

# Efficient palatal expansion with a quadhelix appliance: an *in vitro* study using an experimental dental arch model

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**SUMMARY** This study used an experimental dental arch model to examine the orthodontic forces generated by a quadhelix appliance in terms of parallel expansion, fan expansion, or a combination of the two. Strain gauges were attached to experimental brass rods that represented the teeth arranged in the shape of an average dental arch to detect forces in the buccal, lingual, mesial, and distal directions. Orthodontic forces generated by different types of activation were compared by Scheffe's multiple test.

The largest orthodontic force generated during parallel expansion was observed at the first molar in the buccal direction. When fan expansion was applied, significant orthodontic force was observed at the canine in the mesial and labial directions, whereas force in the mesial and lingual directions was noted at the first molar. When a combination of 3 mm parallel and 5 mm fan expansion was used, the forces generated at the canine and first and second premolar, and first molar were nearly equivalent. Depending on the type of malocclusion, the most appropriate expansion technique may be parallel or fan expansion or a combination of the two. When expanding the entire dental arch simultaneously, a combination of 3 mm parallel and 5 mm fan expansion may be the most suitable.

## Introduction

Lateral expansion is applied in subjects with maxillary dental arch constriction when orthopaedic and/or orthodontic alteration is required. The use of rapid or slow expansion depends on the case in question (Haas, 1961, 1965; Isaacson *et al.*, 1964; Zimring and Isaacson, 1965; Wertz, 1970; Işeri *et al.*, 1998). To produce slow expansion, parallel expansion and/or fan expansion can be applied, depending on whether the arch is narrow in the canine area or throughout the whole buccal segment. Kamogashira *et al.* (1983) measured the strains on a dry human skull when the maxillary dental arch was expanded, and reported differences in the two expansion techniques. When parallel expansion was used, large distortion was observed in the alveolar bone at the first molar; when fan expansion was applied, large distortion was observed at the canine.

Sandikçioğlu and Hazar (1997) and Hermanson *et al.* (1985) examined the dental and skeletal changes associated with the quadhelix appliance to determine the efficacy of possible expansions. However, their studies examined only the effects on the first molar or maxillary bone when parallel or fan expansion was applied separately. No studies have examined the effects of quadhelix expansion on individual teeth in the buccal segment. The present study used an experimental dental arch model with strain gauges to measure the amount and direction of orthodontic force generated on individual teeth in the buccal segment by a

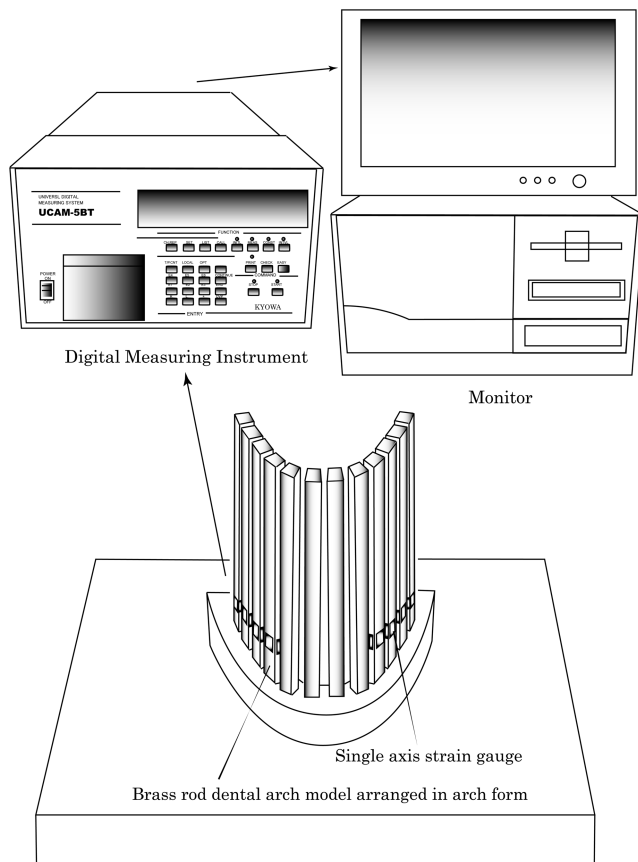
quadhelix appliance. Expansion amounts and techniques were then examined in an attempt to establish clinical guidelines.

## Materials and methods

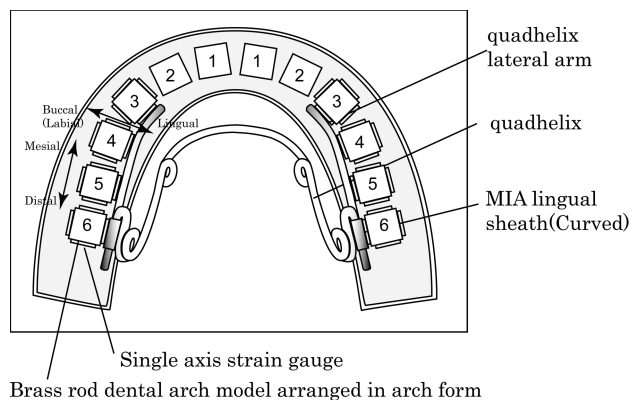
A quadhelix appliance (MIA; 3M Unitek, Tokyo, Japan) was used in this experiment. An experimental model was prepared using 5 × 5 mm rectangular brass rods. The brass rods represented the 12 teeth from the left first molar to the right first molar, as described by Noma (1988). Strain gauges (Kyowa Electronic Instruments Co. Ltd., Tokyo, Japan) were attached with the technical  $\alpha$ -cyanoacrylate instantaneous adhesives (CC-33A; Kyowa Electronic Instruments Co. Ltd.) to the surfaces of four of the rectangular brass rods.

The strain gauges were used to determine forces in the buccal, lingual, mesial, and distal directions (Figure 1). Lingual sheaths were attached 5 mm below the tip of the brass rods representing the first molars into which the quadhelix was inserted with its lateral arms bent to fit onto the canines (Figure 2).

For parallel expansion, the lateral arms were expanded parallel to the dental arch (Figure 3a), and for fan expansion, the points of the lateral arms were expanded, while the bases of the lateral arms were fixed (Figure 3b). The amount of parallel expansion was 3, 5, and 7 mm (6, 10, and 14 mm

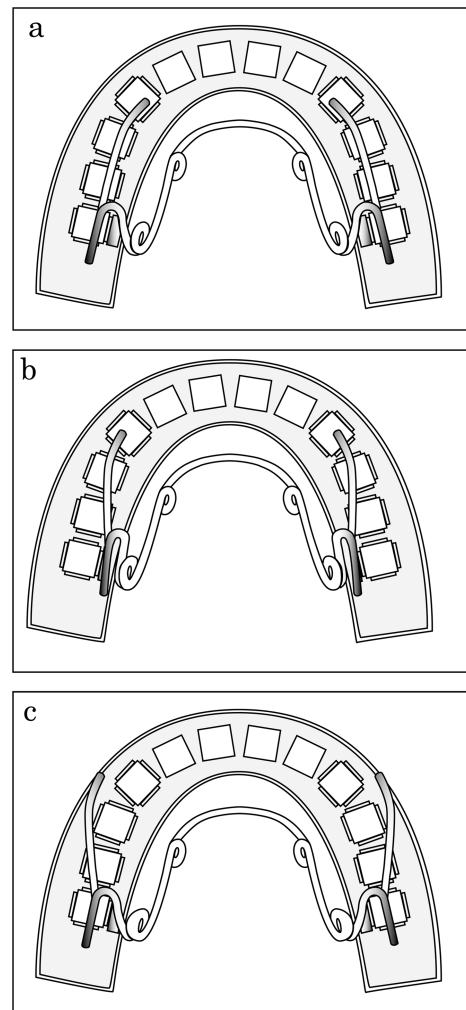


**Figure 1** Experimental model with strain gauge attached (frontal view).



**Figure 2** Experimental model with strain gauge attached (occlusal view).

in total bilaterally) and for fan expansion 3, 5, and 7 mm (6, 10, and 14 mm in total bilaterally) at the point of the lateral arm. Parallel and fan expansion were then combined (Figure 3c) as follows: 3 mm parallel expansion in combination with 3 mm fan expansion, 3 mm parallel expansion in combination with 5 mm fan expansion, 5 mm parallel expansion in combination with 3 mm fan expansion, and 5 mm parallel expansion in combination with 5 mm fan expansion. Although 7 mm parallel expansion in combination



**Figure 3** (a) Parallel expansion, (b) fan expansion, and (c) a combination of parallel and fan expansion with the quadhelix appliance.

with 7 mm fan expansion was attempted, permanent deformation of the quadhelix occurred when the appliance was inserted into the attachment. Therefore, the 7 mm combined expansion was eliminated.

Measurements were performed using a static strain measuring instrument (UCAM-5BT; Kyowa Electronic Instruments Co. Ltd.) and a scanner (USB-20A; Kyowa Electronic Instruments Co. Ltd.). The data were recorded on a personal computer (PC-9801; NEC, Tokyo, Japan) connected to the measuring instrument. Each measurement was performed five times, and the mean and standard deviations were calculated. Vector manifestations of each measurement were drawn to visualize the amount and direction of the orthodontic force, and differences in the orthodontic forces with each type of expansion were examined.

Scheffe's multiple test was employed to compare the forces using the Statistical Package for Social Science version 10 (SPSS Japan Inc., Tokyo, Japan).

## Results

As no significant differences were found between the mean values of the right and left sides, the data from the two sides were pooled for subsequent analyses.

With parallel expansion, the largest orthodontic force was consistently observed at the first molar in the buccal direction (Table 1, Figure 4a). As the amount of expansion increased, the force at the first molar increased and changed slightly to a distal direction. No significant orthodontic force was observed on the other teeth.

With fan expansion, significant orthodontic force was detected at the canine in the mesial and labial directions, whereas significant force at the first molar was observed in the mesial and lingual directions (Table 1, Figure 4b). The force increased with increased expansion.

When 3 mm parallel expansion in combination with 3 mm fan expansion was applied, orthodontic force was observed at the first molar in the buccal and distal directions; however, comparatively, little force was observed at the canine and premolars (Table 2, Figure 5a).

Forces at the first molar in the distal direction and at the canine in the mesial and labial directions were greater with 3 mm parallel expansion in combination with 5 mm fan expansion than with 3 mm parallel and 3 mm fan expansion when all teeth were subject to uniform orthodontic force (Table 2, Figure 5b). Compared with the force observed with parallel expansion, the force generated by 3 mm parallel expansion in combination with 5 mm fan expansion was significantly greater from the canine to the premolars and lower at the first molar in the buccal direction. Compared with fan expansion alone, the force was significantly greater at the first molar in the buccal and distal directions. When other combinations of expansion were applied, the orthodontic force at the premolars in the buccal direction was lower (Table 2, Figure 5a and 5b).

## Discussion

Many investigators have examined orthodontic force generated by a quadhelix appliance. In those studies, strain gauges (Kamogashira *et al.*, 1983), cephalograms (Frank and Engel, 1982; Majourau and Nanda, 1994), dental casts (Bell and LeCompte, 1981), pressure sensors (Fukui, 1998), the Instron testing machine (Urbaniak *et al.*, 1988), and theoretical (Jones and Waters, 1989a) and three-dimensional (Jones and Waters, 1989b) models have been used, and the therapeutic effects of the orthodontic force generated by quadhelix expansion have been reported.

Although the effects of a quadhelix appliance on orthodontic force at the first molar and alveolar bone have been demonstrated, the effects of the various expansion methods on individual teeth and in the buccal segment have not been studied. Furthermore, correct adjustment of the quadhelix to produce effective orthodontic force on each buccal tooth has not been investigated. To determine the most effective adjustment, the amount and direction of the orthodontic force generated by a quadhelix appliance at each individual tooth should be determined.

Jones and Waters (1989b) investigated three types of quadhelix formed of 1 mm diameter stainless steel wire and Size 1:  $H_1$  35 mm (inter mesiodistal helix distance),  $H_2$  15 mm (distance from distal helix to molar), and  $R$  2 mm (radius of helix loop); Size 2:  $H_1$  40 mm,  $H_2$  15 mm, and  $R$  2.5 mm; and Size 3:  $H_1$  25 mm,  $H_2$  5 mm, and  $R$  2 mm.

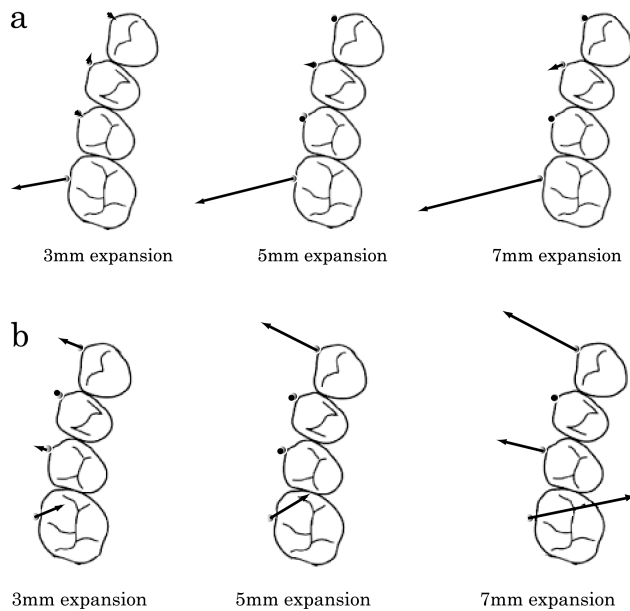
In this study, a ready-made quadhelix was used as measurement error would be reduced. The appliance was formed of 0.9 mm diameter stainless steel wire and  $H_1$  20 mm,  $H_2$  7 mm, and  $R$  2 mm, which was similar to Size 3 in the study by Jones and Waters (1989b). When 3, 5, and 7 mm of parallel expansion was applied, the largest orthodontic force detected at the first molar was  $120 \times 10^{-2}$  N (125 g) to  $268.4 \times 10^{-2}$  N (279 g) in the present study.

**Table 1** Orthodontic force generated by parallel and fan expansion.

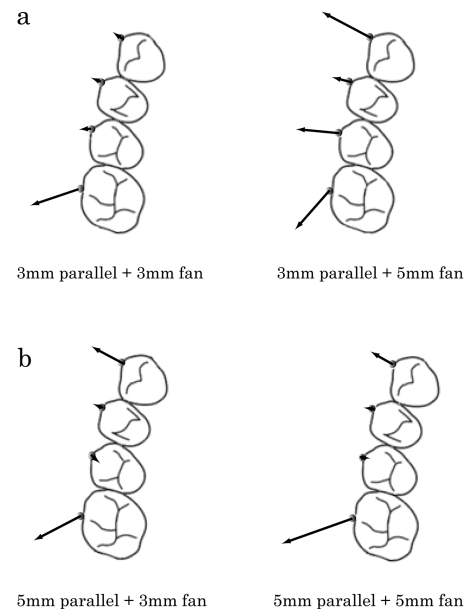
	Parallel expansion			Fan expansion		
	3 mm, mean (SD)	5 mm, mean (SD)	7 mm, mean (SD)	3 mm, mean (SD)	5 mm, mean (SD)	7 mm, mean (SD)
Mesiodistal						
Canine	0.0 (0.00)	-0.4 (0.35)	-1.1 (0.74)	3.2 (1.55)	5.7 (2.56)	4.7 (2.20)
First premolar	12.2 (8.89)	3.9 (3.16)	-9.7 (10.57)	0.0 (0.00)	0.0 (0.00)	0.7 (0.71)
Second premolar	-0.4 (0.35)	-0.4 (0.35)	0.0 (0.00)	-1.1 (0.74)	0.0 (0.00)	-7.2 (3.66)
First molar	-36.9 (8.37)	-82.8 (10.86)	-102.8 (8.11)	-24.7 (4.66)	-55.5 (4.60)	-74.2 (6.10)
Buccolingual						
Canine	-10.4 (7.71)	4.3 (1.85)	0.4 (1.46)	43.7 (13.44)	131.9* (10.93)	181.0* (18.75)
First premolar	2.2 (2.82)	14.0 (5.54)	20.4 (7.86)	0.4 (0.35)	-0.4 (0.35)	0.0 (0.00)
Second premolar	-6.8 (5.85)	0.0 (0.00)	0.0 (0.00)	17.9 (12.41)	5.7 (5.10)	98.2 (43.20)
First molar	120.0 (3.64)	218.2 (6.69)	268.4 (10.62)	-51.2* (12.57)	-77.4** (10.24)	-225.0** (20.24)

Unit:  $\times 10^{-2}$  N.

Significant difference between same amount of parallel and fan expansion (\* $P < 0.05$ , \*\* $P < 0.01$ ).



**Figure 4** Orthodontic force generated by (a) parallel and (b) fan expansion.



**Figure 5** Orthodontic force generated by a combination of (a) 3 mm and (b) 5 mm parallel expansion and various amounts of fan expansion.

**Table 2** Orthodontic force generated by combined parallel and fan expansion.

	3 + 3 mm, mean (SD)	3 + 5 mm, mean (SD)	5 + 3 mm, mean (SD)	5 + 5 mm, mean (SD)
Mesiodistal				
Canine	-1.8† (0.74)	-9.0 (2.80)	-0.7 (1.67)	-3.9† (2.00)
First premolar	1.4 (0.76)	-0.7 (1.39)	-2.9 (1.93)	-0.4 (0.64)
Second premolar	0.4 (2.53)	-6.1 (3.52)	0.7 (1.67)	0.4 (0.64)
First molar	-72.7† (16.03)	-138.3# (8.38)	-109.3 (12.17)	-105.7†† (10.79)
Buccolingual				
Canine	15.4 (12.83)	167.4# (19.00)	74.2 (11.79)	100.3* (19.99)
First premolar	29.7 (9.15)	50.9 (21.99)	0.4 (2.59)	15.8 (14.41)
Second premolar	14.0 (19.85)	131.9## (14.74)	-7.5 (8.78)	-18.6 (16.36)
First molar	159.5! (21.03)	91.0 (32.42)	222.5# (15.75)	143.3*,†† (27.42)

Buccal and mesial direction: +. Unit:  $\times 10^{-2}$  N.

Significant difference compared with parallel expansion (\* $P < 0.05$ ).

Significant difference compared with fan expansion († $P < 0.05$ , †† $P < 0.01$ ).

Significant difference compared with combined 5 mm parallel and 5 mm fan expansion (# $P < 0.05$ , ## $P < 0.01$ ).

Significant difference compared with 3 mm parallel expansion, 3 mm fan expansion, and combined 3 mm parallel and fan expansion (! $P < 0.05$ ).

However, orthodontic force generated by the Size 3 quadhelix was approximately three times larger. Therefore, the diameter of the wire greatly influenced orthodontic force.

No significant orthodontic force was observed except at the first molar. This finding supports the theory that as the distance from the point of force becomes greater, the force decreases, as suggested by Kamogashira *et al.* (1983) and Fukui (1998). When 3, 5, and 7 mm of fan expansion was applied, orthodontic force was detected in the mesiolingual direction at the first molar, with a tendency towards greater mesiolingual force with larger expansion. Chaconas and de Alba y Levy (1977) and Chaconas and Caputo (1982) reported that the orthodontic force produced by fan expansion using a quadhelix appliance resulted not only in

expansion of the maxillary buccal segments but also distobuccal rotation of the first molar. In contrast, the orthodontic force in this study was mesiolingual. This difference can be explained by the different expansion methods; Chaconas and de Alba y Levy (1977) expanded the entire lateral arm in the buccal direction on both sides, whereas in the present study, the lateral arms were bent in a buccal direction without bending their bases. The mesiolingual force observed with fan expansion in this study resulted from the change in the force applied to the canine. The molars in a Class II malocclusion subject typically show mesial rotation, and a tapered upper arch form is often observed (Bench *et al.*, 1978). Orthodontic force that produces distal rotation of the first molar would therefore be useful in



correction of a Class II malocclusion. Because fan expansion entails mesial rotation of the lateral arms, buccal (labial) orthodontic force was observed at the canine and mesiolingual force at the first molar. Based on the results of this study, fan expansion may not be appropriate to correct a Class II malocclusion.

For 3 mm parallel expansion in combination with 5 mm fan expansion, orthodontic force was observed at the canine and first and second premolars in the buccal (labial) and mesial directions, and at the first molar in the distal and buccal directions. Considering the need for sufficient lateral expansion, it is desirable that the orthodontic force produced by a quadhelix appliance acts on all teeth and that the entire dental arch expands laterally. The buccal (labial) direction of orthodontic force was equivalent for all teeth with 3 mm parallel expansion in combination with 5 mm fan expansion. The force vector for each tooth was  $168 \times 10^{-2}$  N (171 g) at the canine,  $51 \times 10^{-2}$  N (52 g) at the first premolar,  $132 \times 10^{-2}$  N (135 g) at the second premolar, and  $165 \times 10^{-2}$  N (168 g) at the first molar.

Quinn and Yoshikawa (1985) stated that a sufficient maxillary canine retraction force is between 100 and 200 g and suggested that the optimal orthodontic force depends on the root surface area. The force in this study with 3 mm parallel expansion in combination with 5 mm fan expansion ranged from 52 to 171 g, which is within the limits of optimum forces.

## Conclusions

The results of this study suggest that lateral expansion should be performed by choosing parallel, fan, or a combination of parallel and fan expansion, depending on the type of malocclusion.

With parallel expansion, the greatest orthodontic force was observed at the first molar, and the forces at the premolar and canine were less. This approach might be suitable for cases with constriction only in the molar region.

With fan expansion, orthodontic forces were detected at the first molar in the mesial and lingual directions and at the canine in the buccal direction. This expansion technique might be effective for Class I and Class III subjects with anterior arch constriction.

With 3 mm parallel expansion in combination with 5 mm fan expansion, orthodontic forces were observed at the canine in the mesial and buccal directions and at the first molar in the distal and buccal directions. This approach might be useful for correcting a Class II malocclusion in which the entire arch is constricted.

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