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ORIGINAL ARTICLE

Short-term treatment effects of quad-helix on maxillomandibular expansion in patients with maxillary incisor crowding

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Abstract The purpose of this study was to evaluate the effects of the maxillary arch expansion on maxillomandibular arch widths in patients treated with the quad-helix versus untreated controls. The treatment group consisted of 50 consecutive patients treated for maxillary incisor crowding with a quad-helix appliance in the early mixed dentition. Lateral cephalograms and dental casts taken at the start (T0) and end (T1) of the quad-helix treatment were obtained. The control group consisted of 50 untreated patients with the same type of malocclusion. Two consecutive lateral cephalograms and dental casts of each untreated patient were taken at about the same time as T0 and T1. All these study materials were analyzed for comparison between the two groups. The mean ages at T0 and T1 in the two groups were about the same. The maxillary first molars moved and tipped distally in the treatment group and mesially in the control group. The quad-helix treatment actually expanded the mandibular and maxillary arches concurrently. The more the maxillary arch widths were expanded and the less the maxillary first molars were inclined distally, the more the mandibular arch widths were expanded. The quad-helix activation caused lingual tipping and mesiobuccal rotation of the maxillary first molars. The mesiobuccal rotation of the maxillary first molars could turn molar occlusal relationships for the better from Class II to Class I. The quad-helix treatment gives rise to spontaneous expansion of the mandibular arch concurrent with maxillary expansion in the early mixed dentition patients with maxillary incisor crowding.

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Introduction

A method commonly recommended for relieving the tooth size–arch length discrepancy in the early mixed dentition is slow maxillary expansion with a quad-helix appliance, although this appliance has been routinely used as a treatment modality for the correction of posterior crossbites [1–6]. Previous studies showed that the expansion effects of the quad-helix treatment were greater than [1–3], or comparable with [4], those of the expansion plate treatment. Others evaluated the maxillary expansion effects of the quad-helix compared with the expansion plate and maxillary rapid expansion [5], and with Haas and hyrax appliances [6], and found no differences among the three types of expanders. Most of these studies did not use control groups or adequate sample sizes, and disregarded measurement bias and errors and sex differences, thus implying a low quality with high risk of achieving insignificant outcomes [7].

Previous studies reported that the quad-helix treatment caused the maxillary first molars to be tipped buccally [2, 3, 5–7] and rotated mesiobuccally [1, 6], which was not the primary intent of the expansion protocol. There are no studies investigating the treatment effects of a quad-helix appliance on molar rotation and sagittal molar relationship in detail.

It has been reported that a significantly spontaneous increase in mandibular arch width could be achieved after rapid maxillary expansion and subsequent orthodontic treatment [8]. Hermanson et al. [1] reported that a slight increase in mandibular intermolar width was noted after maxillary expansion with a quad-helix appliance. Some researchers found that the quad-helix group made no significantly spontaneous expansion of the mandibular intercanine or intermolar widths compared with the expansion plate group [2, 4, 5] or the control group [3]. To our knowledge, there have been few reports, which investigated in detail the changes in mandibular arch width under the influence of maxillary expansion with the quad-helix appliance. The purpose of this study was to evaluate the effect of maxillary expansion with the quad-helix treatment on the mandibular arch widths in patients in comparison with changes in occlusal relationships in untreated patients, who comprised the control group in this study.

Materials and methods

The subjects assigned to the treatment group were 50 consecutive, nonrandomized patients (20 boys and 30 girls), who had been treated for maxillary incisor crowding with a quad-helix appliance at the orthodontic clinic in the Nippon Dental University Hospital (Niigata, Japan). The patients were adopted regardless of treatment outcomes. The materials were lateral cephalograms and dental casts obtained at the start (T0) and end (T1) of the quad-helix treatment. The changes that occurred during the T0–T1 period were compared with those that occurred during the corresponding period in a control group of patients, who had not undergone any orthodontic treatment but were placed under observation. Observation of the control group patients was made once in 2 or 3 months, without any orthodontic appliances during the T0–T1 period. The control group consisted of 50 consecutive, nonrandomized patients (20 boys and 30 girls). The two groups were also well matched with respect to mean ages at T0 and T1. All cephalograms and dental casts were coded by a person who was not directly involved in this study. The selection criteria in the treatment and control groups were: (1) moderate maxillary incisor crowding (<3 mm) with positive overjet and overbite, (2) fully erupted first molars and incisors, (3) presence of deciduous second molars at T0, (4) fully erupted first premolars at T1, (5) 2 consecutive good-quality lateral cephalograms and dental casts, (6) no tooth agenesis excluding third molars, (7) no extraction of permanent teeth during treatment/observation, (8) no restorations, and (9) no previous orthodontic or prosthodontic treatments. The subjects in the treatment and control groups were selected retrospectively. Table 1 shows the mean ages at T0 and T1 and the mean treatment/observation time (T1–T0). As shown in Table 2, a two-way analysis of variance (ANOVA) did not find any significant differences in the mean ages at T0 and T1 and in the mean treatment/observation time between sexes or between groups, or significant interactions between two variables.

Table 1 Mean ages at the start (T0) and end (T1) of treatment/observation, and mean treatment/observation time (T1–T0)

	Treatment group				Control group			
	Boys ($n = 20$)		Girls ($n = 30$)		Boys ($n = 20$)		Girls ($n = 30$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age at the start of treatment/observation (T0)	9y5mo	1y6mo	9y6mo	1y7mo	9y7mo	1y5mo	9y	1y4mo
Age at the end of treatment/observation (T1)	10y7mo	1y6mo	10y10mo	1y4mo	11y1mo	1y	10y4mo	1y4mo
Treatment/observation time (T1–T0)	1y2mo	7mo	1y4mo	9mo	1y6mo	8mo	1y4mo	9mo

SD standard deviation

Table 2 Results of two-way ANOVA for comparisons of mean ages at T0 and T1, and mean treatment/observation time (T1–T0)

	Source	*F* value	*P* value	Power
Age at T0	Sexes	0.421	0.518 NS	0.098
	Groups	0.285	0.594 NS	0.083
	Interaction	1.204	0.275 NS	0.192
Age at T1	Sexes	0.898	0.346 NS	0.155
	Groups	0.001	0.971 NS	0.050
	Interaction	3.248	0.075 NS	0.430
Treatment/observation time (T1–T0)	Sexes	0.187	0.666 NS	0.071
	Groups	0.998	0.320 NS	0.167
	Interaction	1.200	0.276 NS	0.192

NS not significant

The quad-helix appliance used in this study was made of 0.8-mm stainless steel wire soldered to maxillary first molar bands and its lingual arms were extended mesially to the deciduous canines. It was activated primarily to correct the distobuccal rotation of the maxillary first molars and then expand the maxillary first molars and posterior teeth in that order. Prior to cementation, the molar bands were kept parallel to each other and the lingual arms were kept apart from the lingual surfaces of the posterior teeth for correcting molar rotation and torque and expanding the first molars. During treatment, the patients visited us once a month and further activation was performed on the lingual arms and lateral bridges with a pair of three-jawed pliers intraorally and sometimes extraorally. Following the correction of molar rotation, the lingual arms were kept in touch with the lingual surfaces of the posterior teeth for expansion. After adequately relieving the arch length discrepancy, the quad-helix appliance was used as a retention appliance, and then removed at T1.

To avoid measurement bias, a single investigator (I.S.) measured the coded cephalograms and dental casts blindly to group, sex and time of taking them (at T0 and T1). Afterward, the results of the measurements were sorted by these parameters for statistical comparisons.

Cephalometric measurement

All cephalograms were taken with the same cephalostat and with the standardized settings. Each coded lateral cephalogram was traced and measured. Fourteen reference points, and seven angular and four linear measurements were selected to determine changes in dentofacial morphology (Table 3; Fig. 1). The angular measurements were made to the nearest 0.1° using a computer system including a WinCeph analysis software program (Rise Corp, Japan) or a protractor, and the linear measurements were made to the nearest 0.1 mm using a pair of digital sliding calipers.

Cast measurement

Six linear measurements were made on each coded cast to the nearest 0.1 mm using a pair of digital sliding calipers to determine changes in dental arch widths (Table 3). In twenty-three (10 boys and 13 girls) of 50 treated subjects and 26 (10 boys and 16 girls) of 50 controls, four deciduous first molars and four first premolars existed at T1 and T2, respectively. Therefore, the distances between the central pits of the deciduous first molars (CDW) and between the mesial pits of the first premolars (MPW) were measured on the casts of 23 and 26 subjects in the treatment and control groups, respectively, and the statistical comparisons of the differences between CDW and MPW were made to evaluate the changes in dental arch width in the premolar region.

The occlusal relationship between the maxillary and mandibular first molars was evaluated at T0 and T1 according to Angle's classification of malocclusion in the treatment and control groups.

Statistical analysis

Statistical analyses were performed with a commercially available statistical package (SPSS, Ver17). Means and standard deviations were calculated for each cephalometric and cast measurement in each sex and each group. As shown in Tables 4, 5, 6 and 7, unpaired *t* tests revealed no significant differences in any measurements at T0 (S1) or in any changes in measurements during treatment/observation (S4) between sexes in each group. Therefore, all subjects were merged for the rest of the analyses.

Unpaired t tests were used to test for the significance of differences in measurements at T0 and treatment changes (T1–T0) between the treatment and control groups. Paired t tests were used to determine the significance of differences in measurements between T0 and T1 in each group. Pearson's correlation analysis was used to investigate the relationships between the mandibular arch width changes and other measurement changes, which showed significant treatment changes between the two groups.

Measurement error

To assess measurement errors, 60 cephalograms and 60 pairs of dental casts were randomly selected and remeasured by the same examiner (I.S.) for a second time 1 month later. Student's *t* test with a 95% confidence interval did not reveal any systematic errors. Random errors, determined by calculating the standard deviations of the differences between the first and second measurements, were less than 0.37 mm and less than 0.66° for the cephalometric measurements, and less than 0.61 mm for the cast measurements, which were unlikely to affect the significant results in this study.

Results

There were no significant differences in any measurements at T0 or in any changes in measurements during the T1–T0 period between sexes in each group (Tables 4, 5, 6, 7).

Of all the cephalometric and cast measurements, the U6-PP distance, and the U6-PP and L6-Mp angles showed significant differences at T0 between the two groups (Tables 8, 9; S1).

Table 3 Definition of reference points and measurements used

	Definition
Cephalometric reference points	
S	Sella turcica, midpoint of sella turcica
N	Nasion, intersection of the internasal suture and nasofrontal suture in the midsagittal plane
ANS	Anterior nasal spine, tip of the anterior nasal spine seen from norma lateralis
PNS	Posterior nasal spine, tip of the posterior spine of palatine bone in the hard palate
A	Point A, deepest midline point on the premaxilla between the anterior nasal spine and prosthion
B	Point B, most posterior point in the concavity between the infradentale and pogonion
Me	Menton, lowermost point on the symphyseal shadow as seen in the norma lateralis
Ar	Articulare, intersection of the dorsal contours of the mandibular process and temporal bone
Go	Gonion, intersection of the mandibular plane and the ramus plane
Or	Orbitale, lowest point on the lower margin of the bony orbit
Po	Porion, midpoint on the upper edge of the porus acusticus externus
Pt	Pterygoid point, intersection of the foramen rotundum and the pterygomaxillary fissure
U6	Upper 6, the cementoenamel junction on the longitudinal axis of the maxillary first molar
L6	Lower 6, the cementoenamel junction on the longitudinal axis of the mandibular first molar
Cephalometric measurements	
SNA (°)	Prognathism of the maxillary alveolar bone, the angle between the anterior cranial base (SN plane) and the NA plane
SNB (°)	Prognathism of the mandibular alveolar bone, the angle between the anterior cranial base (SN plane) and the NB plane
PP-SN (°)	Palatal plane angle, the angle between the palatal plane (PP, constructed from ANS to PNS) and the anterior cranial base (SN plane)
PP-MP (°)	Mandibular plane angle, the angle between the palatal plane (PP) and the mandibular plane (MP)
Bjork's summation angle (°)	The sum of the saddle angle (NSAr), the articular angle (SArGo) and the gonial angle (ArGoMe)
U6-PTV (mm)	The distance from U6 to the pterygoid vertical (PTV)
U6-PP (mm)	The distance from U6 to the palatal plane (PP)
U6-PP (°)	The angle between the longitudinal axis of the maxillary first molar and the palatal plane (PP)
L6-PTV (mm)	The distance from L6 to the pterygoid vertical (PTV)
L6-MP (mm)	The distance from U6 to the mandibular plane (MP)
L6-MP (°)	The angle between the longitudinal axis of the mandibular first molar and the mandibular plane (MP)
Cast measurements	
CDW (mm)	Central interdeciduous molar width, the distance between the central pits of the deciduous first molars
MPW (mm)	Mesial interpremolar width, the distance between the mesial pits of the fist premolars
LMW (mm)	Lingual intermolar width, the distance between the central lingual grooves of the fist molars
CMW (mm)	Central intermolar width, the distance between the central fossae of the fist molars
MMW (mm)	Mesial intermolar width, the distance between the summits of the mesiobuccal (mesiolingual) cusp of the maxillary (mandibular) first molars
DMW (mm)	Distal intermolar width, the distance between the summits of the distobuccal (distolingual) cusp of the maxillary (mandibular) first molars

Cephalometric measurement

The SNB angle and the U6-PP, L6-PTV and L6-Mp dimensions significantly increased, and the L6-Mp angle significantly decreased during the treatment/observation period in both groups (Table 8; S2, S3). The SNA and U6-PP angles and the U6-PTV dimension significantly increased during the period under observation in the control group (Table 8; S3).

The U6-PTV dimension and the U6-PP angle showed significantly different changes between the two groups (Table 8; S4).

Cast measurement

With regard to the measurements in the maxillary region, the LMW, MMW and DMW dimensions in both groups and the MPW–CDW and CMW dimensions in the treatment group significantly increased during the treatment/observation period (Table 9; S2, S3). As for the mandible, all measurements showed significant increase in the treatment group, while significant decrease in MPW–CDW dimension and significant increase in CMW and DMW dimensions were found in the control group (Table 9; S2, S3).

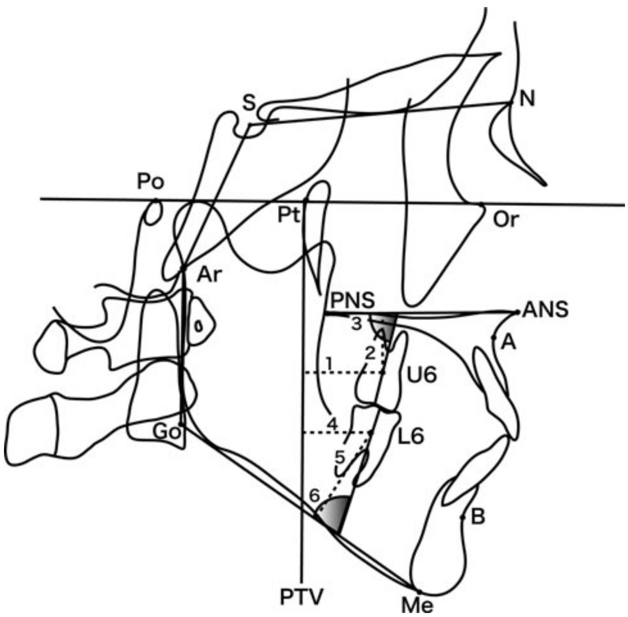

Fig. 1 Reference points and dental measurements used. *1* U6-PTV (mm), *2* U6-PP (mm), *3* U6-PP (°), *4* L6-PTV (mm), *5* L6-MP (mm), *6* L6-MP (°)

All measurements in both maxilla and mandible showed significantly different changes between the two groups (Table 9; S4).

Correlation analysis

The changes in the mandibular LMW, CMW and MMW dimensions had significantly positive correlations with those in the maxillary MPW–CDW, CMW and DMW dimensions. Moreover, the change in the mandibular LMW dimension had significantly positive correlations with the changes in the U6-PP angle and maxillary LMW dimension. The change in the mandibular DMW dimension had significantly positive correlations with the changes in the U6-PP angle, and maxillary MPW–CDW and DMW dimensions (Table 10).

Angle's classification

A few subjects in Class I and Class III groups moved into different molar relationship groups in each treatment and control group. Sixty-three percent and 17% of subjects in Class II moved into the Class I group in the treatment and control groups, respectively (Table 11).

Table 11 shows significant differences in the distribution of subjects with different molar relationship groups between the treatment group at T0 and T1, and between the treatment group at T1 and the control group at T0, thus indicating that the treated subjects had a well-matched molar relationship to the control subjects at T0, and some

Table 4 Results of cephalometric measurements for each sex and statistical comparisons between sexes in the treatment group

	Boys ($n = 20$)						Girls ($n = 30$)						S1	S4
	T0		T1		T1–T0		T0		T1		T1–T0			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value
Skeletal measurement														
SNA (°)	81.80	3.97	81.96	4.46	0.17	2.02	81.88	4.35	82.39	3.81	0.51	2.95	0.936 NS	0.661 NS
SNB (°)	78.10	3.68	78.31	3.52	0.16	2.02	77.39	3.94	78.56	3.53	1.17	2.09	0.498 NS	0.097 NS
PP-SN (°)	8.77	3.14	8.61	3.53	−0.16	2.61	9.07	3.77	9.00	4.96	−0.08	2.92	0.767 NS	0.914 NS
PP-Md (°)	28.60	5.08	28.36	6.25	−0.25	5.61	28.63	4.51	27.57	5.17	−1.07	2.72	0.981 NS	0.492 NS
Bjork's summation angle (°)	396.40	5.22	395.80	6.33	−0.60	5.26	395.73	7.96	395.90	5.63	0.17	6.88	0.743 NS	0.675 NS
Dental measurement														
U6-PTV (mm)	19.30	3.13	19.13	2.80	−0.18	3.30	19.37	3.54	19.13	2.66	−0.23	2.67	0.946 NS	0.945 NS
U6-PP (mm)	10.85	3.46	12.48	2.45	1.63	2.96	12.00	2.42	14.17	3.90	2.17	2.96	0.172 NS	0.529 NS
U6-PP (°)	76.18	6.73	74.48	4.83	−1.70	8.38	75.30	4.92	75.13	4.97	−0.17	4.17	0.598 NS	0.456 NS
L6-PTV (mm)	14.25	3.91	16.68	4.56	2.43	3.18	15.80	4.60	17.83	3.70	2.03	3.39	0.222 NS	0.683 NS
L6-Mp (mm)	23.53	2.46	24.43	2.49	0.90	2.13	24.40	3.21	26.20	3.63	1.80	3.49	0.307 NS	0.308 NS
L6-Mp (°)	79.20	7.04	76.48	5.25	−2.73	9.21	80.40	5.57	78.77	6.05	−1.63	5.01	0.506 NS	0.632 NS

NS not significant, *S1* statistical comparison at T0 between sexes, *S4* statistical comparison of treatment change (T1–T0) between sexes

Table 5 Results of cephalometric measurements for each sex and statistical comparisons between sexes in the control group

	Boys ($n = 20$)						Girls ($n = 30$)						S1	S4
	T0		T1		T1–T0		T0		T1		T1–T0			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value
Skeletal measurement														
SNA (°)	81.70	2.65	82.58	2.74	0.87	2.67	80.97	3.53	81.65	3.67	0.68	2.47	0.436 NS	0.791 NS
SNB (°)	77.15	2.78	78.58	2.69	1.43	1.90	75.69	3.99	76.96	4.42	1.27	2.56	0.162 NS	0.819 NS
PP-SN (°)	7.96	2.82	8.35	2.51	0.39	2.23	8.61	3.15	8.47	3.32	−0.14	2.02	0.462 NS	0.390 NS
PP-Md (°)	28.38	3.14	27.48	3.70	−0.90	2.82	27.97	5.81	27.83	5.94	−0.13	3.38	0.775 NS	0.407 NS
Bjork's summation angle (°)	396.20	4.05	395.88	4.80	−0.32	2.64	396.50	5.89	395.97	6.77	−0.53	2.74	0.844 NS	0.790 NS
Dental measurement														
U6-PTV (mm)	18.78	2.23	21.45	3.30	2.68	2.88	17.53	2.60	20.37	3.10	2.83	3.43	0.086 NS	0.866 NS
U6-PP (mm)	10.20	2.38	12.18	2.67	1.98	2.85	9.63	2.53	11.70	2.49	2.07	3.64	0.430 NS	0.925 NS
U6-PP (°)	73.55	4.87	76.65	6.03	3.10	5.10	70.95	5.13	74.30	6.30	3.35	5.15	0.080 NS	0.867 NS
L6-PTV (mm)	15.08	3.93	18.40	4.58	3.33	4.63	13.40	2.19	16.40	4.45	3.00	3.94	0.094 NS	0.791 NS
L6-Mp (mm)	23.95	3.15	26.58	3.60	2.63	2.63	23.80	2.22	25.30	2.38	1.50	2.45	0.844 NS	0.129 NS
L6-Mp (°)	83.33	5.39	82.08	6.62	−1.25	5.49	85.77	6.74	84.00	7.11	−1.77	5.35	0.182 NS	0.742 NS

NS not significant, *S1* statistical comparison at T0 between sexes, *S4* statistical comparison of treatment change (T1–T0) between sexes

Table 6 Results of cast measurements for each sex and statistical comparisons between sexes in the treatment group

	Boys						Girls						S1	S4
	T0		T1		T1–T0		T0		T1		T1–T0			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value
Maxilla														
CDW (mm)	36.84	1.89	–	–	2.25	2.09	35.31	2.32	–	–	3.15	1.72	0.103 NS	0.267 NS
MPW (mm)	–	–	31.10	0.39			–	–	38.46	2.17			0.502 (at T1) NS	
LMW (mm)	35.68	2.90	38.90	3.10	3.22	1.89	34.84	2.60	38.53	2.90	3.69	2.00	0.287 NS	0.402 NS
CMW (mm)	47.09	3.18	50.23	2.84	3.14	2.19	45.76	2.64	49.20	2.54	3.44	1.72	0.115 NS	0.586 NS
MMW (mm)	52.69	3.49	56.60	3.61	3.91	3.63	51.44	2.76	56.33	2.64	4.90	1.86	0.165 NS	0.273 NS
DMW (mm)	55.51	3.02	58.36	2.96	2.85	2.16	54.05	2.62	56.80	2.60	2.75	1.44	0.076 NS	0.843 NS
Mandible														
CDW (mm)	31.10	0.39	–	–	1.38	2.94	30.93	1.96	–	–	0.71	1.61	0.765 NS	0.495 NS
MPW (mm)	–	–	32.47	3.03	–	–	–	–	31.64	2.19			0.450 (at T1) NS	
LMW (mm)	34.32	2.59	35.86	2.47	1.55	1.73	33.95	2.19	35.31	2.37	1.36	0.99	0.588 NS	0.633 NS
CMW (mm)	42.20	2.95	44.53	2.37	2.33	2.17	41.53	2.21	43.40	2.23	1.87	0.66	0.361 NS	0.369 NS
MMW (mm)	35.48	3.39	37.48	2.66	2.00	2.67	34.80	2.18	36.60	2.18	1.80	1.07	0.434 NS	0.757 NS
DMW (mm)	36.93	3.39	39.25	2.76	2.32	2.46	36.27	2.49	38.06	2.44	1.78	0.81	0.463 NS	0.355 NS

NS not significant, *S1* statistical comparison at T0 between sexes, *S4* statistical comparison of treatment change (T1–T0) between sexes

subjects attained Class I from Class II and III molar relationships after the quad-helix treatment.

Discussion

Our results showing no significant sex differences in any cephalometric or cast measurements at T0 in each group were supported by Broadbent et al. [9], who stated that sex differences were mainly an expression of secondary sexual characteristics, which occurred after puberty and during the adolescent years. No isolated subjects according to sex were used in several studies on the effects of maxillary expanders on transverse dentofacial structure [1–5, 8]. This might have been due to the small sample size of either sex or in conformity with the statement by Broadbent et al. [9],

Table 7 Results of cast measurements for each sex and statistical comparisons between sexes in the control group

	Boys						Girls						S1	S4
	T0		T1		T1–T0		T0		T1		T1–T0			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value
Maxilla														
CDW (mm)	37.23	2.27			0.06	1.63	35.70	2.52			−0.22	3.10	0.130 NS	0.796 NS
MPW (mm)			37.30	2.96					35.48	2.93			0.139 (at T1) NS	
LMW (mm)	36.57	2.23	36.94	2.36	0.37	0.88	35.39	2.36	36.65	4.62	1.26	3.43	0.083 NS	0.261 NS
CMW (mm)	47.55	2.19	48.24	2.68	0.69	1.05	46.48	2.16	46.67	2.83	0.19	2.32	0.093 NS	0.374 NS
MMW (mm)	53.28	2.67	54.22	2.90	0.94	1.11	52.02	2.29	52.40	2.44	0.38	1.50	0.081 NS	0.161 NS
DMW (mm)	55.65	2.31	56.03	2.59	0.38	1.01	54.48	2.03	55.03	2.17	0.55	1.02	0.065 NS	0.550 NS
Mandible														
CDW (mm)	31.32	3.00			−0.52	1.02	30.92	2.03			−1.19	1.91	0.685 NS	0.317 NS
MPW (mm)			30.80	3.12					29.73	1.66			0.260 (at T1) NS	
LMW (mm)	34.67	2.09	35.02	2.24	0.34	0.74	33.86	1.73	34.00	1.86	0.14	1.00	0.141 NS	0.450 NS
CMW (mm)	41.91	3.01	42.65	2.30	0.73	2.21	41.34	1.72	41.74	2.04	0.40	1.06	0.397 NS	0.480 NS
MMW (mm)	35.59	2.12	35.66	2.38	0.07	0.85	34.66	1.86	34.84	2.11	0.18	1.22	0.106 NS	0.706 NS
DMW (mm)	37.04	2.25	37.35	2.36	0.32	1.15	36.24	2.12	36.61	2.09	0.37	0.95	0.209 NS	0.847 NS

NS not significant, *S1* statistical comparison at T0 between sexes, *S4* statistical comparison of treatment change (T1–T0) between sexes

that there is no gender difference in maxillofacial morphology before the secondary sex characteristics appear. Bashara et al. [10] showed that males were significantly larger than females in both maxillary and mandibular arch widths from 3 to 45 years of age, which was inconsistent with our results. Our findings that there were no significant differences in any changes in cephalometric or cast measurements between sexes in the treatment group may validate proper and equivalent activation of the quad-helix appliance to each subject.

In our cephalometric measurements, the actual treatment changes after the quad-helix treatment were found in the U6-PTV dimension and the U6-PP angle because of significant differences between the treatment and control groups, which showed that the maxillary first molars moved posteriorly and retroclined in the treatment group, but moved anteriorly and tipped mesially in the control group. Our results showing the retrusion and retroclination of the maxillary first molars were inconsistent with those by Crozza et al. [11] who reported that there were no significant changes in the horizontal and vertical dimensions of the maxillary and mandibular first molars in the quad-helix group using lateral cephalograms, compared with untreated controls. The reason for the contrary results might be due to the fact that the quad-helix with a crib used in their study was different from ours. Another possible reason may be due to different activation of the quad-helix appliance. In our study, prior to cementation, the molar bands were kept parallel to each other and the lingual arms were kept apart from the lingual surfaces of the posterior teeth so that the correction for rotation, torque and expansion of the maxillary first molars were made before other posterior teeth were expanded, thus resulting in the retrusion and retroclination of the maxillary first molars. On the other hand, in the studies by Crozza et al. [11] and other researchers [1–4], the quad-helix was expanded before cementation by 3–10 mm or one-half of the buccopalatal molar width, keeping the lingual arms parallel to one another, without activation for rotation or torque of the maxillary first molars.

Our results showed that increases in all maxillary arch widths were actually significant treatment changes in the treatment group, which were only to be expected. Parts of these results were consistent with those of previous studies [1, 2, 5, 6], in that the maxillary interpremolar and intermolar widths significantly increased with the quad-helix treatment, although there was no control group of untreated subjects in those studies. Erdinc et al. [3] demonstrated the actual treatment increases in the maxillary intercanine and intermolar widths as a result of the quad-helix treatment using the controls. These findings were in accordance with our study.

In the treatment and control groups, the increases in the mean maxillary LMW (3.5 and 0.91 mm, respectively) were larger than those in the mean maxillary CMW (3.32 and 0.39 mm, respectively). However, there were insignificant differences in the CMW–LMW dimension between the two groups ($P = 0.601$), thus indicating that the quad-helix treatment, as well as growth, caused lingual crown

Table 8 Results of cephalometric measurements for combined sexes and statistical comparisons between the treatment and control groups

	Treatment group ($n = 50$)						Control group ($n = 50$)						S1	S2	S3	S4
	T0		T1		T1–T0		T0		T1		T1–T0					
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value	*P* value	*P* value
Skeletal measurement																
SNA (°)	81.84	4.16	82.21	4.04	0.37	2.60	81.26	3.20	82.02	3.33	0.76	2.53	0.438 NS	0.317 NS	0.040*	0.458 NS
SNB (°)	77.69	3.82	78.46	3.49	0.76	2.10	76.27	3.60	77.60	3.87	1.33	2.30	0.059 NS	0.013*	0.000***	0.198 NS
PP-SN (°)	8.95	3.50	8.84	4.41	−0.11	2.78	8.35	3.01	8.42	3.00	0.07	2.10	0.357 NS	0.777 NS	0.804 NS	0.706 NS
PP-Md (°)	28.62	4.69	27.88	5.57	−0.74	4.09	28.13	4.89	27.69	5.12	−0.44	3.16	0.610 NS	0.208 NS	0.330 NS	0.685 NS
Bjork's summation angle (°)	396.00	6.94	395.86	5.86	−0.14	6.24	396.38	5.19	395.93	6.01	−0.45	2.67	0.757 NS	0.875 NS	0.239 NS	0.488 NS
Dental measurement																
U6-PTV (mm)	19.34	3.35	19.13	2.69	−0.21	2.91	18.03	2.51	20.80	3.19	2.77	3.20	0.359 NS	0.612 NS	0.000***	0.000***
U6-PP (mm)	11.54	2.90	13.49	3.46	1.95	2.94	9.86	2.46	11.89	2.55	2.03	3.31	0.002**	0.000***	0.000***	0.899 NS
U6-PP (°)	75.65	5.66	74.87	4.87	−0.78	6.17	71.99	5.14	75.24	6.24	3.25	5.08	0.034*	0.376 NS	0.000***	0.018*
L6-PTV (mm)	15.18	4.36	17.37	4.06	2.19	3.28	14.07	3.08	17.20	4.56	3.13	4.19	0.145 NS	0.000***	0.000***	0.214 NS
L6-Mp (mm)	24.05	2.94	25.49	3.31	1.44	3.03	23.86	2.60	25.81	2.96	1.95	2.56	0.733 NS	0.001***	0.000***	0.365 NS
L6-Mp (°)	79.92	6.16	77.85	5.80	−2.07	6.93	84.79	6.29	83.23	6.92	−1.56	5.35	0.000***	0.040*	0.045*	0.681 NS

NS not significant, *S1* statistical comparison at T0 between the treatment and control groups, *S2* statistical comparison of treatment change (T1–T0) in the treatment group, *S3* statistical comparison of change (T1–T0) in the control group, *S4* statistical comparison of change (T1–T0) between the treatment and control groups

* <0.05, ** <0.01, *** <0.001

Table 9 Results of cast measurements for combined sexes and statistical comparisons between the treatment and control groups

	Treatment group						Control group						S1	S2	S3	S4
	T0		T1		T1–T0		T0		T1		T1–T0					
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value	*P* value	*P* value	*P* value
Maxilla																
CDW (mm)	35.97	2.24			2.76	1.90	36.29	2.50			−0.11	2.60	0.647 NS	0.000***	0.833 NS	0.000***
MPW (mm)			38.73	2.18					36.18	3.02						
LMW (mm)	35.18	2.73	38.68	2.96	3.50	1.95	35.86	2.36	36.77	3.85	0.91	2.73	0.181 NS	0.000***	0.023*	0.000***
CMW (mm)	46.29	2.91	49.61	2.68	3.32	1.90	46.91	2.22	47.30	2.85	0.39	1.92	0.239 NS	0.000***	0.156 NS	0.000***
MMW (mm)	51.94	3.10	56.44	3.03	4.50	2.72	52.52	2.50	53.13	2.76	0.60	1.37	0.302 NS	0.000***	0.003**	0.000***
DMW (mm)	54.64	2.85	57.43	2.83	2.79	1.74	54.95	2.20	55.43	2.37	0.48	1.01	0.546 NS	0.000***	0.001***	0.000***
Mandible																
CDW (mm)	31.00	1.47			1.00	2.25	31.07	2.40			−0.93	1.64	0.894 NS	0.044*	0.007**	0.001***
MPW (mm)			32.00	2.56					30.14	2.33						
LMW (mm)	34.09	2.34	35.53	2.40	1.44	1.32	34.19	1.90	34.41	2.06	0.22	0.90	0.827 NS	0.000***	0.088 NS	0.000***
CMW (mm)	41.80	2.52	43.85	2.33	2.05	1.46	41.57	2.31	42.11	2.17	0.54	1.61	0.640 NS	0.000***	0.023*	0.000***
MMW (mm)	35.07	2.72	36.95	2.40	1.88	1.86	35.03	2.00	35.17	2.24	0.14	1.08	0.933 NS	0.000***	0.375 NS	0.000***
DMW (mm)	36.54	2.87	38.54	2.61	2.00	1.68	36.56	2.19	36.91	2.21	0.35	1.03	0.965 NS	0.000***	0.019*	0.000***

NS not significant, *S1* statistical comparison at T0 between the treatment and control groups, *S2* statistical comparison of treatment change (T1–T0) in the treatment group, *S3* statistical comparison of change (T1–T0) in the control group, *S4* statistical comparison of change (T1–T0) between the treatment and control groups

* <0.05, ** <0.01, *** <0.001

Table 10 Results of Pearson correlation coefficients for treatment change in the treatment group

	Cephalometric measurement		Cast measurement (maxilla)				
	U6-PTV (mm)	U6-PP (°)	MPW–CDW (mm)	LMW (mm)	CMW (mm)	MMW (mm)	DMW (mm)
Cast measurement (mandible)							
MPW–CDW (mm)	0.031	0.308	0.381	0.138	0.340	−0.274	0.350
LMW (mm)	0.230	0.316*	0.606**	0.307*	0.418**	−0.174	0.442***
CMW (mm)	0.217	0.145	0.606**	0.211	0.336*	−0.182	0.354*
MMW (mm)	0.247	0.243	0.574**	0.276	0.416**	−0.077	0.432**
DMW (mm)	0.199	0.307*	0.518 *	0.155	0.269	−0.168	0.351*

NS not significant

* <0.05, ** <0.01, *** <0.001

tipping of the maxillary first molars. These results were contrary to those of previous studies [2, 3, 5–7], in that the buccal crown tipping of the maxillary first molars was observed after the quad-helix treatment. It has been reported that the buccal tipping of the maxillary first molars causes the downward and backward rotations of the mandible after maxillary expansion with the quad-helix appliance [12]. Our results suggested that the lingual crown tipping of the maxillary first molars might not cause the rotation of the mandible as evidenced by our cephalometric skeletal measurements.

The mean value given by subtracting the DMW from the MMW was significantly larger in the treatment group (1.71 mm) than in the control group (0.12 mm), and a significant difference was noted between the two groups ($P = 0.000$). This fact suggested a more significant degree of the mesiobuccal rotation of the maxillary first molars after the quad-helix treatment. Hermanson et al. [1] reported that a tendency toward the mesial rotation of the maxillary first molars was found as a result of the quad-helix treatment. The mesiobuccal rotation and retrusion of the maxillary first molars could change the occlusal relationships from Class II to Class I, as evidenced by our results that 63% of Class II subjects moved into the Class I in the treatment group (Table 11). These lingual tipping and mesiobuccal rotation of the maxillary first molars could be attributed to the activation of the quad-helix appliance, as mentioned above.

Table 11 Distribution of subjects with Class I, Class II and Class III molar relationships at T0 and T1

	Class I	Class II	Class III	Class I	Class II	Class III	Class I	Class II	Class III	Statistical comparisons	
										Kruskal–Wallis test/*P* value	
Treatment group (TG)											
Number of subjects at T0	13 (26.0)	–	–	–	30 (60.0)	–	–	–	7 (14.0)	0.005**	
Change in number of subjects from T0 to T1	11 (84.6)	1 (7.7)	1 (7.7)	19 (63.3)	11 (36.7)	0 (0.0)	2 (28.6)	0 (0.0)	5 (71.4)	Steel–Dwass test/significant comparison/*P* value	
										TG at T0 vs. TG at T1	0.008**
Number of subjects at T1	32 (64.0)	–	–	–	12 (24.0)	–	–	–	6 (12.0)	TG at T1 vs. CG at T0	0.030*
Control group (CG)											
Number of subjects at T0	15 (30.0)	–	–	–	30 (60.0)	–	–	–	5 (10.0)		
Change in number of subjects from T0 to T1	13 (86.7)	1 (6.7)	1 (6.7)	5 (16.7)	25 (83.3)	0 (0.0)	1 (20.0)	0 (0.0)	4 (80.0)		
Number of subjects at T1	19 (38.0)	–	–	–	26 (52.0)	–	–	–	5 (10.0)		

Percentage in parentheses

* <0.05, ** <0.01

Our results showed that the quad-helix treatment actually increased the interpremolar and intermolar widths in the mandibular dentition. These results were inconsistent with those of Erdinc et al. [3], who reported that the quad-helix group achieved no significantly spontaneous expansion of the mandibular intercanine or intermolar widths compared with the control group. Hermanson et al. [1], and Bell and LeCompte [13] reported that a slight increase in mandibular intermolar width was noted in association with the maxillary expansion with the quad-helix appliance. Our significant increase in mandibular width might be explained by altered occlusal force after maxillary expansion. This explanation could be warranted by our results of the correlation analyses (Table 10), which showed that the more the maxillary inter-first premolar and intermolar widths were expanded, and the less the maxillary first molars were inclined distally, the more the mandibular molar widths were expanded. Reported average amounts of expansion of the intermolar width varied: 0.3 mm [3], less than 0.9 mm [13], and 0.0 and 0.2 mm, [4], which were considerably smaller than our corresponding values (1.44–2.05 mm). The greater expansion of the intermolar width in our study could be due to differences in treatment time and activation of the quad-helix appliance. Our study had a longer mean treatment time of 12–14 months than previous studies [2–4, 13], in which the mean treatment time varied from 2.6 months [13] to 7.7 months [4].

In conclusion, the quad-helix treatment gives rise to spontaneous expansion of the mandibular arch concurrent with maxillary expansion in early mixed dentition patients with crowding.

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