European Journal of Orthodontics 25 (2003) 401–410

Quantitative effects of a nickel-titanium palatal expander on skeletal and dental structures in the primary and mixed dentition: a preliminary study

Virgilio F. Ferrario*, Giovanna Garattini**, Anna Colombo*, Vittorio Filippi**, Silvio Pozzoli** and Chiarella Sforza*

*Functional Anatomy Research Center, Laboratorio di Anatomia Funzionale dell'Apparato Stomatognatico, Dipartimento di Anatomia Umana, Facoltà di Medicina e Chirurgia and Facoltà di Scienze Motorie, and **Dipartimento di Medicina, Chirurgia ed Odontoiatria, Università degli Studi di Milano, Italy

SUMMARY The present study analysed the six-month effects of a nickel-titanium (NiTi) palatal expander on the dental and palatal structures of four primary (mean age 5.8 years) and nine mixed dentition children (mean age 8.7 years), with a posterior unilateral crossbite. Standardized dental and palatal landmarks were digitized using a three-dimensional (3D) electromagnetic instrument. Collected data were analysed with geometric-mathematical models. During a six-month interval, the natural growth and development of the dental arches and hard tissue palate was negligible, as assessed in seven control children (two in the primary dentition, mean age 4.4 years; five in the mixed dentition, mean age 7.7 years).

In all children the crossbite was completely corrected. Indeed, dental expansion was always more than or corresponded to the palatal expansion. A smoothing of the size-independent (shape) palatal curvature in the transverse plane was observed. No differences in maximum palatal height were noted. Symmetrical derotation of the anchorage teeth in a distal direction occurred in almost all children. The inclination of the facial axis of the clinical crown (FACC) in the anatomical transverse plane of those teeth with differences between dental and palatal expansion always showed significant modifications (vestibular inclination up to 16.7°). The clinical crown height of anchorage teeth remained nearly the same in all patients. No significant modifications in mandibular arch size were observed.

The increase in maxillary arch width, especially in younger children, was probably due to a combination of different effects: opening of the midpalatal suture, tipping of the alveolar process, and molar tipping.

Introduction

One of the most common transverse plane malocclusions in the posterior areas of the dental arch is the 'crossbite', a term meaning the inversion of occlusal relationships, that is, when both arches are in occlusion. Crossbite may involve just one tooth, a group of teeth, or all the teeth. Moreover, it may be of skeletal or dental-alveolar origin, either uni- or bilateral.

In Caucasian children, the prevalence of posterior crossbite in the primary and mixed dentitions ranges from 8 to 22 per cent, with a greater prevalence of the unilateral forms (Egermark-Eriksson *et al.*, 1990; Airoldi *et al.*, 1997).

This malocclusion can be of multifactorial origin, in which environmental factors and habits play a fundamental role (Kohler and Holst, 1973; Larsson, 1975; Infante, 1976; Melsen *et al.*, 1979).

Several studies have shown how crossbite, especially when associated with a lateral shift, plays an important role in the onset of cranio-mandibular disorders (Myers *et al.*, 1980; Hesse *et al.*, 1997). Since a posterior crossbite often causes a dual-bite with a lateral mandibular shift, an asymmetrical condylar movement pattern may occur (Myers *et al.*, 1980; Hesse *et al.*, 1997). In particular, not only has an asymmetrical condylar movement pattern been reported to be connected to a crossbite with a shift, but it is also present in patients where the malocclusion has been treated at a late stage. Indeed, changes in condylar movement may induce asymmetrical mandibular growth (Thilander *et al.*, 1984; Pirttineimi *et al.*, 1990; O'Byrn *et al.*, 1995). The current clinical tendency, therefore, seems to be early treatment of crossbite to prevent progressive mandibular dysfunction, as well as cranio-facial asymmetry (Kurol and Berglund, 1992).

Presently, several devices are available for the correction of a posterior crossbite (rapid maxillary expander, Quad Helix, etc.), giving both rapid and slow palatal expansion. A nickel-titanium (NiTi) alloy device (Nitanium® Palatal Expander 2™) has recently been made available to induce slow, dento-alveolar expansion. This

NiTi device takes advantage of the shape memory typical of this alloy, and exercises a constant and continuous force, such to allow dental and bone movements. Its action appears more physiological than that induced by the devices used so far, mostly made of stainless steel alloys (Airoldi *et al.*, 1993; Arndt, 1993; Abdoney, 1995; Gerberg, 1996; Corbett, 1997; Ciambotti *et al.*, 2001).

A correct assessment of the actual effects of all these devices cannot be limited to clinical observations, but requires a quantitative approach (Schiffman and Tuncay, 2001; Ciambotti *et al.*, 2001). Currently, several automatic and semi-automatic electronic instruments allow the quantitative analysis of dental casts with a limited method error (see Ferrario *et al.*, 1998, 2001b for review). On most occasions, dental and palatal landmarks are digitized in three-dimensional (3D) space, and their co-ordinates are used in mathematical and geometric models (Ferrario *et al.*, 1994, 1997, 1998, 2001a).

To this aim, the dental casts of children in the primary and early mixed dentitions with a dento-alveolar unilateral posterior crossbite either treated with a NiTi device (experimental group) or without treatment (control group) were studied before and after a six-month period in order to statistically compare the changes in dental and palatal size and shape.

Materials and method

Sample

The dental casts of 13 patients were analysed before and after a six-month palatal expansion period with the Nitanium® Palatal Expander 2™ (Ortho Organizers Inc., San Marcos, CA, USA). All patients had a dento-alveolar unilateral posterior crossbite with a transverse maxillary dimension deficiency. The patients were divided into two groups according to the stage of dental development. The first group, 'primary dentition' (four females, mean age 5.8 years, SD 0.7), had a complete primary dentition at the beginning of treatment. The second group, 'mixed dentition' (six males, mean age 8.7 years, SD 1.2; three females, mean age 8.7 years, SD 0.6), had permanent incisors, primary canines, first and second primary molars, and first permanent molars erupted. A removable plastic inferior bite was used in all patients. Only one female did not use the device due to lack of compliance. This appliance controls the occlusion during expansion and favours movement. The bite plane was worn full time (except during meals) to prevent adverse occlusal forces during expansion. The maxillary and mandibular dental arches of all subjects were reproduced from alginate impressions cast in dental stone. The impressions were taken before treatment and after six months, immediately as the device was removed.

Seven patients with unilateral posterior crossbite (four males, three females) were included in the study as the 'control' group. These subjects were also divided into two groups: 'primary dentition' (one male, aged 4.8 years; one female, aged 4.0 years) and 'mixed dentition' (three males, mean age 7.9 years, SD 1.5; two females, mean age 7.4 years, SD 0.3) groups. The dental impressions of these control subjects were also taken twice with an interval of six months during which no treatment was performed.

Digitization of dental casts

On all casts a set of standardized landmarks was identified and digitized as detailed by Ferrario *et al.* (1994, 1997, 1998, 2001a).

Palatal landmarks. The intersections of the palatal sulci of the left and right first permanent (mixed dentition group) or of the second primary (primary dentition group) molars with the gingival margin (landmarks MR and ML; Figure 1), the intersections of the palatal crest of the left and right primary canines with the gingival margin (landmarks CR and CL), the incisal papilla (IP) and the posterior-most limit of the palatal raphe (PR) were identified and marked. The intermolar MR–ML line was traced, as well as its perpendicular starting from IP. The intersection point between these two lines was marked as 'M'. On both the IP–M and MR–ML lines, several nearly equidistant points were further marked.

Dental landmarks. The midpoints of incisal edges, canine cusps, buccal and lingual cusps of primary molars

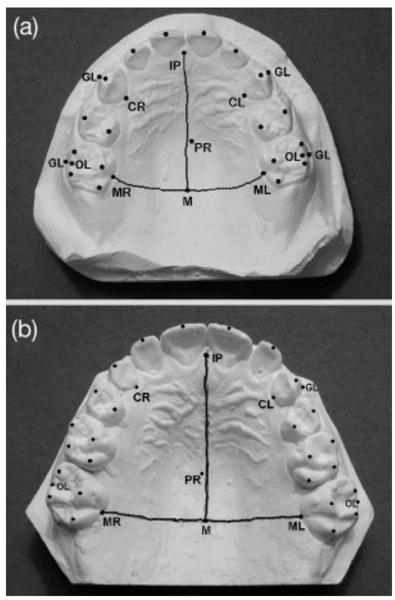

Figure 1 Digitized points on the stone casts of the 'primary dentition' (a) and 'mixed dentition' children (b), occlusal view. IP, incisal papilla; PR, most posterior raphe point; MR, ML, left and right molar points; CR, CL, left and right canine points; GL, OL, gingival and occlusal limits of the facial axis of the clinical crown (FACC), respectively.

and first permanent molars (when present), gingival (GL) and occlusal (OL) limits of the facial axis of the clinical crown (FACC) (Andrews, 1993) of the primary canines, second primary molars (primary dentition group), or first permanent molars (mixed dentition group) were identified and marked (Figures 1 and 2).

The 3D (x, y, z) co-ordinates of the landmarks were obtained with an electromagnetic 3D digitizer (3Draw, Polhemus Inc., Colchester, VT, USA) interfaced with a computer (resolution 1.3 mm/mm of range, accuracy 2.5 mm). A single operator performed digitization of the landmarks. For a detailed description of the digitizer see Ferrario *et al.* (1997, 1998). ASCII files of the 3D co-ordinates were then obtained, and computer programs devised and written by one of the authors (VFF) were used for all the following calculations.

Mathematical models and measurements

Palatal size and shape. All palates were orientated by mathematically setting the plane described by IP, MR, and ML as horizontal (y-axis, anterior-posterior; x-axis, corresponding to the MR–ML line, right–left; and z-axis, caudo-cranial), thus allowing a common orientation for all casts (Ferrario *et al.*, 1998, 2001b). For each palate, the following measurements were performed:

sagittal plane: palatal length, horizontal projection of the IP–M distance (unit: mm); palatal slope, slope of the maximum palatal height versus the horizontal axis (degrees); maximum palatal height (mm);
frontal plane: palatal width at the first permanent or second primary molars (distance MR–ML) (mm); palatal width at the primary canines (distance CR–CL) (mm); maximum palatal height (mm);
horizontal plane: papilla raphe angle: angle between the IP–PR and IP–M lines (degrees).

The curvature of the palatal surface was then fitted by a four-degree polynomial (Ferrario *et al.*, 1994, 1998) separately for the sagittal and the frontal plane projections. In the frontal plane projections, the origin of the axes was set at MR; the x-axis corresponded to the MR–ML line, and the y-axis to its vertical perpendicular. In the sagittal plane projection, the origin of the axes was set at IP; the x-axis corresponded to the horizontal projection of the IP–M distance, and the y-axis to its vertical perpendicular.

All co-ordinates were then standardized, in the frontal plane as percentages of the intermolar distance MR–ML (x co-ordinate), and in the sagittal plane as percentages of the horizontal projection of the IP–M distance (y co-ordinate). Using the new 3D standardized (i.e., size-independent) co-ordinates of the digitized landmarks, the curvature of the palatal surface for the sagittal and the frontal plane projections was then modelled by further four-degree polynomials, which describe palatal shape.

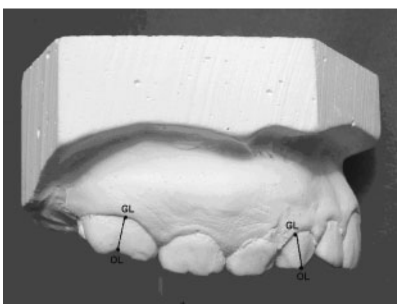

Figure 2 Gingival (GL) and occlusal (OL) limits of the facial axis of the clinical crown (FACC) of the primary canine and first permanent molar, lateral view.

Dental arch size and shape. Maxillary and mandibular arch size were also calculated. From the occlusal centre of gravity of the central incisors (corresponding to the digitized midpoint of the incisal edge), canines (digitized canine cusps), and first permanent/second primary molars (computed from the digitized buccal and lingual cusps), the transversal (intercanine cusps, intermolar-first permanent, or second primary molars) and anteroposterior (midpoints of central incisors to mid-molar, and to mid-canine lines) 3D dimensions of arches were computed, as well as the relevant ratios (Ferrario *et al.*, 1994, 1997).

To assess arch shape, the dental centres of gravity (occlusal surface) were interpolated by a fourth-order polynomial (Ferrario *et al.*, 1994).

Monson's curve. For each mandibular arch of the mixed dentition group, the 3D curvature of the occlusal surface was modelled by a curve (Ferrario *et al.*, 1997). From the best interpolating curve, the radii of the left and right curves of Spee (quasi-sagittal plane) and curve of Wilson passing through left and right first permanent molar (frontal plane) were computed. In the primary dentition group the absence of the first permanent molar did not allow evaluation of Monson's curve.

Dental rotation. For each patient, the rotation of the first permanent or second primary molars in the horizontal plane, as an effect of treatment (or time, in the control group), was quantified by calculating the angle between the lines intersecting the mesio-vestibular and disto-vestibular dental cusps on the first and second dental casts.

Dimension of the clinical crowns and inclination of the facial axis of the clinical crown (FACC). The height of the clinical crown (linear distance between the gingival and occlusal limits of the FACC, mm) of the maxillary first permanent or second primary molars and of the primary canines was also computed for each tooth (Ferrario *et al.*, 2001a).

The inclinations of the FACC of the maxillary first permanent or second primary molars and of the primary canines were calculated in the anatomical frontal and sagittal planes relative to the same horizontal reference plane described for palatal orientation. The co-ordinates of the landmarks were rotated and translated according to the new reference system, and used to calculate the inclination of the FACCs in the frontal and sagittal planes. As detailed by Ferrario *et al.* (2001a), in the frontal plane, positive angles were those with a cervical-to-occlusal FACC directed towards the same side of the mouth (buccal-vestibular direction for the posterior teeth; in a direction diverging from the midline plane of symmetry for the anterior teeth); in the sagittal plane, positive angles were those with a cervical-to-occlusal FACC directed from posterior to anterior.

Statistical calculations

For all children (controls and patients), inter-individual differences were computed for each variable (time and treatment effects). Descriptive statistics (mean, standard deviation) of the six-month differences were calculated within each group. Statistics for angular variables were computed using the rectangular components of the angles. The effect of time (control group) was assessed by paired Student's *t*-tests. For all analyses, the significance level was set at 5 per cent ($P \leq 0.05$).

Error of method

The method error has already been reported in part (Ferrario *et al.*, 1997, 1998, 2001a). In brief, intra-operator repeatability was assessed by repeated digitizations (landmark co-ordinates) of the same five casts that were digitized twice by the same operator with a one-week interval. Calculations were repeated for each digitization. The differences between paired measurements were calculated, and systematic and random errors computed.

For all variables, no systematic errors were found. For palatal landmark identification, the error percentage was always less than 10 per cent of the total biological variance; for landmark digitization, the error percentage ranged between 1.76 and 8.26 per cent (Ferrario *et al.*, 1998). For the measurements of Monson's curve (radii of the curve, left and right curves of Spee and curve of Wilson), coefficients of variation up to 1.23 per cent were found (Ferrario *et al.*, 1997).

Overall, the mean random error for dental inclination (transverse and sagittal plane) was 2.4 degrees, with a standard angular deviation of 0.3 degrees; the mean random error for clinical crown height was 0.19 mm (SD 0.18 mm) (Ferrario *et al.*, 2001a), while dental rotation had a mean random error of 1.39 degrees (standard angular deviation 0.3°). The random errors for transverse and anteroposterior dental arch measurements were 0.22 mm (intercanine), 0.14 mm (intermolar), 0.16 mm (mid-incisor to mid-molar), and 0.08 mm (mid-incisor to mid-canine), respectively.

Moreover, in all repeated analyses, the fourth-order polynomial equations used to interpolate the arch curvature of the same cast were well superimposed.

Results

Before expansion, within each group, dental and palatal measurements did not differ significantly between the control and experimental groups.

'Control' group

All children (primary and mixed dentition groups) showed no modifications of their dental arches and palatal size and shape during the six-month interval without any treatment. Indeed, the mean modifications in the transverse and anteroposterior dimensions of the maxillary and mandibular arches were low and not significant (paired Student's *t*-test, $P > 0.05$) (Table 1). No variations in the shape of the maxillary and mandibular arches were observed.

No significant eruption of maxillary first permanent, second primary molars or primary canines was measured: the mean changes of clinical crown height were 0.16 mm (SD 0.26, primary dentition) and –0.05 mm (SD 0.32, mixed dentition). FACC inclinations of the same teeth in the anatomical frontal and sagittal planes showed low variations (mean differences: primary dentition 0.46°, SD 1.02°, mixed dentition 0.5°, SD 0.69°), which reached statistical significance only in the mixed

Table 1 'Control' group children. Mean six-month modifications in the transverse and anteroposterior dimensions of the maxillary and mandibular arches.

	Unit	Maxilla		Mandible	
		Mean	SD	Mean	SD
3–3	mm	0.41	0.45	0.06	0.69
6–6 or E–E	mm	0.04	0.87	0.10	0.79
1–3m	mm	0.07	0.10	–0.13	0.39
1–6m	mm	–0.77	0.62	–0.47	1.18

3–3, intercanine distance; 6–6 or E–E, intermolar (first permanent or second primary) distance; 1–3m, distance between midpoint of central incisors and midpoint of intercanine line; 1–6m, distance between midpoint of central incisors and midpoint of intermolar line.
No significant differences (Student's *t*-test for paired samples, $P > 0.05$ for all variables).

dentition group (paired Student's *t*-test, $P < 0.001$). Rotation of the second primary molar ranged between –5.8 and –2.9 degrees (primary dentition, mean –4.93°, SD 0.68°; paired Student's *t*-test, $P < 0.005$); rotation of the first permanent molars ranged between –4.0 and 4.7 degrees (mixed dentition, mean 0.45°, SD 0.96°, paired Student's *t*-test, $P > 0.05$).

The radii of the left and right curves of Spee and of the molar curve of Wilson showed minimal and not significant changes (mean modification –5.65 mm, SD 6.92, paired Student's *t*-test, $P > 0.05$). Hard tissue palate maintained the same size and shape in the six-month control interval (Table 2).

'Experimental' group

A great individual variability between the two assessments was observed in all measurements, without consistent patterns. No differences between the primary and mixed dentition children were found.

In all children the crossbite was completely corrected, and the increase in maxillary intermolar distance (left–right centre of gravity of first permanent or second primary molars) was always higher than the expansion required (range of increase obtained 0.6–5.8 mm). In all patients, except one, there was an increase of maxillary intercanine distance (left–right canine cusps) (range of increase obtained 0.2–7.3 mm), always higher than or equivalent to the increase in intermolar distance. Six-month differences in anteroposterior dental arch dimensions ranged between 0 and 3 mm.

No significant modifications in mandibular arch size were observed (Student's *t*-test for paired samples, $P > 0.05$ for all variables and both dentition groups).

As an example, the digitized dental cusps of one mixed dentition male patient reproduced before and after the six-month treatment are shown in Figure 3 (horizontal plane projection). While mandibular teeth did not move in the horizontal plane, all maxillary primary and permanent molars translated and rotated.

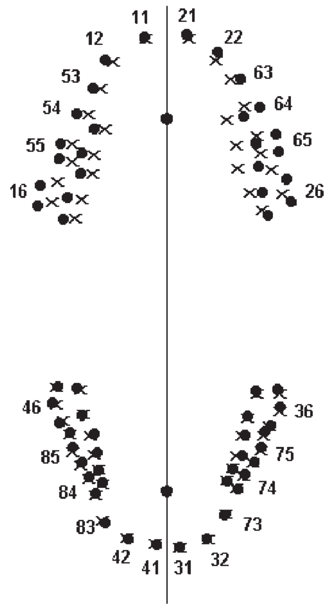

Figure 3 Dental arch modifications (horizontal plane projection) of one 'mixed dentition' male patient. Crosses, first impression; dots, second impression (6-month treatment).

Indeed, derotation of the anchorage teeth in a distal direction occurred in all children in the mixed dentition group (except in boys M9 and M30, Table 3). The movement was always symmetrical except in girl F23 who did not use a bite plane. In the primary dentition group teeth rotated in two patients, but not in the other two.

Dental expansion was always higher than or corresponded to palatal expansion (Table 4).

Both the primary and mixed dentition groups showed an increase in left–right molar or canine palatal dimensions (MR–ML increase range: 0.3–4.9 mm; CR–CL increase range: 0.04–6.4 mm). The amount of palatal expansion was similar to dental expansion, and was a function of the treatment required. The papilla raphe angle became more symmetrical in all patients. Palatal

Table 2 'Control' group children. Mean and standard deviation of six-month modifications in palatal measurements.

Plane	Measure	Unit	Mean	SD
Sagittal	Palatal length (IP–M)	mm	–0.52	1.10
	Maximum palatal height	mm	–0.02	0.49
	Palatal slope (papilla-max height)	°	0.74	0.39*
Frontal	Palatal width (MR–ML)	mm	–0.09	0.50
	Palatal width (CR–CL)	mm	0.36	0.39
	Maximum palatal height	mm	0.01	0.44
Horizontal	Papilla raphe (angle)	°	–0.37	0.47

*Significant difference (Student's *t*-test for paired samples, 6 degrees of freedom, $P < 0.005$).

Table 3 Dental rotations of the anchorage teeth in the 'mixed dentition' experimental group.

Patient	Unit	Tooth 16*	Tooth 26**
F39	°	+11.0	–12.8
F23	°	+16.2	–5.3
F44	°	+11.9	–12.3
M9	°	+1.9	–2.7
M22	°	+13.2	–11.8
M25	°	+17.0	–16.5
M30	°	+5.5	–5.1
M24	°	+11.6	–12.5
M23	°	+9.7	–11.1

*Positive values indicate distal rotation; **negative values indicate distal rotation.

Table 4 Differences between dental and palatal expansion.

	Unit	Patients Primary dentition		Patients Mixed dentition		Controls	
		Mean	SD	Mean	SD	Mean	SD
3–3D–P	mm	0.7	0.6	1.2	0.9	0.4	0.4
(6–6 or E–E) D–P	mm	1.0	0.6	1.4	0.9	0.3	0.3

3–3D–P, intercanine dental distance minus intercanine palatal distance; (6–6 or E–E) D–P, intermolar (first permanent or second primary) dental distance minus intermolar palatal distance.

length (IP–M) increased and, at the same time, the palatal slope reduced in five patients (two in the primary and three in the mixed dentition). In contrast, IP–M reduced in three children with an increase of the palatal slope (one in the primary and two in the mixed dentition). Maximum palatal height in the transverse plane did not show significant modifications, while in the sagittal plane a variable pattern was recorded.

In all patients but two, a smoothing of the size-independent (shape) palatal curvature in the frontal plane was observed. Sagittal plane palatal shape showed great variability. Figure 4 shows the palatal modifications of one mixed dentition girl patient. Figure 5 illustrates the most important clinical steps in the treatment of the same patient.

FACC inclinations of the maxillary first permanent or second primary molars and of the primary canines in the anatomical sagittal and frontal planes showed a variable pattern. The pre-/post-treatment differences ranged between 0.1 and 16 (primary) or 17.3 (mixed dentition) degrees. The modification of the inclination was different in each patient and for each tooth. However, in the anatomical sagittal plane those teeth with the largest variations were always more 'vertical' at the end than at the beginning of treatment. FACC inclination in the anatomical frontal plane of those

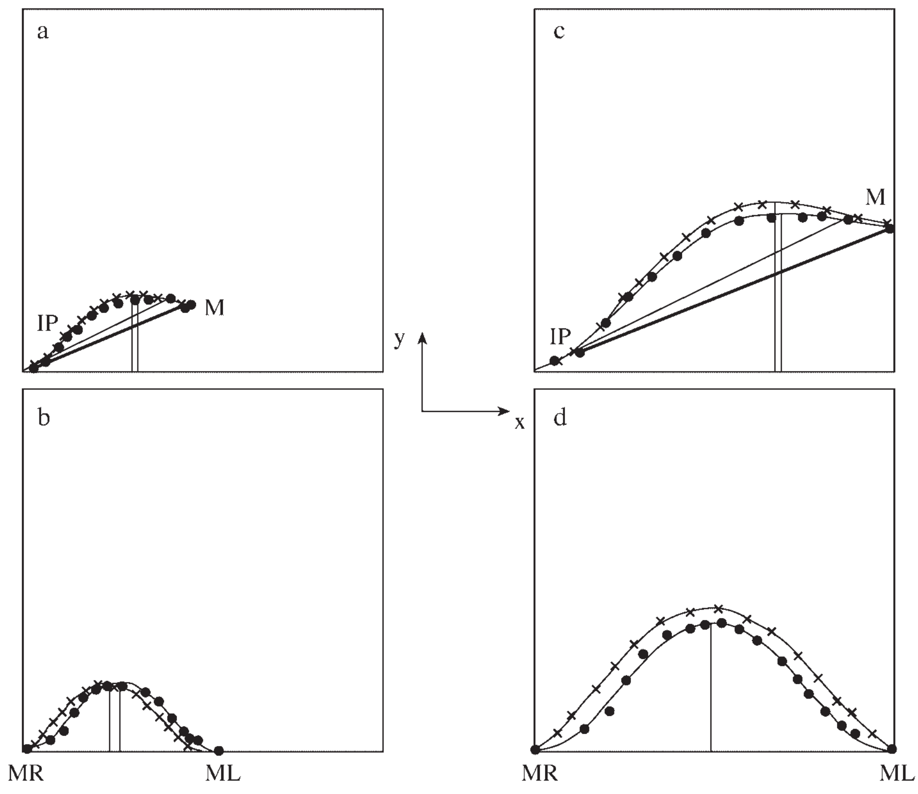

Figure 4 Palatal size (a, b) and shape (size-independent) (c, d) differences of one 'mixed dentition' female patient. (a, c) sagittal view; (b, d) frontal view. Crosses, first impression; dots, second impression (6-month treatment).

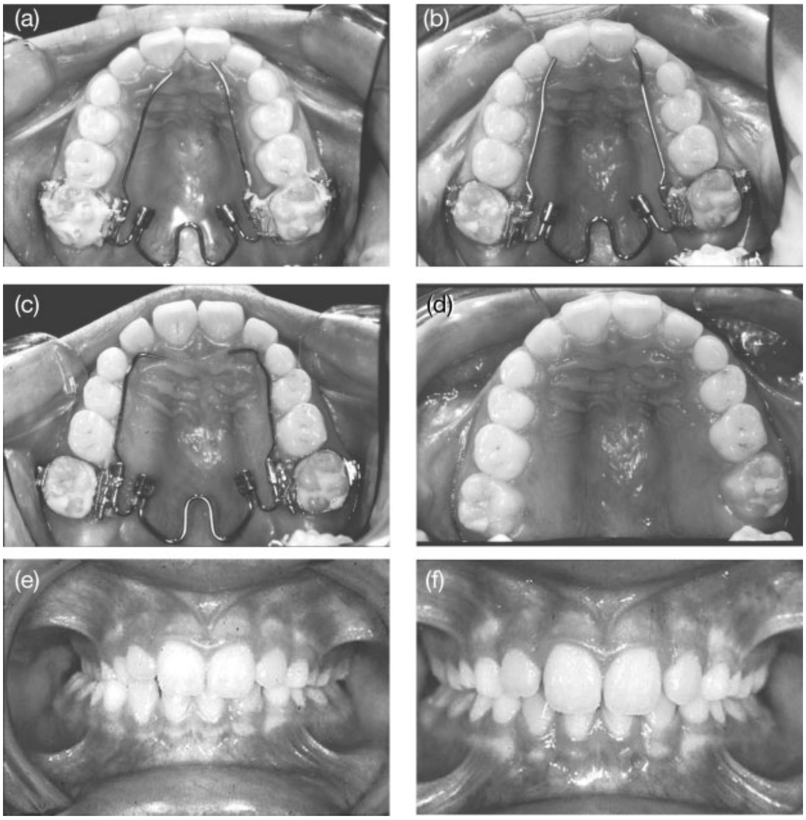

Figure 5 (a) Occlusal view of the same patient with early cementation of the Nitanium® Palatal Expander 2™. In this case, the first movement to be obtained is rotation of the first molars. For this reason, the arms of the appliance are far from both the anterior and lateral teeth. (b) Occlusal view after two months. The arms are now close to the teeth, especially in the anterior segment. The maxillary first molars are rotated. At this point of treatment it is necessary to modify the arms to avoid labial displacement of the lateral incisors. (c) Both the arms are now working in the lateral segment of the palatal arch correcting its shape and dimensions. (d) Occlusal view of the palatal arch after treatment. (e) Frontal view of the occlusion of the patient before orthodontic treatment with the NiTi palatal expander. A severe unilateral posterior crossbite was present on the right side. (f) Frontal view of the same patient after six months of treatment. The crossbite has been totally corrected.

teeth involved in evident differences between dental and palatal expansion also always showed significant modifications, with a movement of vestibular inclination (up to 16.7°). The clinical crown height of anchorage teeth remained nearly the same in all patients but one (six-month difference range 0.05–0.58 mm in the mixed dentition patients, 0.05–0.76 mm in the primary dentition patients).

There was an increase in the radii of the curves of Spee and the molar curve of Wilson in six patients in the mixed dentition, ranging between 22 and 97 mm. This measurement was not performed in children in the primary dentition.

Discussion

The present study analysed the six-month effect of a NiTi palatal expander on the dental and palatal structures of primary and mixed dentition children with a posterior unilateral crossbite. During this time span, the natural growth and development of dental arches and hard tissue palate was negligible, as assessed in the control group children. Therefore, all the modifications found in the experimental group children can be attributed to the actual effect of treatment.

To analyse the model casts, a landmark-based computerized system was used. All measurements were performed with an electromagnetic digitizer (Ferrario *et al.*, 1997, 1998) that allows collection of landmarks once only, independent of the number of measurements, thus reducing measurement errors (Ciambotti *et al.*, 2001). Collected data were analysed with geometric-mathematical models (Ferrario *et al.*, 1994, 1997, 1998, 2001a). The method is easy, fast, low-cost, associated with an acceptable method error and computer-graphic supported.

Even if in all patients the crossbite was completely corrected, a great variability in the actual modifications of hard tissue palate and dental arches was observed.

In all patients except one, there was an increase in the maxillary intercanine distance, the effect being more evident in the primary dentition group. The increase of intercanine distance was probably due to the action of the palatal arms. Moreover, in the younger group, an opening of the midpalatal suture may be a further factor (Arndt, 1993). Indeed, the difference between dental and palatal expansion in each group was higher for the intermolar than for the intercanine distance and, between groups, in the mixed dentition subjects (Table 4). Due to the small number of children it was not possible to statistically evaluate the difference between the mixed and primary dentition groups. In any event, this finding agrees with the non-parallel separation of the midpalatal suture (triangular pattern), that is, in an occlusal view, the suture opens in a wedge-shaped manner (Bell, 1982; Bishara and Staley, 1987). Moreover, it is widely known that opening of the midpalatal suture depends on suture resistance, which increases with age. The primary dentition group showed smaller differences between dental and palatal expansion, probably because the palatal suture opened more easily and less forces were delivered to the teeth. In the mixed dentition group, the palate expanded but dental inclination occurred. Indeed, the inclination of the FACC of those teeth with evident differences between dental and palatal expansion always modified (vestibular inclination in the anatomical frontal plane up to 16.7°). Ciambotti *et al.* (2001) also found a significant increase in molar tipping (mean 11.69°) in those patients that underwent NiTi palatal expansion. This adverse feature of the NiTi device is probably due to the lack of rigidity of the appliance itself. Several authors have reported molar buccal tipping after both rapid and slow maxillary expansion, generally more evident for slow expansion and depending on the device used (Hicks, 1978; Adkins *et al.*, 1990; Ladner and Muhl, 1995). In the anatomical sagittal plane, those teeth with the largest variations of FACC inclination were always more 'vertical' at the end than at the beginning of treatment, probably because as more space is available, an initially misaligned or lingually inclined tooth may find a more normal position. However, FACC inclinations in the anatomical sagittal and frontal planes showed a variable pattern (difference range 0.1–17.3°). The modification was different in each patient and for each tooth.

The molars rotated in a distal direction in all females and in most males in the mixed dentition group (Table 3), the amount of rotation depending on the position of the teeth at the beginning of treatment. The movement was always symmetrical, except in girl F23 who did not use a bite plane. In the primary dentition group teeth rotated in two patients, but not in the other two. It is well known that most Class II malocclusions can be improved by molar rotation, so this effect is advantageous. Moreover the rotation seemed to be related to the need of the single patient, probably due to the flexibility of the device.

Again, when different appliances are used, the degree of dental rotation varies. Ciambotti *et al.* (2001), in a comparison study between rapid palatal expansion (RPE) and NiTi palatal expansion appliances, found a mean distal molar rotation of 26.61 degrees in the NiTi group and only 1.58 degrees in the RPE group, probably because the RPE appliance is rigid and fabricated from the pre-treatment dental cast and no rotational movements can be expected. The method used by Ciambotti *et al.* (2001) did not allow evaluation of rotation for each tooth and thus the symmetry of movement. Moreover, the technique was time-consuming and more prone to bias. Ladner and Muhl (1995) used a similar procedure to evaluate molar rotation for each single tooth. They found 23.8 and 16.5 degrees of rotation respectively for the quad helix and rapid expansion group, but no significant differences between the two groups.

Extrusion of abutment teeth is generally considered a side-effect of RPE that causes vertical opening. In this investigation, no modifications of the height of the clinical crowns were found.

No modifications in mandibular arch dimensions were observed in the children analysed, but this can be explained by the use of a bite plate.

There was an increase in the radii of the curve of Spee in six patients in the mixed dentition group (range 22–97 mm), indicating a smoothing of the curve of Spee. In any event, as the curve is basically flat at the beginning of treatment, no relevant clinical differences in arch dimensions and dental inclination were expected or were detectable.

The papilla raphe angle became more symmetrical in all patients. This could mean that the device can improve an asymmetrical palatal morphology.

Palatal length (IP–M) increased and, at the same time, the palatal slope reduced in five patients (two in the primary and three in the mixed dentition groups). In contrast, IP–M reduced in three children with an increase of the palatal slope (one in the primary and two in the mixed dentition groups). The increase of palatal length could be due to some distalization of teeth, an effect also reported by Corbett (1997). Otherwise, reduction of palatal length could be a result of lowering of the palate in the sagittal plane.

Maximum palatal height in the frontal plane did not show significant modifications, in agreement with Davis and Kronman (1969) and Ciambotti *et al.* (2001). In contrast, Spillane and McNamara (1995) described a very slight but significant decrease in palatal depth with RPE in mixed dentition patients. Ladner and Muhl (1995) demonstrated an increase in palatal depth in both rapid and slow palatal expansion, which they ascribed to extrusion of the dentition. In the sagittal plane, a variable pattern was recorded, but no literature is available on this matter.

In all patients but two in the mixed dentition group, a smoothing of the size-independent (shape) palatal curvature in the frontal plane was observed, a finding in agreement with Davis and Kronman (1969). The two patients without modifications in palatal shape needed and obtained low expansion. Sagittal plane palatal shape showed a significant variability, without consistent patterns.

The main limitation of the present investigation was the reduced sample size, which prevented any formal age- and sex-related analysis. In addition, only a few patients had follow-up dental impressions, thus making impossible the evaluation of long-term stability of the therapy. The analysis of a larger group of children, as well as a radiographic assessment of the palatal suture, may allow further insight into dental arch and palatal modifications.

Conclusions

Although the NiTi palatal expander may effectively correct dentoalveolar posterior crossbite, the increase of maxillary arch width is probably due to a combination of orthopaedic and orthodontic effects, especially in younger children. In particular, the increase of the transverse dimension of the maxillary arch seems to be due to: (a) opening of midpalatal suture, (b) tipping of the alveolar process, (c) molar tipping.

The device can rotate molars and expand both posterior and anterior teeth due to its flexibility and to the presence of adjustable stainless steel palatal extensions. No extrusion of the abutment teeth was observed.

Address for correspondence

Professor Virgilio F. Ferrario
Dipartimento di Anatomia Umana
Università degli Studi di Milano
via Mangiagalli 31
I-20133 Milano, Italy

References

Abdoney M O 1995 Use of the Arndt nickel titanium palatal expander in cleft palate cases. Journal of Clinical Orthodontics 29: 496–499

Adkins M D, Nanda R S, Currier G F 1990 Arch perimeter changes on rapid palatal expansion. American Journal of Orthodontics and Dentofacial Orthopedics 97: 194–199

Airoldi G, Riva G, Vanelli M, Filippi V, Garattini G 1997 Oral environment temperature changes induced by cold/hot liquid intake. American Journal of Orthodontics and Dentofacial Orthopedics 112: 58–63

Andrews L F 1993 Straight wire. Basi teoriche e applicazioni. Masson. Milano

Arndt W V 1993 Nickel titanium palatal expander. Journal of Clinical Orthodontics 27: 129–137

Bell R A 1982 A review of maxillary expansion in relation to rate of expansion and patient's age. American Journal of Orthodontics 81: 32–37

Bishara S E, Staley R N 1987 Maxillary expansion: clinical implications. American Journal of Orthodontics and Dentofacial Orthopedics 91: 3–14

Ciambotti C, Ngan P, Dunkee M, Kohli K, Kim H 2001 A comparison of dental and dentoalveolar changes between rapid palatal expansion and nickel-titanium palatal expansion appliances. American Journal of Orthodontics and Dentofacial Orthopedics 119: 11–20

Corbett M C 1997 Slow and continuous maxillary expansion, molar rotation, and molar distalization. Journal of Clinical Orthodontics 31: 253–263

Davis W M, Kronman J H 1969 Anatomical changes induced by splitting of the midpalatal suture. Angle Orthodontist 39: 126–132

Egermark-Eriksson I, Carlsson G E, Magnusson T, Thilander B 1990 A longitudinal study on malocclusion in relation to signs and symptoms of cranio-mandibular disorders in children and adolescents. European Journal of Orthodontics 12: 399–407

Ferrario V F, Sforza C, Miani A Jr, Tartaglia G 1994 Mathematical definition of the shape of dental arches in human permanent healthy dentitions. European Journal of Orthodontics 16: 287–294

Ferrario V F, Sforza C, Miani A Jr 1997 Statistical evaluation of Monson's sphere in permanent healthy dentitions in man. Archives of Oral Biology 42: 365–369

Ferrario V F, Sforza C, Schmitz J H, Colombo A 1998 Quantitative description of the morphology of the human palate by a mathematical equation. Cleft Palate-Craniofacial Journal 35: 396–401

Ferrario V F, Sforza C, Colombo A, Ciusa V, Serrao G 2001a Three-dimensional inclination of the dental axes in healthy permanent dentitions: a cross-sectional study in a normal population. Angle Orthodontist 71: 257–264

Ferrario V F, Sforza C, Colombo A, Dellavia C, Dimaggio F R 2001b Three-dimensional hard tissue palatal size and shape in human adolescents and adults. Clinical Orthodontics and Research 4: 141–147

Gerberg J W 1996 Alternative to extraction orthodontics: a nitanium palatal expander. Functional Orthodontics 13: 19–22

Hesse K L, Årtun J, Joondeph D R, Kennedy D B 1997 Changes in condylar position and occlusion associated with maxillary expansion for correction of functional unilateral posterior crossbite. American Journal of Orthodontics and Dentofacial Orthopedics 111: 401–408

Hicks E P 1978 Slow maxillary expansion. A clinical study of the skeletal versus dental response to low-magnitude force. American Journal of Orthodontics 73: 121–141

Infante P F 1976 An epidemiologic study of finger habits in preschool children, as related to malocclusion, socioeconomic status, race sex, and size of community. Journal of Dentistry for Children 43: 33–38

Kohler L, Holst K 1973 Malocclusion and sucking habits of four-year-old children. Acta Paediatrica Scandinavica 62: 373–379

Kurol J, Berglund L 1992 Longitudinal study and cost-benefit analysis of the effect of early treatment of posterior cross-bites in the primary dentition. European Journal of Orthodontics 14: 173–179

Ladner P T, Muhl Z F 1995 Changes concurrent with orthodontic treatment when maxillary expansion is a primary goal. American Journal of Orthodontics and Dentofacial Orthopedics 108: 184–193

Larsson E 1975 Dummy- and finger-sucking habits in 4-year-olds. Swedish Dental Journal 68: 219–224

Melsen B, Stengaard K, Pedersen J 1979 Sucking habits and their influence on swallowing pattern and prevalence of malocclusion. European Journal of Orthodontics 1: 271–280

Myers D, Barenie J, Bell R, Williamson E 1980 Condyle position in children with functional posterior crossbite correction: before and after crossbite correction. Pediatric Dentistry 2: 190–194

O'Byrn B L, Sadowsky C, Schneider B, BeGole E A 1995 An evaluation of mandibular asymmetry in adults with unilateral posterior crossbite. American Journal of Orthodontics and Dentofacial Orthopedics 107: 394–400

Pirttiniemi P, Kantomaa T, Lahtela P 1990 Relationship between craniofacial and condyle path asymmetry in unilateral cross-bite patients. European Journal of Orthodontics 12: 408–413

Schiffman P H, Tuncay O C 2001 Maxillary expansion: a meta analysis. Clinical Orthodontics and Research 4: 86–95

Spillane L M, McNamara J A 1995 Maxillary adaptation to expansion in mixed dentition. Seminars in Orthodontics 1: 176–187

Thilander B, Wahlund S, Lennartsson B 1984 The effect of early interceptive treatment in children with posterior cross-bite. European Journal of Orthodontics 6: 25–34