The following parameters were also measured or calculated in millimetres:

- 1. Maxillary base width: the distance between points 5 and 6
- 2. Suture opening (at the molar): the distance between points 13 and 14
- 3. Suture opening (at the canine): the distance between points 15 and 16
- 4. Nasal width: the distance between points 11 and 12



Figure 3 Computer tomographic scan at the molar level before (a) and after (b) expansion.

- 5. Maxillary alveolar width: the distance between points 3 and 4
- 6. Intermolar width (apex): the distance between points 9 and 10
- 7. Intermolar width (crown): the distance between points 7 and 8
- 8. Right molar angulation: 7-9 to the baseline
- 9. Left molar angulation: 8-10 to the baseline
- Intermolar root angle: the angle of intersection of lines 7-9 and 10-8

In order to calculate the relative skeletal and dentoalveolar changes, the ratio between the sutural opening (parameter 2) and intermolar width at the crown (parameter 7) was expressed as a percentage.

The sutural opening could only be measured on the posttreatment scans. Prior to expansion, the suture could be defined anatomically although no space between the sutural surfaces could be measured.

Parameters 1, 2, and 3 represented the skeletal base and parameter 5, the alveolar supporting tissue. The linear dental relationships were represented by parameters 6 and 7 and angular relationships by parameters 8, 9, and 10. Parameter 4 described the width of the nasal cavity.

Results

The mean values for changes resulting from the RME are shown in Table 1. The changes in the linear and angular



Figure 4 The molar slice with reference points and measured parameters. Points 1 and 2, the inner lower surface (left and right, respectively) of the nasal cavity defined by a tangent to the base of the nose, thereafter termed 'baseline', 1-2. Points 3 and 4, the most coronal points on the maxillary alveolar process, left and right side, respectively. Points 5 and 6, established as points at which the baseline intersects the buccal alveolar contour and represent the width of the alveolar process at the level of the apices of the roots. Points 7 and 8, the cusp tips of the mesio-buccal cusp on the maxillary first molars, left and right, respectively. Points 10, the apices of the palatal roots of the first molars, left and right, respectively. The points 11 and 12, the inner lateral limits (left and right, respectively). The points were joined using a line parallel to the baseline in order to determine the maximum width of the nasal cavity. Points 13 and 14, the medial limits of the palatine processes, left and right, respectively.



Figure 5 The canine slice showing the reference points relevant to the measurement of the suture opening. Points 15 and 16, the medial limits of the palatine processes, left and right, respectively.

parameters are shown in Figure 6a,b, respectively, and the linear and angular measurements for the individual patients in Figure 7a,b, respectively. The results were based on the average of the two readings.

As anticipated, there were individual variations although all values showed clear differences between T1 and T2, indicating that, in all patients, the appliance had an expansive effect. In general, the expansion measured at the molar crowns was greater than that measured at the suture, which implies that the clinical effect is a result of both skeletal and dentoalveolar components. The average total expansion at the molar crown was 3.60 mm (minimum: 2.10 mm, maximum: 5.38 mm), although the average sutural opening at the molar, representing the true maxillary skeletal expansion, was considerably less with a mean value of 1.60 mm (minimum: 1.12 mm, maximum: 1.97 mm). The sutural opening described by parameter 2, was reflected in the increase in the width of the maxillary base, which measured an average of 1.70 mm (minimum: 0 mm, maximum: 2.00 mm). For the canine region, the sutural opening was generally less, with an average measurement of 1.52 mm (minimum: 1.12 mm, maximum: 1.98 mm). The ratio between the magnitude of the sutural opening was greater anteriorly, and in others posteriorly. These skeletal changes were accompanied by an average increase in nasal width (parameter 4) of 1.20 mm (minimum: -0.25 mm, maximum: 3.50 mm). This parameter appeared to be more variable and not so clearly related to the amount of sutural opening, with several subjects showing virtually no increase in nasal width.

At the alveolar level, the increase in maxillary alveolar width was, on average, 2.60 mm (minimum: 1.35 mm, maximum: 5.25 mm) and was therefore greater than that seen at the maxillary base. This finding was also reflected in the individual values shown in Figures 6 and 7.

The relationship between the observed skeletal and dentoalveolar changes was expressed as a proportion by dividing the increase in width at the sutural opening (at the molar) by the intermolar width at the crown. These results were then converted to a percentage and Table 1 shows that the average value was 39.58 per cent (minimum: 25.21 per cent, maximum: 53.33 per cent).

Expansion of the skeletal structures was accompanied by tipping of the maxillary first molars. Tipping was not identical for the right and left side; the changes for the right molar being on average 2.5 degrees (minimum: -6.0 degrees, maximum: 7.5 degrees), and for the left molar an average of -1.2 degrees (minimum: -5.0 degrees, maximum: 4.0 degrees; Table 1).

 Table 1
 Changes resulting from the rapid maxillary expansion for each of the nine patients.

Parameter	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8	Patient 9	Mean	Maximum	Minimum
(1) Width of the	0	1.5	1.2	2	0.5	1	2	2	1	1.7	2	0
(2) Suture opening (molar, mm)	1.24	1.12	1.22	1.91	1.97	1.58	1.74	1.38	0.86	1.6	1.97	1.12
(3) Suture opening (canine, mm)	1.12	1.43			1.98	1.23	1.82	1.57		1.52	1.98	1.12
(4) Nasal width (mm)(5) Maxillary alveolar	0.25 2.32	0.65 1.35	-0.25 1.51	1.35 3.8	1.3 3.24	2 1.5	3.5 5.25	1 2.43	1.5 3.52	1.2 2.6	3.5 5.25	-0.25 1.35
(6) Intermolar width (apex_mm)	1.21	2.5	3.11	1.25	1.54	1.2	4.81	1.12	2.13	2	4.81	1.2
(7) Intermolar width (crown, mm)	2.84	2.1	3.85	5.38	5.12	4.03	3.75	3.22	3.41	3.6	5.38	2.1
(8) Right molar angulation (°)	1	1	7.5	3	5	5	0	-1	-6	2.5	7.5	-6
(9) Left molar angulation (°)	-2	0	-2.5	3	3	-3	-5	-3	4	-1.2	4	-5
(10) Intermolar root angulation (°)	-2	0	2	2	7	6	-5	-2	5	1	7	-5
Skeletal: dental %	43.66	53.33	31.68	35.5	38.47	39.2	46.4	42.85	25.21	39.58	53.33	25.21



Figure 6 Individual changes in linear (a) and angular (b) measurements.

The change in intermolar root angle (parameter 10) reflected buccal tipping of these teeth, on average 1.0 degrees (minimum: -5.0 degrees, maximum: 7.0 degrees).

The individual changes in linear and angular measurements are shown in Figure 7a,b, respectively. For skeletal changes, all patients exhibited an opening of the maxillary suture and all but one an increase in maxillary base width. There did not seem to be a direct relationship between the degree of sutural expansion and the increase in maxillary base width, with all but one subject showing a measurable increase in nasal width. The changes in dentoalveolar structures, namely alveolar and intermolar widths, were generally



Figure 7 Patient to patient variations in changes in linear (a) and angular (b) parameters. The final column indicates the mean changes.

greater than for the skeletal components. Tipping of the teeth occurred in all subjects but not always in a buccal direction as would have been expected. In general, the greatest change was observed in the intermolar width of the crowns, and the smallest in nasal width, with the exception of patient 7.

Considering the individual parameters for each patient (Figure 7a,b), there was reasonable homogeneity for those parameters describing skeletal change and greater variation for those describing dentoalveolar change.

Discussion

The principle of sutural expansion through the application of orthopaedic forces represents a method of effecting skeletal change in subjects with a transverse skeletal-palatal deficiency. The principle, originally introduced by Goddard (1893) and later developed by Haas (1961, 1965, 1970), has now become a standard treatment modality. The effect of treatment has previously been described using both frontal cephalograms and titanium implants (Krebs, 1958). The previous investigations concluded that the two halves of the maxilla are separated in an arcial movement when seen from the frontal plane, the centre of the rotation being approximately at the level of the frontonasal suture. In some studies, it has been reported that the anterior part of the palatal suture opens more than the posterior (Wertz and Dreskin, 1977; da Silva Filho et al., 1995), thus also creating an arcial movement in the horizontal plane. Recent reports (Cross and McDonald, 2000) have raised doubt as to the effectiveness of RME treatment, underlining the fact that despite the severity of the treatment, the changes are relatively modest. The changes achieved through the use of RME must also be compared with those using different appliances. For example, Frank and Engel (1982) reported a mean increase in maxillary width of 0.92 mm using the quadhelix appliance.

Even when RME is preceded by surgical corticotomy, the amount of sutural expansion is not significantly greater and relapse can still be expected (Byloff and Mossaz, 2004). Some studies have suggested that the construction of the appliance is important in that a certain degree of non-parallel movement could be the result of the flexibility of the appliance itself (Lamparski *et al.*, 2003). A recent report comparing the effect of tooth- and tissue-borne RME indicated greater orthopaedic movement when treatment was performed with a Haas (tissue-borne) expander (Oliviera *et al.*, 2004).

The results of frontal cephalometric studies are usually presented as angular changes and the extent of change is therefore difficult to quantify. Linear measurement made on either lateral or frontal cephalograms is especially difficult to quantify due to distortion and the associated magnification factors. Direct measurement using CT scans is therefore indicated. RME was initially investigated using CT scanning in a pilot study in the 1980s (Timms et al., 1982) and further research using this methodology was recommended. The main problem associated with CT scanning is that of the radiation dose. Hassfeld et al. (1998) measured the absorbed radiation delivered by CT and panoramic radiography and showed that by reducing the milliamperes in a so-called 'lowdose scanning protocol' the dose could be reduced to 76 per cent without any reduction in diagnostic sensitivity. Rustemeyer et al. (1999) also showed that a considerable dose reduction was achievable, without loss of quality, when using a low-dose protocol. However, even taking these reductions into account, the radiation is still considerable compared with other types of radiography in everyday dentistry (Gahleitner et al., 2001).

The present study used a method, the reproducibility of which has been reported previously (Podesser *et al.*, 2004), involving quantification in the frontal plane based on standardized slices at the first molar and canine teeth. In this way, the problems of magnification are avoided and the results are expressed in metric units rather than angles. All measurements were performed by the same observer, thus eliminating interobserver error factor. The measurements were also repeated and the average values of the two readings calculated as recommended by Baumrind and Frantz (1971).

The findings of this study support the investigation of Byloff and Mossaz (2004) who found a maximal opening of the palatal sutures of approximately 2.0 mm, even when surgical corticotomy was used in advance of screw activation.

The results of the present study show that, in all subjects, the width dimension at the suture, maxillary base and molar (cusps and root) increased, demonstrating that the method represented a reliable way of effecting maxillary transverse expansion. The skeletal changes seen in all patients were, however, considerably less than those observed at the occlusal level. It must be remembered though that as this was a clinical study with a relatively small number of patients, the values for expansion (Table 1) are not an expression of the maximum values possible.

The greatest increase in dimensions was found at the molar crowns, which may be expected to represent the sum of skeletal and dentoalveolar changes. The actual skeletal improvement, estimated as the increase of the sutural width, expressed as a percentage of the total expansion (molar cusp width) varied from 25.21 per cent to a maximum of 53.33 per cent. This compares favourably with the findings from the implant study by Krebs (1958), although the latter investigation was based on limited material.

Molar tipping was also observed in nearly all subjects, confirming that the dentoalveolar component of change was considerable. Several reasons could explain the difference between the total effect and the pure skeletal effect.

- The geometry of the induced changes on the maxillary bone. On frontal radiographs, it has been shown that maxillary expansion is by arcial movement. Anatomically, the dental arch on which the forces are applied represents the lowest part of the maxillary skeletal structure and the centre of resistance of the maxilla is therefore at a much higher level. Indeed, other experiments have suggested that the centre of resistance of the maxillary complex is at the level of the pterygopalatine fossa (Teuscher, 1986).
- 2. The flexibility of the appliance, as a result of the length of the arms from the screw to the acrylic, could significantly reduce force levels. This could have been minimized by using a cast metal appliance based on cap splints as described by Cross and McDonald (2000).
- 3. Anatomical factors, such as the large surface area of sutures surrounding the maxilla and the complex nature of the sutures. It is interesting that the reaction of palatine

bone, which articulates with the posterior edge of the horizontal processes of the maxillary bone, is not reported in detail in previous studies.

The results of this study demonstrate a combination of a modest skeletal change accompanied by clear tipping of the dentoalveolar structures.

Maxillary expansion is usually accompanied by an increase in nasal width, although this change appears not to be totally dependent on the amount by which the suture is expanded. This corroborates the findings of Timms *et al.* (1982) who found that maxillary expansion usually resulted in a reduction in nasal resistance, although not to such a degree that RME could be recommended for treatment of nasal obstruction.

The findings of this study support the hypothesis that RME can result in skeletal change, although the changes observed were modest, especially taking the young age of the patients into consideration. Other reports (Wertz and Dreskin, 1977) have suggested that greater expansion may be achieved in the anterior part of the suture, which could not be measured in this study and might have given a more positive impression of skeletal change. Caution is therefore recommended in the use of these appliances and consideration should be given in the future to the use of alternative methods.

Conclusions

The conclusions of the present study are twofold:

- 1. Quantitative analysis of changes in the transverse dimension using CT scanning in order to investigate the effect of Hyrax-induced RME is possible and gives a clear image of the changes taking place.
- RME represents a method whereby both skeletal and dentoalveolar changes in a transverse direction can be performed.

Almost 50 per cent of the alterations in occlusion were the result of dentoalveolar change and, in view of the relatively modest skeletal development and the complicated method involved, similar studies using wire appliances (quadhelix, bihelix) where lower but constant forces are applied should be considered.

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Acknowledgement

The authors would like to thank Ms Lenka Tomašovičová for assistance in the preparation of the manuscript.

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