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A clinical comparison of the quadhelix appliance and the nickel titanium (tandem loop) palatal expander: a preliminary, prospective investigation

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SUMMARY Maxillary expansion using either a quadhelix appliance (Qx) or a nickel titanium palatal expander (Nt) was prospectively compared in 28 consecutive new patients (19 female, nine male) presenting with posterior buccal segment crossbites. Study models taken at each activation were measured to determine the mean maxillary expansion efficacy (E_{max}) and the mean expansion rate (m_{max}) across the first molars and first premolars. Patient discomfort was assessed using visual analogue scores, and cost-effectiveness was also considered.

Neither E_{max} nor m_{max} differed significantly between Qx and Nt across either the first molars or the first premolars. However, both E_{max} and m_{max} were significantly greater across the first molars than across the first premolars only with Qx (E_{max}: 8.4 ± 0.7 mm versus 5.1 ± 0.6 mm, $P = 0.001$; m_{max}: 0.09 ± 0.005 mm/day versus 0.05 ± 0.006 mm/day, $P = 0.0001$). In addition, greater variance was apparent in m_{max} with Nt than with Qx across both the first molars and the first premolars. Overall, Qx and Nt elicited similar discomfort. However, significantly less was reported with Nt on days 6 ($P = 0.04$) and 7 ($P = 0.03$) following the second 'activation'.

These preliminary results suggest that Qx and Nt are equally efficacious maxillary expanders. However, Qx expansion appeared significantly more controlled, as well as more individually predictable in expansion rate. Overall, Qx and Nt probably elicit similar discomfort, but significantly less discomfort may be seen with Nt following the second activation. Finally, because more than one appliance is invariably required with Nt, Qx expansion is potentially less costly.

Introduction

A unilateral or bilateral posterior buccal segment crossbite may complicate any malocclusion, with a prevalence of 7.7–16 per cent (Kutin and Hawes, 1969; Hanson *et al.*, 1970; Thilander *et al.*, 1984). Often, although not exclusively, posterior crossbites present in the primary dentition, and cases of self-correction have been recorded (Thilander *et al.*, 1984; Kurol and Berglund, 1992). More usually, however, maxillary expansion is required to permit normal closure patterns (Bell, 1982) and to encourage the correct eruption pathway of permanent successors (Breitner, 1940; Kutin and Hawes, 1969; Clifford, 1971; Bell, 1982). Normal closure patterns may be achieved by eliminating mandibular shift and correcting the condylar position (Hesse *et al.*, 1997; Myers *et al.*, 1980). However, Brin *et al.* (1996) showed that midline deviation, as well as a reverse sequencing pattern of jaw movement, persisted in a group of 24 children in the mixed dentition following correction of a unilateral crossbite with an upper removable appliance. They proposed that this, at least partly, may relate to undetected mandibular asymmetry.

Evidence from animal (Cotton, 1978) and clinical (Hicks, 1978) studies strongly favours the use of slow maxillary expansion (SME) over rapid expansion (RME) to correct posterior crossbites. SME produces relatively small forces acting over several months which, thus, allows supporting tissues to respond physiologically, and, in principle, minimizes relapse (Storey, 1973; Cotton, 1978; Ficarelli, 1978; Hicks, 1978; Frank and Engel, 1982). The quadhelix (Qx) (Figure 1) is a frequently employed SME appliance, the original design and subsequent modifications of which have been described (Ricketts, 1975; Chaconas and de Alba y Levy, 1977; Birnie and McNamara, 1980; Chaconas and

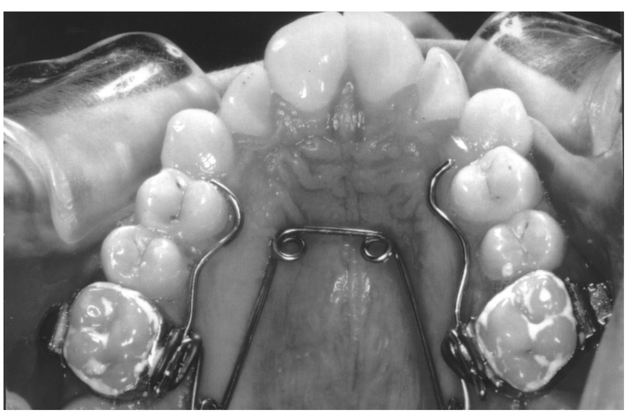

Figure 1 The quadhelix appliance.

Caputo, 1982; Asher, 1985; Wallis *et al.*, 1998). In contrast, the nickel titanium palatal expander (Nt; Nitanium Palatal Expander®, Precision Orthodontics, Walton-on-Thames, Surrey, UK; Figure 2) first described by Arndt (1993), is a relatively recent innovation. Nt was heralded by its manufacturers as an 'ideal' SME appliance on the basis of its low load deflection, high springback properties; as well as on its temperature-dependent shape memory. Considered together, such factors should conspire to produce a light continuous force ideal for tooth movement, and which, at least in principle, should elicit minimal discomfort. By contrast, a Qx constructed from Elgiloy® appears analogous in performance to stainless steel (Urbaniak *et al.*, 1988). In consequence, higher and therefore potentially more painful initial unloading forces are produced with subsequent decay between reactivations. On a theoretical comparison of the manufacturers' claims, Nt appears the more ideal expansion appliance.

Numerous clinical studies have been undertaken to investigate Qx (Bell and LeCompte, 1981; Frank and Engel, 1982) and to compare it with other SME appliances (Hermanson *et al.*, 1985; Boysen *et al.*, 1992; Hesse *et al.*, 1997), RME appliances (Ladner and Muhl, 1995) or both (Herold, 1989; Sandikçioglu and Hazar, 1997). However, such studies have often been retrospective, have lacked any standardized expansion regime, and have considered only overall increases in maxillary dimensions. In contrast, little comparative work appears to have focused on Nt. While the study of Ciambotti *et al.* (2001) represents an exception in this regard, those authors nevertheless attempted to make direct comparisons with a rapid palatal expander. Furthermore, any firm conclusions were prohibited by incomplete details of appliance activation. Thus, given the aforementioned theoretical advantages of Nt, this preliminary study was undertaken to compare both the mean maxillary expansion efficacy (E_{max}) and the mean rate of maxillary expansion (m_{max}) of Qx with Nt, with any ancillary effect induced upon mandibular dimensions analysed secondarily. In addition, relative patient discomfort was compared for each appliance using visual analogue scores (VAS) [as previously validated by McGrath (1987) with children older than 5 years of age], as well as an assessment of relative appliance cost.

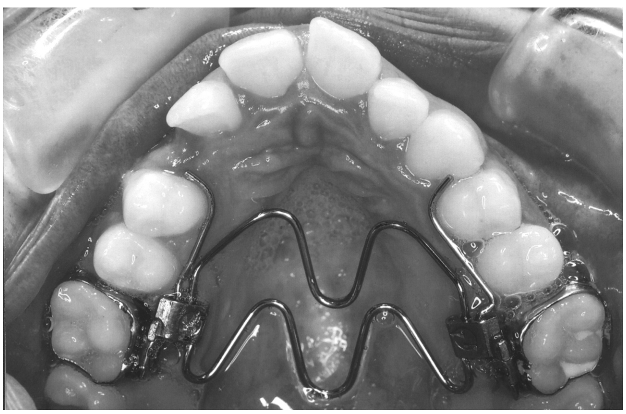

Figure 2 The nickel titanium palatal expander.

Subjects and methods

Thirty-three consecutive new patients (22 female, 11 male) in the late mixed or permanent dentition, presenting with either unilateral or bilateral posterior buccal segment crossbites, were entered into this preliminary study. A posterior segment crossbite was defined as the buccal cusps of the posterior segment extending from the maxillary first premolar to the last fully erupted molar occluding palatal to the buccal cusps of the corresponding mandibular teeth. Each consecutive new patient was alternately allocated either a Qx or a Nt for maxillary expansion. All classifications of Angle's malocclusions were included in the study, as only the transverse dimension was under investigation (Table 1). However, patients with obvious developmental facial anomalies, lateral open bites or previous orthodontic treatment were specifically excluded. Patients presenting with unilateral or bilateral crossbites with or without mandibular displacements were not specifically allocated either a Nt or a Qx alternately, nevertheless a similar distribution was obtained (Table 1). The purpose of the investigation was explained to the patient and guardian, and fully informed consent obtained. Four experienced clinicians participated in the study and a strict protocol was established.

Study models, incorporating a wax bite to register the intercuspal position, were taken at the outset to record the original malocclusion. The presence of a mandibular displacement was noted. Following separation, two upper first molar bands were selected and placed in an upper alginate impression. For the Qx group, a custom-made removable 0.8 mm heat-treated blue Elgiloy® removable appliance was constructed. For the Nt group, a pre-formed removable appliance incorporating two stainless steel palatal arms (0.8 mm) connected to a nickel titanium tandem loop (0.9 mm) was selected. A fundamental design change in the Nt by the manufacturer (whereby the tandem loop was replaced by a single transpalatal arch) curtailed the study such that only the tandem loop design was analysed. The Nt is supplied by the manufacturer in eight widths (26–47 mm) and the appropriate size was selected by measuring the mandibular first molar width between the central fossae, with an additional 4 mm allowed for overcorrection. As advised by the manufacturer, if greater than or equal to 6 mm expansion was deemed necessary, then successive Nts were used. Each appliance was inserted into palatal sheaths that were soldered to the first molar bands, from which the palatal arms were extended to the first premolar region. No torque was incorporated during activation.

Table 1 Comparison of individual variables.

	n	Quadhelix appliance	*n*	Nickel titanium palatal expander	*P*
Age (years)					
Mean	14	13.2 ± 0.4	14	14.3 ± 0.5	0.09
Range	14	10.5–13.8	14	13.8–17	
Gender		8 female, 6 male		11 female, 3 male	
Malocclusion					
Class I		6		5	
Class II division 1		2		5	
Class II division 2		–		1	
Class III		6		3	
Crossbite type		8 unilateral, 6 bilateral		9 unilateral, 5 bilateral	
Mandibular displacement		7		8	
Initial maximum width (mm)					
6-6	14	47.1 ± 0.9	14	46.4 ± 1.1	0.6
4-4	14	36.1 ± 0.7	14	36.5 ± 1.1	0.72
Appointment interval (days)					
First to second	14	32.8 ± 1.4	14	28.9 ± 1.5	0.07
Second to third	13	30 ± 0.8	13	30.4 ± 1.2	0.8
Third to fourth	11	30.9 ± 1.7	10	34.1 ± 2.5	0.3

Statistical analyses were not carried out with respect to appointment intervals after the fourth visit due to the small number of patients in subsequent interval groups.

At the second clinical visit, each Qx was activated one molar width posteriorly and one premolar width anteriorly. Each Nt was cooled using a tetrafluoroethane refrigerant spray (Endo Ice®, Precision Orthodontics) to facilitate insertion. All appliances were then cemented using glass ionomer cement (ESPE Ketac® Cem radioopaque, Kent Express Ltd, Gillingham, Kent, UK). Each patient was given a VAS sheet to record, on a scale of 1–10, both their anticipated discomfort and any actual discomfort experienced over the following 10 days. For each day the scale was divided into 10 equally spaced marks, with a score of 0 representing 'no discomfort' and 10 'unbearable discomfort'. Each subject was then reviewed at approximately 4 weekly intervals.

At each review appointment, the transverse buccal segment relationship of the upper relative to the lower arch was carefully checked in the retruded contact position to determine the interval expansion achieved. The palatal appliance was then detached from the palatal sheaths, and upper and lower study models, including a wax bite, were taken. The Qx was then re-expanded one molar posteriorly and one premolar width anteriorly, as estimated directly from the patient's upper arch. By contrast, the same Nt expander was reinserted unless a second expander was deemed necessary (as determined by measuring the interim upper first molar width). The completed VAS sheet was then collected, and a second issued to record actual discomfort over the next 10 days.

The above cycle was repeated until an overcorrected position was achieved, i.e. until the palatal cusps of the erupted maxillary first molars and premolars contacted the lingual slopes of the buccal cusps of the corresponding mandibular teeth in intercuspal position. Final study models were taken at this juncture, and the final VAS sheet also collected. No other aspect of treatment was undertaken until maxillary expansion had been completed.

Measurement of the study models

One person was responsible for study model measurement. This individual, who was not involved in the clinical treatment of the cases, was supplied only with the study models, and was blind to the appliance details. Each upper and lower study model was measured across the tips of the mesiobuccal cusps in the first molar region, as well as across the tips of the buccal cusps in the first premolar region. All measurements were made to the nearest 0.1 mm using dial gauge callipers (Orthocare, Bradford, West Yorkshire, UK).

Statistical analysis

E_{max} (mm) of each appliance was calculated from the arithmetic mean increase across the first molar and premolar widths for each appliance group. M_{max} (mm/day) across the same dimensions was derived from the gradients of linear regression graphs obtained from individual expansion profiles (cumulative expansion, mm/cumulative number of days) (Figure 3). The average time taken to attain the overcorrected maxillary expansion (T, days) was calculated for each group.

The effect of maxillary expansion on the mandibular arch was also established by measurement of the lower study model. The mean maximal mandibular change (E_{mand}, mm) was determined across the mandibular first molar and first premolar regions from the start and final models. Expansion profiles were also constructed to calculate the mean rate of change (m_{mand}, mm/day).

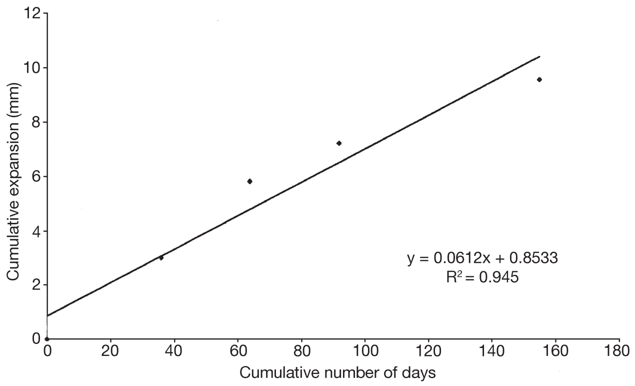

Figure 3 The rate of expansion (m_{max}, mm/day) across maxillary 6-6—an example of a subject's expansion profile calculated from cumulative expansion (mm)/cumulative number of days.

All results were expressed as the mean ± standard error. Following statistical testing of the variance in E_{max} (V_E) and m_{max} (V_m) of each experimental group using Fisher's test (F test), E_{max} was assessed using ANOVA, while m_{max} was assessed using a t-test with unequal variances, both at $P < 0.05$.

Ten random sets of study models were re-measured after a 3 week interval to check repeatability (Bland and Altman, 1986).

VAS

VAS of anticipated discomfort were displayed in a frequency histogram. Comparison of the VAS of actual discomfort from day 1 to day 10, following first, second and third activations, was undertaken using a Wilcoxon rank sum test. The median VAS of actual discomfort, over the same activations, were also displayed graphically. Completed VAS forms after the third activation were not compared as only a small number of patients remained in the study.

Cost-effectiveness

Episodes, such as displacement of appliance and breakages, were recorded over the expansion period for each participating subject.

Results

Of the 33 patients originally included in the study, 28 successfully completed maxillary expansion. Of the five excluded, two developed a mandibular skeletal asymmetry which only became truly apparent during expansion treatment (both patients were later offered orthognathic surgery—one accepting treatment, the other declining). The remaining three patients who were excluded were non-compliant in terms of poor attendance and inability to cope with treatment (two eventually completed treatment, whereas the third opted out). The final Qx group comprised eight females and six males, the final Nt group 11 females and three males. The relative female excess with Nt probably reflected the greater demand of this sex for treatment: notwithstanding, no effect on significance testing with either E_{max} or m_{max} on intergroup comparison was recorded. The mean age for Qx (13.2 ± 0.4 years, range 10.5–13.8 years) did not differ significantly from that of Nt (14.3 ± 0.5 years, range 13.8–17 years) (Table 1). The ratio of unilateral:bilateral crossbites between each group was well matched, and the mean starting maxillary first molar and premolar widths between each group were also comparable (Table 1). Although patients did not consistently attend at exactly 4 weekly intervals, the mean appointment interval comparisons (days) between each group did not differ significantly (Table 1).

Maxillary expansion

E_{max} for Qx and Nt did not differ significantly across the first molars (Qx: 8.4 ± 0.7 mm versus Nt: 7.8 ± 0.9 mm, $P = 0.60$; Table 2) or across the first premolars (Qx: 5.1 ± 0.6 mm versus Nt: 5.9 ± 0.7 mm, $P = 0.38$; Table 2). While no significant difference was found in E_{max} with Nt between the first molars and the first premolars ($P = 0.11$; Table 3), E_{max} was significantly greater across the first molars than the first premolars with Qx (8.4 ± 0.7 mm versus 5.1 ± 0.6 mm, $P = 0.001$; Table 3). There was no significant difference in V_E for Qx or Nt across the first molars ($P = 0.17$; Table 2) and the first premolars ($P = 0.16$; Table 2).

m_{max} across the first molar regions for Qx (0.09 ± 0.005 mm/day) and Nt (0.09 ± 0.011 mm/day) was almost identical ($P = 0.98$; Table 2). Although a slightly higher rate was found with Nt across the first premolars (Nt: 0.07 ± 0.012 mm/day versus Qx: 0.05 ± 0.006 mm/day), this was not significant ($P = 0.25$; Table 2). Once again, while no significant difference was found in m_{max} with Nt between the first molars and the first premolars ($P = 0.24$; Table 3), m_{max} was significantly greater with Qx across the first molars than across the premolars ($P = 0.0001$; Table 3). V_m for Nt was significantly greater than that with Qx across both the first molars ($P = 0.0039$; Table 2) and the first premolars ($P = 0.009$; Table 2). The values for m_{max} appear small because they specifically refer to the daily rate of SME as derived from the individual expansion profiles (e.g. Figure 3).

The mean time taken to achieve E_{max} (T) for Qx (101.6 ± 10.3 days) did not differ significantly from that with Nt (98.1 ± 8.5 days) ($P = 0.80$; Table 2).

Effect of maxillary expansion on the mandibular arch

E_{mand} following maxillary expansion did not differ significantly between Qx and Nt, either across the first molars (0.5 ± 0.3 and 0.5 ± 0.1 mm, respectively;

Table 2 Summary comparison of quadhelix appliance (Qx) and nickel titanium palatal expander (Nt) efficacy (E_{max}) and expansion rates (m_{max}) in maxillary first molar (6-6) and premolar (4-4) regions.

	Qx 6-6 (n = 14)	Nt 6-6 (n = 14)	P-value	Qx 4-4 (n = 14)	Nt 4-4 (n = 14)	P-value
E_{max}	8.4 ± 0.7	7.8 ± 0.9	0.60	5.1 ± 0.6	5.9 ± 0.7	0.38
m_{max}	0.09 ± 0.005	0.09 ± 0.011	0.98	0.05 ± 0.006	0.07 ± 0.012	0.25
V_E	4.51	7.76	0.17	5.87	10.43	0.16
V_m	0.00036	0.00176	0.0039*	0.00049	0.00194	0.009*
T	101.6 ± 10.3	98.1 ± 8.5	0.80	101.6 ± 10.3	98.1 ± 8.5	0.80

E_{max}, mean ± standard error of maximal maxillary expansion (mm); m_{max}, mean rate ± standard error of maxillary expansion (mm/days); V_E, variance of E_{max} values; V_m, variance of m_{max} values; T, mean ± standard error of time to E_{max} (days).
*Statistically significant ($P < 0.05$).

Table 3 Comparison of appliance efficacy (E_{max}) and expansion rates (m_{max}) across maxillary first molar (6-6) and premolar (4-4) regions within the quadhelix appliance (Qx) and nickel titanium palatal expander (Nt) groups.

	Qx 6-6 (n = 14)	Qx 4-4 (n = 14)	P-value	Nt 6-6 (n = 14)	Nt 4-4 (n = 14)	P-value
E_{max}	8.4 ± 0.7	5.1 ± 0.6	0.001*	7.8 ± 0.9	5.9 ± 0.7	0.11
m_{max}	0.09 ± 0.005	0.05 ± 0.06	0.0001*	0.09 ±0.011	0.07 ± 0.012	0.24

E_{max}, mean ± standard error of maximal maxillary expansion (mm); m_{max}, mean rate ± standard error of maxillary expansion (mm/days).
*Statistically significant ($P < 0.05$).

Table 4 Summary comparison of mandibular change (E_{mand}) and rate of change (m_{mand}) across first molar (6-6) and first premolar (4-4) regions following maxillary expansion with a quadhelix appliance (Qx) and a nickel titanium palatal expander (Nt).

	Qx 6-6 (n = 14)	Nt 6-6 (n = 13)	P-value	Qx 4-4 (n = 14)	Nt 4-4 (n = 13)	P-value
E_{mand}	0.5 ± 0.3	0.5 ± 0.1	0.93	0.3 ± 0.2	0.2 ± 0.1	0.70
m_{mand}	0.005 ± 0.003	0.005 ± 0.001	0.93	0.003 ± 0.002	0.002 ± 0.001	0.47

E_{mand}, mean ± standard error of mandibular change (mm); m_{mand}, mean rate ± standard error of mandibular change (mm/days).
There were 13 patients in the Nt group as one patient had only upper study models taken at the reactivation appointments.

P = 0.93; Table 4) or across the first premolars (0.3 ± 0.2 and 0.2 ± 0.1 mm, respectively; P = 0.70; Table 4). These values, however, concealed a wide range of individual variations that included either those who exhibited no change at all (30 per cent across the first premolars for both Qx and Nt jointly), to those who exhibited contraction (26 per cent across the first molars and 15 per cent across the first premolars for both Qx and Nt jointly).

Similarly, m_{mand} did not differ significantly between Qx and Nt, either across the first molars (0.005 ± 0.003 and 0.005 ± 0.001 mm/day, respectively; P = 0.93; Table 4) or across the first premolars (0.003 ± 0.002 and 0.002 ± 0.001 mm/day, respectively; P = 0.47; Table 4). However, as with E_{mand}, marked individual variation was again apparent, with some exhibiting no change (15 per cent across the premolars for both Qx and Nt jointly), to those who exhibited a contraction (30 per cent across the first molars and 15 per cent across the first premolars for both Qx and Nt jointly). Indeed, for some individuals, first molar expansion was concurrent with first premolar contraction and *vice versa*, a phenomenon seen in 29 per cent of Qx and 31 per cent of Nt.

Repeatability of measurements

The Bland and Altman (1986) method of testing repeatability showed that consistent measurement of study models occurred, as greater than 95 per cent of differences between the repeated measurements were within two standard deviations of the mean (Table 5).

VAS

The rate of return of the VAS forms was 100 per cent. A similar range of VAS of anticipated discomfort was evident for each appliance, with a mode of 4 (indicating expected mild discomfort) for both appliances (Figure 4). Overall, the VAS for actual discomfort within each appliance group did not differ significantly (Table 6). Although a trend was apparent, suggesting that less discomfort was experienced with Nt following the

Table 5 Statistical testing of repeated measurements of 10 sets of study models across maxillary first molars (max 6-6) and premolars (max 4-4) and mandibular first molars (mand 6-6) and premolars (mand 4-4).

	n	Max 6-6	Max 4-4	Mand 6-6	Mand 4-4
Mean difference	20	0.16	0.08	0.24	0.2
Mean difference ± 2 SD	20	–0.52–0.84	–0.43–0.58	–0.42–0.9	–0.36–0.76
Range of actual differences	20	–0.2–0.7	–0.2–0.6	–0.4–0.7	–0.3–0.6

All measurements in mm.
Mean difference, mean difference between repeated measurements; SD, standard deviation; range of actual differences, range of differences between first and second measurements.

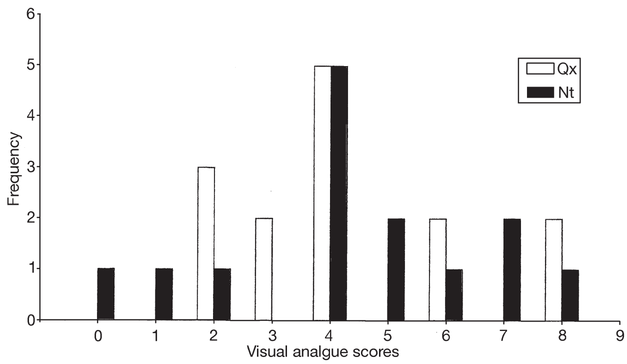

Figure 4 Visual analogue scores of anticipated discomfort.

second activation, this, however, proved significant only on days 6 and 7 (P = 0.04 and P = 0.03, respectively; Table 6). Figure 5 shows the median VAS calculated from days 1–10 of actual discomfort experienced following the first, second, and third activations (subsequent activations were not considered, as only 25 per cent of patients remained in the study beyond this point). Following the first activation, the median scores for both Qx and Nt were initially moderately high (6 and 6.5, respectively): nevertheless, these gradually decreased to 2.5 and 2, respectively, by day 4, with a further decrease by day 10. After the second activation, both groups (Qx: n = 13; Nt: n = 13) experienced 'minimal' discomfort, with starting median scores of 1, further reducing to 0 by day 8. After the third 'activation' (Qx: n = 11; Nt: n = 10), the median scores were less than or equal to 1, similarly indicating either 'minimal' or 'no' discomfort. (Not all median values are apparent in Figure 5 owing to excessive superimposition of values at the lower end of the discomfort scale at intervals beyond the first activation).

Cost-effectiveness

While one Qx was capable of fully expanding the maxillary arch, successive Nts were advised if greater than or equal to 6 mm first molar expansion was required. For the Nt group, 3/14 patients required less than 6 mm first molar expansion, 10/14 required 6–11 mm and 1/14 required greater than 11 mm. On considering both groups jointly, 5/28 required less than 6 mm first molar

Table 6 Comparison of visual analogue scores following first, second and third activation of a quadhelix appliance (Qx) and a nickel titanium palatal expander (Nt).

	Group	*n*	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
First activation	Qx	14	6	5	4.5	2.5	2	1	0.5	0.5	0.5	0
	Nt	14	6.5	5.5	5	2	2.5	1.5	1.5	1	1	1
W			192	201	201	199.5	203	197.5	193	195	190.5	183
Z			0.51	0.09	0.09	0.16	0.00	0.26	0.48	0.39	0.60	
P-value			0.61	0.93	0.93	0.87	1.00	0.80	0.63	0.70	0.54	0.31
Second activation	Qx	13	1	1	1	1	1	1	1	0	0	0
	Nt	13	1	0	0	0	0	0	0	0	0	0
W			166	167.5	163.5	164	146.5	140	137	151.5	151.5	163.5
Z			1.52	1.46	1.67	1.66	1.66	2.04	2.22	1.46	1.46	0.69
P-value			0.13	0.14	0.10	0.10	0.10	0.04*	0.03*	0.14	0.14	0.49
Third activation	Qx	11	1	1	1	1	0	0	1	1	0	0
	Nt	10	1	1	1	1	1	1	1	1	0.5	0.5
W			111.5	108	116.5	117	116	112	120	99	115.5	111
Z			0.69	0.15	0.34	0.30	0.38	0.68	0.08	0.50	0.42	0.77
P-value			0.51	0.92	0.76	0.81	0.76	0.56	0.97	0.62	0.67	0.44

W, Wilcoxon rank sum statistic; *Z*, normal approximation.
*Statistically significant ($P < 0.05$).
Statistical analyses were not carried out after the third activation due to the small group numbers in subsequent activations.

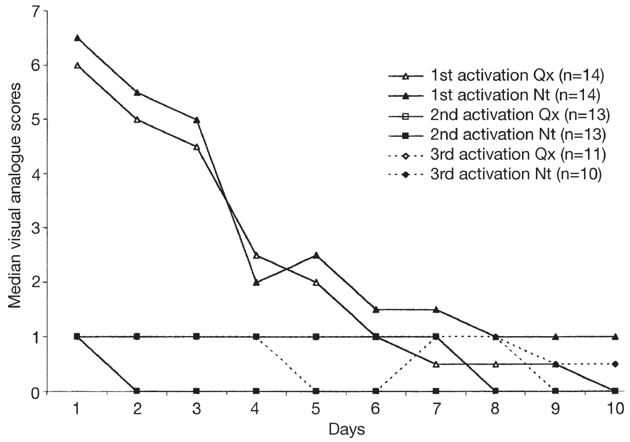

Figure 5 Median visual analogue scores of actual discomfort.

expansion, 21/28 required 6–11 mm and 2/28 required greater than 11 mm.

In total, 15 complications were reported by 13/28 patients who participated in the study (Table 7). These were fairly evenly distributed between the groups (Qx = 7; Nt = 8). The most frequent complication was displacement of the appliance ‘body’ from the palatal sheaths. One episode of Nt fracture was reported.

Discussion

Maxillary expansion

The craniofacial growth series (Moyers *et al.*, 1976) provides standard figures for normal transverse maxillary growth in untreated North American white individuals from 10 to 18 years of age. In that series, mean increases of 2.2 and 2.3 mm across the first molar and first premolars were established for males, and 0.4 and 1 mm for females. In this current prospective study, both Qx and Nt produced mean maxillary width increases (E_{max}) markedly in excess of these ‘normal’ growth values (Table 2). Indeed, the values obtained were greater than those previously reported, using either a Qx (Bell and Le Compte, 1981; Frank and Engel, 1982; Hermanson *et al.*, 1985; Herold, 1989; Boysen *et al.*, 1992; Ladner and Muhl, 1995; Sandikçioglu and Hazar, 1997) or a Nt (Ciambotti *et al.*, 2001). Such smaller E_{max} values previously reported might be explained by differences in appliance activation regimes, as well as the occasional inclusion of further active treatment and/or a retention period.

Table 7 Problems experienced (number of episodes) with the quadhelix appliance (Qx) and the nickel titanium palatal expander (Nt).

	Qx group	Nt group
Dislodgement of appliance	4	5
Loose band	2	1
Soft tissue trauma	1	1
Fracture of appliance	–	1

In the present investigation, no significant difference was found in E_{max} between the Qx and Nt across either the first molars or the first premolars (Table 2). This result is not entirely surprising as each group had comparable mean starting widths (Table 1): in consequence, the overcorrected final maxillary widths and therefore the amount of expansion, were also likely to be comparable. However, while the first molar E_{max} exceeded the first premolar value for both appliances, this difference was significant only for Qx ($P = 0.001$; Table 3). This suggests that the Qx produced a significantly more controlled differential expansion between the first molars and the first premolars than Nt. Such an effect might be explained by the method of Nt selection, as this is based solely upon correcting the first molar transverse deficit: as a result, expansion forces exerted upon the first premolars might be expected to resemble those upon the first molars. By contrast, Qx activation was effected entirely independently across the first molars and the first premolars: indeed, differential expansion is an anecdotally recognized advantage of Qx. Conceivably, potentially excessive premolar expansion, as implied by these findings with Nt, could result in ‘round tripping’ when full arch mechanics are subsequently introduced to control arch-form as previously reported by Braun *et al.* (1999) using nickel titanium archwires.

Other studies have invariably omitted analysing m_{max}. In the present investigation, values for m_{max} did not differ significantly between either appliance, either across the first molars or the first premolars: indeed, the values obtained across the first molars were almost identical (Table 2). This finding suggests that each appliance possessed an equivalent expansile potential. However, as with the E_{max} obtained with Qx, m_{max} was significantly greater with Qx across the first molars than across the first premolars ($P = 0.0001$; Table 3). Once again, this is probably attributable to ‘molar’ forces being simultaneously applied to premolar regions with Nt. Of further interest still was that, in contrast to V_E, V_m was significantly greater with Nt than with Qx, across both first molars ($P = 0.0039$) and first premolars ($P = 0.009$; Table 2). As both appliances produced similar mean expansion rates, this suggests that the expansion rate produced by Nt was both significantly less controlled, as well as significantly less predictable on an individual basis, to that obtained with Qx. One possible explanation for this may again relate to the mode of Nt reactivation: thus, while Qx was re-expanded at each visit with direct reference to the patient’s maxillary arch, each Nt in contrast was reinserted until its potential width had been fully realized. In consequence, had the predetermined width of any utilized Nt actually been achieved between appointments, the appliance would then not have been continuously activated throughout that period. An alternative explanation, however, relates to the fact that Nt is a temperature-sensitive appliance: thus, as oral temperatures vary considerably between individuals (Moore *et al.*, 1999), a wide variance in Nt efficacy would be an entirely plausible finding. Although the values quoted for m_{max} *per se* might appear rather small, it should be noted that these values specifically refer to the daily rate of SME as derived from the individual expansion profiles (e.g. Figure 3).

The mean time taken for either Qx or Nt to achieve overcorrected maxillary expansion (T) was strikingly similar (Table 2). With reference to Qx, this active treatment interval is in general agreement with the 3 month active expansion period recommended by Birnie and McNamara (1980). Moreover, Boysen *et al.* (1992) reported a mean expansion time of 101.2 days (range 42–147 days) to correct unilateral posterior crossbites in 34 children (mean age 8 years 3 months). In contrast, the considerably shorter treatment time of 30 days reported by Bell and LeCompte (1981) to 'correct a functional posterior crossbite' probably related to the younger age considered in that sample (mean age 6 years 9 months). Similarly, while Sandikçioglu and Hazar (1997) reported a mean of only 56 days to correct unilateral and bilateral posterior crossbites in a mixed dentition group, all of their cases had undergone intra-oral Qx activation at fortnightly intervals.

Overall, the current results generally support the 'null hypothesis' that both Qx and Nt appliances are equally efficient maxillary expanders. As this might not have been expected given the theoretical advantages of Nt, several explanations are proffered. First, the highly variable response with Nt could have been due to highly variable individual oral temperatures (Moore *et al.*, 1999). Second, Nt efficacy could also have been reduced by a potential period of redundancy between appointments prior to the fitting of the next active appliance. Third, handling inconsistencies could have confounded Nt results by virtue of it representing a new and unfamiliar technique. Fourth, as the manufacturers of the Nt procured a fundamental design change during the study, the results (i.e. obtained from a tandem loop) cannot be assumed to translate to Nt's current design (i.e. a single transpalatal arch) performance. Finally, this preliminary study necessarily utilized small group numbers which, thus, renders conclusive remarks on accepting the null hypothesis strictly limited. For any future study based on the present findings, the chance of detecting a difference in E_{max} between each appliance of 0.5 mm (giving $P < 0.05$ at 80 per cent power) would require a study population of at least 120 patients.

Effect of maxillary expansion on the mandibular arch

Maxillary expansion may also be accompanied by mandibular arch expansion as a response to both altered occlusion and altered muscle balance (Gryson, 1977; Cotton, 1978; Hermanson *et al.*, 1985; Boysen *et al.*, 1992). In the present study, overall slight increases in E_{mand} and m_{mand} were recorded across both the first molars and the first premolars with Qx and Nt (Table 4). However, marked individual fluctuations were found that included either no changes at all or, even, actual decreases in both E_{mand} and m_{mand}. It must be emphasized that the absolute values recorded *per se* in any direction were of such small magnitude so as to render them both clinically and statistically insignificant. Thus, in contrast to some expansion studies (Gryson, 1977; Hesse *et al.*, 1997), but in accordance with others (Bell and LeCompte, 1981; Boysen *et al.*, 1992), the outcome of maxillary expansion upon the mandibular arch in the present study was both clinically negligible and individually unpredictable using either appliance.

Patient discomfort

Both groups anticipated a similar range of mild-to-severe discomfort prior to treatment (Figure 4). In a similar manner, the actual discomfort subsequently reported was also moderately 'high' with either appliance during the initial days following insertion and activation (Table 6, Figure 5). Moreover, following familiarization, an equivalent fall in median pain scores also occurred with both appliances to levels of either 'minimal' or 'no' discomfort by day 10 (from whence they remained in those undergoing further activations). Notwithstanding, a definite trend existed following the second 'activation' where less discomfort was recorded with Nt: this, however, proved significant only on days 6 and 7 following the second 'activation' ($P = 0.04$ and $P = 0.03$, Table 6). While such a finding might seem supportive of claims that Nt exerts significantly lighter forces than Qx (Arndt, 1993), a more likely explanation relates to the practice of having reinserted the same Nt until its full potential width had been achieved: in consequence, and because of a period of potential redundancy, weaker forces could have been exerted specifically following this second 'activation' with Nt.

Cost-effectiveness

The cost of an appliance is an important clinical consideration. The approximate cost of either appliance *per se* was £35. However, while a solitary Qx was always appropriate to expand any transverse deficit, multiple Nts were required where greater than or equal to 6 mm expansion was necessary (i.e. 11/14 patients with Nt in the current study). Indeed, even by following the suggestion of Marzban and Nanda (1999) to restrict successive Nts only to those cases where greater than 8 mm expansion is required, extra cost may still inevitably be incurred with Nt. Moreover, Endo Ice® refrigerant spray is required to facilitate insertion of any Nt. One undeniable advantage of Nt, however, is that removal and reinsertion is not required at each clinical visit: as a result, each Nt can be left *in situ* until its full width has been expressed, thus conserving clinical time.

Both appliances were equally associated with recognized 'fixed appliance' complications, although one case of fracture was recorded with Nt (Table 7).

Methodology

This prospective study uniquely followed the expansion profiles of Qx and Nt by regular study models taken at successive appointments. In contrast, previous investigations have only recorded maxillary expansion without any consideration of expansion rate (Frank and Engel, 1982; Hermanson *et al.*, 1985; Herold, 1989; Boysen *et al.*, 1992; Ladner and Muhl, 1995). Furthermore, while these also included analyses of further fixed appliance treatment and/or retention periods, the present study focused solely on the active expansion phase.

The relatively small sample size (i.e. $n = 28$) largely reflected the study's preliminary nature. Nevertheless, it was also enforced by a fundamental design change in Nt by the manufacturers, from a tandem loop to a single transpalatal arch. As the study had already started using the tandem loop design, it was more sound to complete the investigation using this design: as a result, limited numbers were necessarily enforced with Nt.

While random allocation might have been considered a more appropriate way to preclude bias, a considerably larger sample was required, incompatible with the study's limited design. Indeed, Gore and Altman (1991) stated that when comparing two treatments 'unequal randomization' may be appropriate as it allows greater clinical experience of the new treatment, and a more precise estimation of its outcome. In further defence, no pre-selection of the new patients was undertaken: only alternate allocation was practised.

Although a relative preponderance of females existed with Nt, no statistically significant changes were found in either E_{max} or m_{max} when subsequent sex adjustments were made. Furthermore, given the small degree of transverse growth reported from 10 to 18 years of age by Moyers *et al.* (1976), a significant effect of sex difference on transverse growth would not have been expected during the time period of the study. Each group was well matched for Angle's malocclusions, as well as for unilateral:bilateral crossbites (Table 1). Moreover, no significant differences were observed in initial maxillary widths across either first molar or premolar regions between Qx or Nt (Table 1). Although it was requested that patients returned at 4 weekly intervals, this was not always the case: nevertheless, a comparison of appointment intervals showed no significant differences between the groups (Table 1).

The relative influence of all such potentially confounding factors could be more fully investigated in a larger future study where, of course, greater confidence could also be realized in accepting the null hypothesis.

No attempt was made to either measure or determine the nature of the force exerted by each appliance in this study. However, considering the age range of the patients involved, it would seem most likely that the main effect produced was orthodontic (Chaconas and de Alba y Levy, 1977; Ficarelli, 1978; Bell, 1982; Chaconas and Caputo, 1982; Bishara and Staley, 1987). This conclusion would be compatible with widespread scepticism regarding the proposed orthopaedic potential of Qx (Chaconas and Caputo, 1982; Bishara and Staley, 1987) although in contention to Ciambotti *et al.* (2001) with regard to Nt.

Conclusions

1. Qx and Nt are equally efficient maxillary expanders, in terms of the magnitude of the expansion obtained and the expansion rate (indeed, low significance values suggest a remarkable degree of uniformity between each appliance in both of these parameters).
2. Qx expansion appeared significantly more controlled than Nt, by virtue of both a significantly differential first molar–premolar expansion efficacy and expansion rate.
3. The Qx expansion rate appeared more predictable on an individual basis than Nt.
4. Maxillary expansion using either appliance elicited insignificant and unreliable effects upon the mandibular arch.
5. While in general both appliances elicited similar discomfort, significantly less discomfort was experienced with Nt but only in a delayed manner following the second activation.
6. Cost considerations suggest that Qx expansion is probably less expensive compared with Nt.
7. Larger studies are indicated to confirm or refute these findings.

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