# Distal molar movement using the pendulum appliance. Part 1: Clinical and radiological evaluation



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One way to create space or to correct a dental Class II relationship in the maxillary arch is to move the molars distally. In addition to traditional distal movement techniques, such as extraoral force applications[1-5] and removable appliances,[6-8] various intra-arch devices have been introduced since the 1980s. Clinical experience using repelling magnets has demonstrated promising results.[9-13] Other researchers have focused on the simplicity and efficiency of intra-arch devices, which improve the continuity and constancy of forces, reach optimal force levels, and make good oral hygiene easier to maintain. Superelastic coils,[14-16] superelastic nickel titanium wires,[17] and the Wilson arch[18] have been designed to move maxillary molars distally. A modified Nance appliance has often been employed in conjunction with these force delivery systems to increase anchorage during distal movement or to keep the molars in position following distal movement.

Patient compliance with extraoral forces and removable appliances has been widely discussed, and it has been concluded that patient cooperation is the key factor in obtaining successful results. The introduction of intra-arch systems has nearly eliminated the need for patient cooperation, except in cases where Class II elastics are needed.

The pendulum appliance was first described by Hilgers[19] in 1992. Until now, no research has been conducted to analyze the effects of this intraoral appliance for distal movement of the maxillary molars. Thus, the purpose of this clinical study was to evaluate the dental and skeletal effects of the pendulum appliance, and to assess its influence on the vertical dimension.

**Abstract**
Intra-arch distal molar movement techniques have recently assumed an important role in clinical orthodontics. In this study, the dental and skeletal effects of the pendulum appliance, applying 200 to 250 g of force to the molars in 13 patients (age range 8 years to 13 years 5 months) were evaluated by means of cephalometric radiographs. The results showed that the pendulum appliance moved the molars distally without creating dental or skeletal bite opening and with little incisor anchorage loss. However, important molar tipping should be taken into consideration when using this appliance.

**Key Words**
Class II malocclusion • Pendulum appliance • Distal molar movement • Second molar position

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**Figure 1A-B**
**A: Pendulum appliance on plaster cast, springs passive.**
**B: Springs bent back at 45° angle, producing 200 to 250 g of force when activated.**

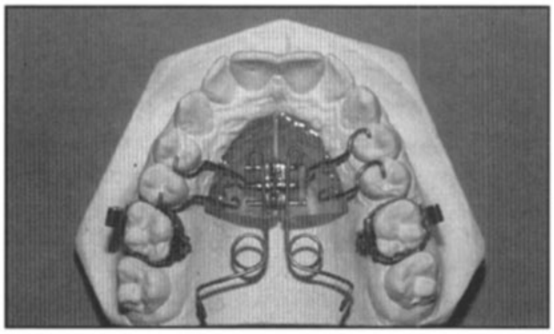

Figure 1A

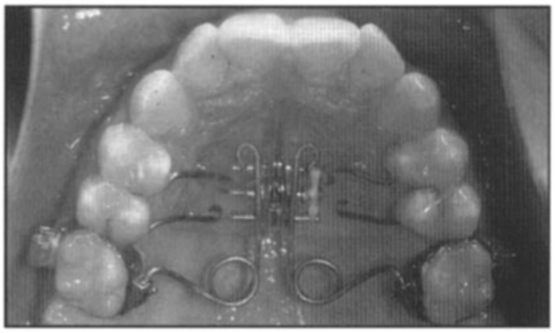

Figure 1B

## Materials and methods

After the evaluation of a pilot study sample of 5 patients, a sample consisting of 13 patients (9 females and 4 males, mean age 11 years 1 month [± 1 year 9 months]) was selected. Clinically, each patient had a dental Class II relationship with moderate space deficiency in the maxillary arch; none had a dental openbite. Nonextraction treatment was planned, and the patients were treated by one of the authors in his private practice.

### Appliance design and activation

The pendulum appliance consists of an anterior acrylic Nance portion with an expansion screw and two posteriorly extending TMA® coil springs that were recurved at the end where they fit into the lingual sheath (.032″ TMA wire, Ormco Corp, Glendora, Calif) (Figure 1). Using a composite resin and auxiliary wires, the appliance was bonded to the maxillary premolars or molars, avoiding occlusal interferences. In contrast to the recommendation of Hilgers,[19] the pendulum springs were activated 45° (instead of 60°) in the center of the helices on the sagittal plane with an initial force of 200 to 250 g (Figure 1). Depending on the molar movement required, activation was repeated intraorally once or twice during treatment. Patients were instructed to turn the expansion screw once every 3 days for a period of 4 weeks. As a general principle, patients with molar crossbite tendencies or complete crossbites were asked to continue the activation for up to 12 weeks, depending on how much expansion was needed. The pendulum appliance was worn until a super Class I molar relationship was obtained.

Lateral headfilms were taken prior to treatment (T1) and on the day the appliance was removed (T2). The sample was also analyzed, taking into consideration the eruption pattern of the maxillary left second molars detected on panoramic X-rays. The three eruption stages were: (Table 1)

A. Maxillary second molar crowns above the level of the trifurcation of the first molars (four patients);

B. Maxillary second molar crowns on the level of the bone surface of the maxillary alveolar crest (five patients);

C. Half of the maxillary second molar crown erupted or in complete occlusion (four patients).

### Reference points and superimposition method

On the initial cephalometric X-ray (T1) the palatal plane (constructed x-axis) and the occlusal plane were traced and a plane was drawn perpendicular to the palatal plane through Ricketts' Pt point (constructed y-axis). The palatal plane was used to describe angular and vertical measurements, the occlusal plane was used to describe vertical movements only, and the constructed y-axis was used to describe sagittal movements of the molars, second premolars, and incisors. The final cephalometric X-ray (T2) was superimposed on the initial one (T1) on the anterior part of key ridge using vertical adaptations as described by Björk,[20] and the reference system was transferred from the first tracing to the second. Thus, dental movements due to growth and remodeling changes of the maxilla during the experimental period were eliminated and dental movements alone were measured.

The center of the crown was taken as the reference point for the left molar and second premolar. Each author independently paid maximum attention to identification of the left side teeth, verifying from panoramic and apical X-rays and study models. The tooth reference points were transferred from the first X-ray to the second one by superimposing the tracings of individual teeth. Because an occlusal point such as the top or the intersection of the molar cusps will exaggerate the distal movement of the molar crown, we used the center of the crown, which we believe better represents the reference point. On the other hand, the exaggerated distal movement should be

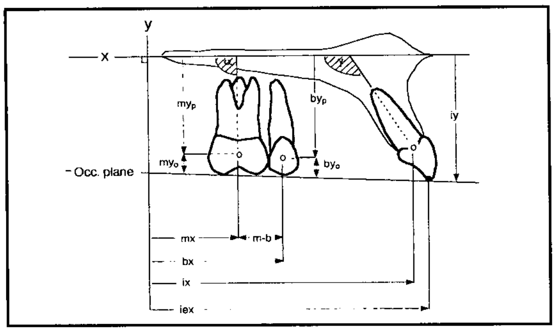


Figure 2

Figure 2
**Schematic illustration of sagittal (mm), vertical (mm), and angular measurements (°) of maxillary first molar (mx, $my_p$, $my_o$, α), maxillary second premolar (bx, $by_p$, $by_o$), maxillary incisor (ix, iy, γ), and maxillary incisor edge (iex).**

evaluated by taking into account the distal angular tip of the molars. The reference point for the incisor was the midpoint of the lateral projection of the circumference formed by the root and crown junction.

The following variables were constructed (Figure 2) :

*Maxillary first molars*

mx: distance between center of molar crown and y-axis.

$my_P$: distance between center of molar crown and x-axis.

$my_o$: distance between center of molar crown and occlusal plane.

α: angle between molar long axis and x-axis, expressing inclination of the molar.

*Maxillary second premolar*

bx: distance between center of premolar crown and y-axis.

$by_P$: distance between center of premolar crown and x-axis.

$by_o$: distance between center of premolar crown and occlusal plane.

*Maxillary central incisor*

ix: distance between incisor reference point and y-axis.

iex: distance between incisor edge and y-axis.

iy: distance between incisor reference point and x-axis.

γ: angle between incisor long axis and x-axis, expressing inclination of the incisor.

m-b: shortest distance between centers of the molar and second premolar crowns.

The percentage of distal molar movement (mx/mx+bx), percentage of mesial premolar movement (bx/mx+bx) to the overall space gained, and the difference between these two [(mx/mx+bx)-(bx/mx+bx)] ratios were calculated.

On the lateral headfilms, the palatal plane/mandibular plane (PP/MP) and the y-axis angles were evaluated to examine changes in the vertical dimension, and SNA angle was evaluated for changes in the sagittal dimension.

**Table 1**
**Patient identification, treatment time, and second molar position**

| Patient | Sex | Age (year-month) | Treatment time (weeks) | Second molar position |
|---|---|---|---|---|
| 1 | F | 11 - 1 | 19 | B |
| 2 | F | 12 - 4 | 16 | B |
| 3 | F | 11 - 7 | 16 | C |
| 4 | F | 9 - 0 | 11 | A |
| 5 | M | 11 - 4 | 15 | B |
| 6 | M | 13 - 0 | 12 | B |
| 7 | F | 8 - 0 | 6 | A |
| 8 | F | 10 - 0 | 13 | C |
| 9 | M | 13 - 5 | 19 | A |
| 10 | F | 11 - 0 | 17 | C |
| 11 | F | 11 - 9 | 18 | B |
| 12 | F | 8 - 3 | 21 | A |
| 13 | M | 12 - 5 | 35 | C |
| Mean ± SD | | 11-1 ± 1-9 | 16.6 ± 7.0 | |

Following the distal movement, the pendulum appliance was removed and a Nance appliance was immediately cemented to prevent relapse (Figure 3). The changes obtained during the experiment were evaluated using Student's *t*-test for paired samples.

## Results

In all patients, a super Class I relationship was obtained using the pendulum appliance (Figures 3 and 4). Mean treatment time was 16.6 ± 7 (Table 1). In patients with crossbite or crossbite tendency, a slow rate of maxillary expansion seemed to be successful.

In the sagittal plane, distal movement of the molar (3.39 mm ± 1.25 mm; $p<0.001$), mesial movement of the second premolar (1.63 mm ± 1.37 mm; $p<0.01$), anterior movement of the incisor-center (0.74 mm ± 0.72 mm; $p<0.01$), anterior movement of the incisor edge (0.92 mm ± 0.67 mm; $p<0.001$) as well as space opening between the molar and second premolar (5.53 mm ± 2.00 mm; $p<0.001$) were found to be statistically significant. In case 1, the mesial movement of the second premolar was more important then the distal movement of the molar (Table 2, Figure 5).

In the vertical plane, molar intrusion in relation to palatal plane (1.68 mm ± 1.33 mm, $p<0.001$) and occlusal reference plane (1.17 mm ± 1.29 mm, $p<0.01$) was statistically significant. However, second premolar extrusion was statistically significant in relation to palatal plane

Figure 3A

Figure 3B

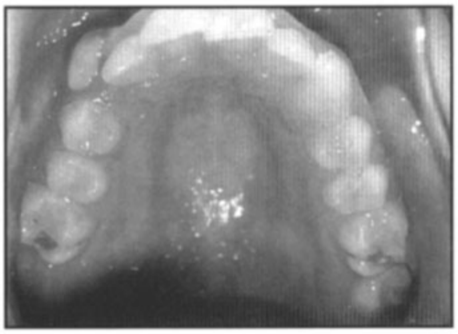

Figure 3C

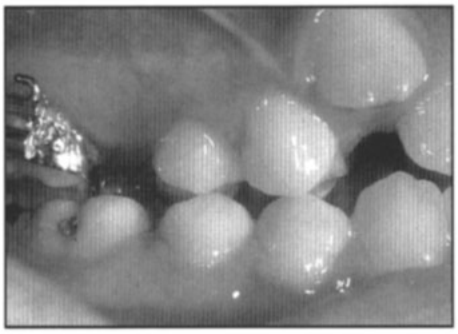

Figure 3D

Figure 3E

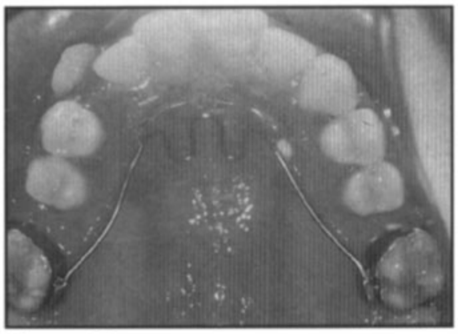

Figure 3F

**Figure 3A-L**
**Patient (HP).**
**A-C: Before treatment.**
**D-F: After appliance removal.**
**G: Lateral headfilm before treatment.**
**H: The day of pendulum removal**
**I-J: Panoramic X-ray before treatment.**
**K-L: After treatment.**

Figure 3G

Figure 3H

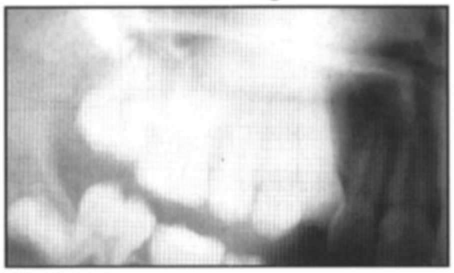

Figure 3I

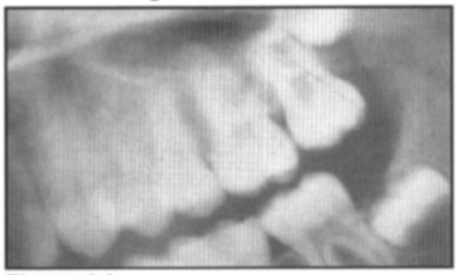

Figure 3J

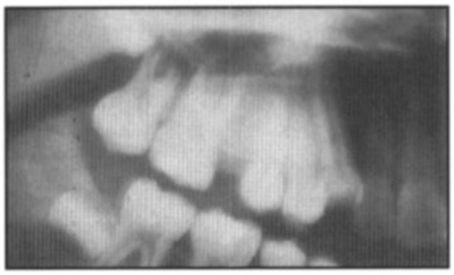

Figure 3K

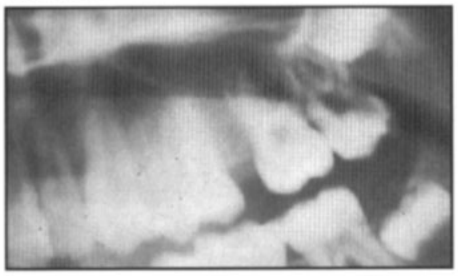

Figure 3L

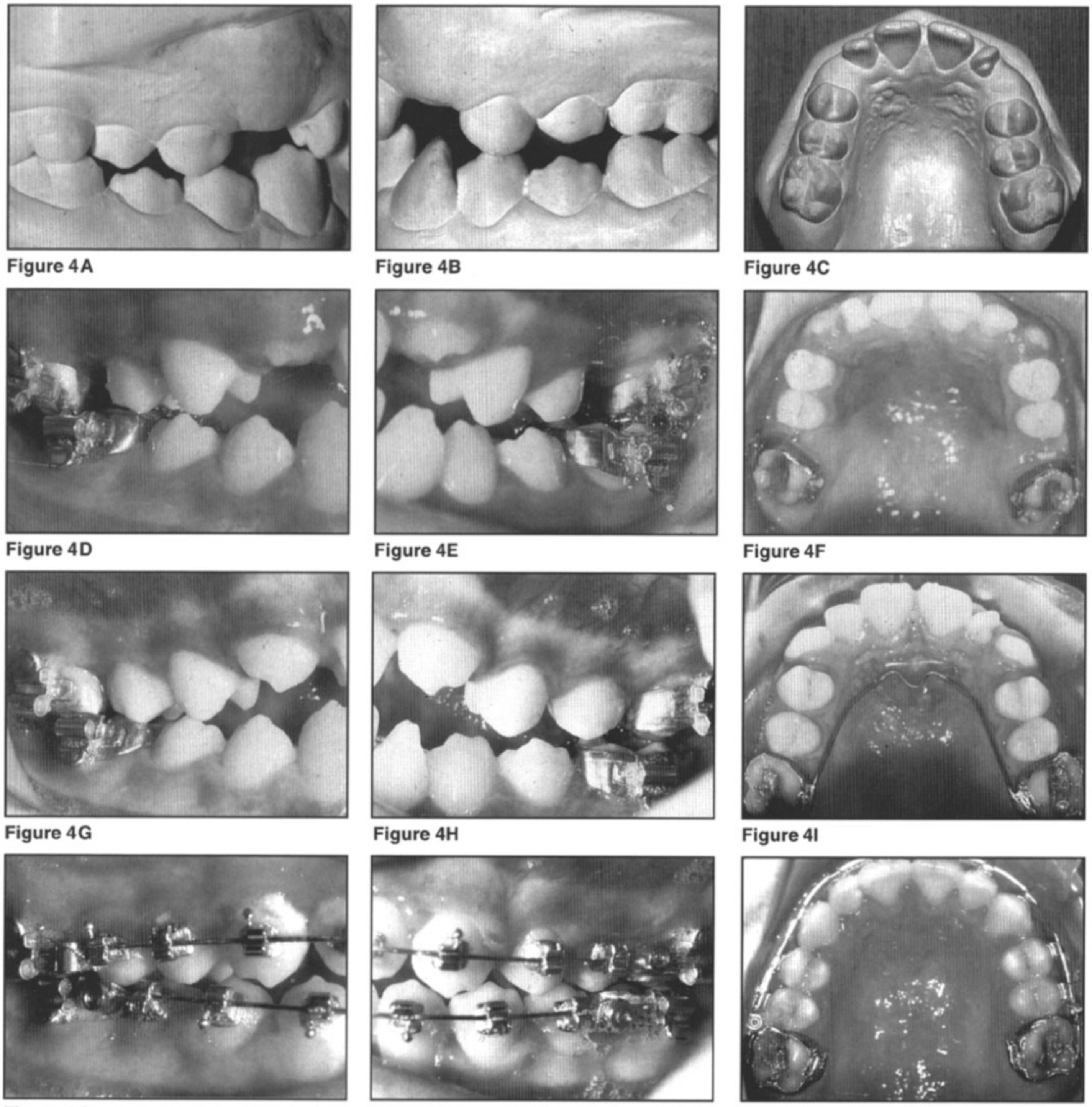

Figure 4A Figure 4B Figure 4C
Figure 4D Figure 4E Figure 4F
Figure 4G Figure 4H Figure 4I
Figure 4J Figure 4K Figure 4L

**Figure 4A-L Patient (AL).**
**A-C: Before treatment.**
**D-F: Just after pendulum removal.**
**G-I: After 2.5 months with the Nance arch in place.**
**J-L: After treatment.**

(0.78 mm ± 1.23 mm, $p<0.05$) but not occlusal plane as a reference line (0.42 mm ± 1.14 mm). In our sample, 10.73° ± 3.87° of angulation was found between palatal plane and occlusal plane (Figure 6).

According to the angular measurements, statistically significant amounts of molar distal tipping ($\alpha$: 14.50° ± 8.33°; $p<0.001$) and incisor labial tipping ($\gamma$:1.71° ± 1.48°; $p<0.001$) were found (Figure 7).

There were no significant differences between second molar eruption stage groups concerning distal molar movement and molar tipping.

None of the skeletal values measured showed significant changes (Figure 8).

The pendulum appliance was very well tolerated by all but one patient; in this one patient the appliance had to be removed due to inflammation of the palatal mucosa. This patient was not included in the study sample. All

**Table 2**
**Dental and skeletal changes during pendulum appliance treatment**

| Patient | SNA (°) | Y-axis (°) | PP/MP (°) | mx (mm) | $my_p$ (mm) | $my_o$ (mm) | bx (mm) | $by_p$ (mm) | $by_o$ (mm) | ix (mm) | iex (mm) | iy (mm) | m-b (mm) | a (°) | g (°) | Distal rate (mm/mo) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. 1 | -0.50 | 1.00 | 3.00 | -2.00 | -1.50 | -2.00 | 4.85 | 2.00 | 0.50 | 0.85 | 1.50 | 1.50 | 7.40 | -9.50 | 2.75 | 0.46 |
| No. 2 | 0.00 | 0.50 | 0.00 | -4.80 | -1.10 | -0.50 | 3.20 | 2.80 | 3.00 | 2.50 | 1.50 | 0.10 | 8.70 | -28.00 | 1.00 | 1.30 |
| No. 3 | 1.00 | 0.50 | 2.00 | -3.00 | -0.20 | -0.50 | 1.50 | 1.00 | 0.50 | 0.50 | 0.50 | -0.20 | 5.00 | -8.00 | 4.00 | 0.81 |
| No. 4 | 0.00 | 1.00 | -1.00 | -1.50 | -2.30 | -1.70 | 0.80 | 1.50 | 1.50 | 1.50 | 2.00 | 0.50 | 4.00 | -14.00 | 3.50 | 0.59 |
| No. 5 | 0.00 | -1.00 | 0.50 | -2.00 | -1.60 | -1.00 | 0.10 | 0.50 | 0.50 | 0.10 | 1.50 | 1.20 | 2.50 | -16.50 | 1.00 | 0.58 |
| No. 6 | 0.00 | 0.00 | -1.50 | -2.80 | -3.10 | -2.50 | | | | 0.70 | 0.50 | 0.90 | | -9.50 | 2.00 | 1.01 |
| No. 7 | 0.00 | -3.00 | -2.00 | -4.20 | -1.00 | 0.00 | 1.00 | -0.50 | 0.00 | 0.00 | -0.50 | 0.90 | 4.50 | -11.50 | 3.00 | 3.03 |
| No. 8 | -1.50 | 1.00 | 1.00 | -3.30 | 0.50 | 1.00 | 0.50 | 0.50 | 0.00 | 0.00 | 1.00 | 0.00 | 4.10 | -3.50 | 3.00 | 1.10 |
| No. 9 | 2.00 | -2.00 | -1.00 | -3.50 | -3.00 | -2.50 | 1.50 | -2.00 | -2.00 | 0.80 | 0.50 | 1.00 | 4.50 | -19.00 | 0.00 | 0.80 |
| No. 10 | -0.50 | 1.00 | 2.00 | -5.20 | -0.60 | 0.50 | 2.00 | 1.60 | 1.00 | 0.30 | 1.00 | -0.90 | 8.00 | -21.00 | 2.00 | 1.33 |
| No. 11 | 0.00 | 1.50 | 3.00 | -2.80 | -2.10 | -1.50 | 0.70 | 1.00 | 0.50 | 0.40 | 0.50 | -1.10 | 5.70 | -5.50 | -0.50 | 0.67 |
| No. 12 | -0.50 | 2.00 | 1.00 | -5.50 | -4.50 | -3.50 | 1.00 | 0.50 | 0.00 | 0.50 | 0.50 | 1.00 | 8.00 | -31.00 | 0.00 | 1.13 |
| No. 13 | 0.50 | 0.50 | -2.50 | -3.50 | -1.40 | -1.00 | 0.40 | 0.50 | -0.50 | 1.50 | 1.50 | 0.90 | 4.00 | -11.50 | 0.50 | 0.43 |
| Mean Values | | | | | | | | | | | | | | | | |
| | -0.04 | 0.23 | 0.35 | -3.39 | -1.68 | -1.17 | 1.63 | 0.78 | 0.42 | 0.74 | 0.92 | 0.45 | 5.53 | -14.50 | 1.71 | 1.02 |
| ± SD | 0.92 | 1.42 | 1.85 | 1.25 | 1.33 | 1.29 | 1.37 | 1.23 | 1.14 | 0.72 | 0.67 | 0.81 | 2.00 | 8.33 | 1.48 | 0.68 |
| p | NS | NS | NS | 0.000 *** | 0.001 *** | 0.007 ** | 0.002 ** | 0.049 * | NS | 0.003 ** | 0.000 *** | NS | 0.000 *** | 0.000 *** | 0.001 *** | |

$p<0.05$ (*), $p<0{,}01$ (**), $p<0.001$ (***)
% of distal molar movement (mx/ mx+bx) 70.92 ± 18.68
% of mesial premolar movement (bx/ mx+bx) 29.08 ± 18.68
difference (mx/mx+bx) and (bx/mx+bx) 41.92 ± 37.33p<0.003

patients experienced slight inflammation of the palatal mucosa under the acrylic button at the time of appliance removal, but these symptoms disappeared within 1 week. In this sample, no debonding of the pendulum appliance during the treatment period occurred.

## Discussion

### Treatment time, distal molar movement, molar and incisor tipping

The data gathered in this study suggest that the pendulum appliance is effective in moving the maxillary first molars distally at a mean monthly rate of 1.02 mm (± 0.68 mm) using an initial force of 200 to 250 g in a mean period of 4 months.

Previous studies of the characteristics and magnitude of distal molar movement using different appliance designs showed inconsistent results. Kurol and Bjerklin[21] advocated the use of 250 g of cervical force on each side and moved molars distally in 9 to 12 months. Hubbard et al.[22] used records of treatment with the traditional Kloehn-type of cervical headgear delivering 1.5 to 1.7 pounds (680 g to 770 g) on each side for a mean of 6 months, depending on patient cooperation. When combined highpull and cervical traction was used, the total force level was 2.5 to 3 pounds (1135 g to 1360 g per side), and molars moved distally an average of 2.4 mm in a mean of 4 months.[23] On the other hand, treatment with a combination of cervical headgear and activator[24] or highpull headgear and activator[25] producing 400 g of extraoral force per side required a period of about 1 year to obtain a Class I molar relationship. In theory, greater skeletal changes are expected from higher levels of force. However, cephalometric studies of patients treated with cervical traction including headgear that used relatively light forces for longer treatment periods showed more skeletal changes than heavy-force highpull headgears, which produced more dental effects.[26] These results are consistent with other studies.[4,27-29]

Intraarch devices are another alternative to the use of relatively light forces for distal molar movement. Repelling magnets exerting an initial force of approximately 225 g could move molars distally 0.75 to 1.5 mm/mo without patient cooperation.[9,11] Bondemark and Kurol[13] moved first and second molars simultaneously over 16.6 weeks using magnets generating 220 g of initial force, and obtained mean molar crown movement of 4.2 mm. Likewise, Itoh et al.[12] achieved a mean distal movement of 2.1 mm (range 0.5 mm to 3.7 mm) with magnets during a treatment period of approximately 1 to 2.5 months in the early mixed dentition. With the intraoral Wilson "rapid molar distalization" appliance,[18] mean molar movement was 0.56 ± 0.37 mm/mo. However, this appliance required patient cooperation because different Class II intermaxillary elastic forces were used. Reiner[30] used a modified Nance appliance delivering 150 g of force for unilateral molar distal movement. He obtained a mean molar distal movement of approximately 0.76 mm/mo with uncooperative patients who missed the reactivation appointment and 0.96 mm/mo with the others. Nickel titanium (NiTi) coils moved molars distally at a rate of 1 to 1.5 mm/mo using 100 g of force.[14,17] In a recent study, Bondemark et al.[16] compared two intraoral distal movement systems and found that mean distal molar movement achieved with NiTi coils was 3.2 mm, whereas magnets resulted in 2.2 mm of movement after 6 months of treatment. Both systems exerted 225 g of force at the start of treatment. Although different force levels were used in these previous studies, the monthly molar distalization value found in the present study (1.02 mm/mo ± 0.68 mm/mo) was close to the findings mentioned above. But it must be stated that measurement systems in the previous studies differ from those employed in the present study, and the use of different reference points may lead to different linear results of distal movement, as discussed earlier.

A controversy exists concerning the influence of second molars on the distal movement of the first molars. Graber[31] noted that extraoral traction on the first molars, when the second molars have not totally erupted, led to distal tipping only and not to bodily distal movement. Bondemark et al.[16] stated that the presence of second molars did influence tipping and distal movement of the first molars.

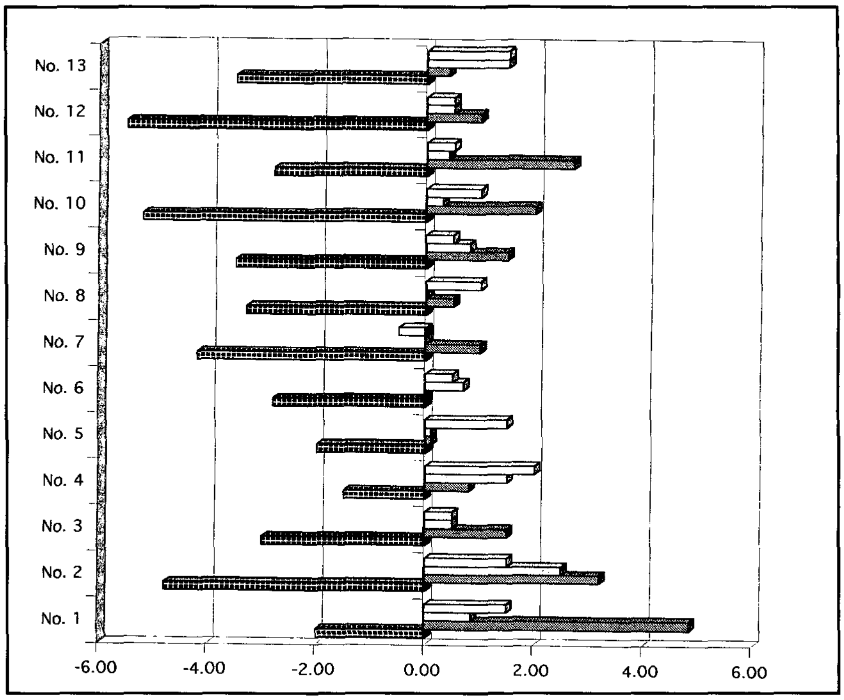


Figure 5A

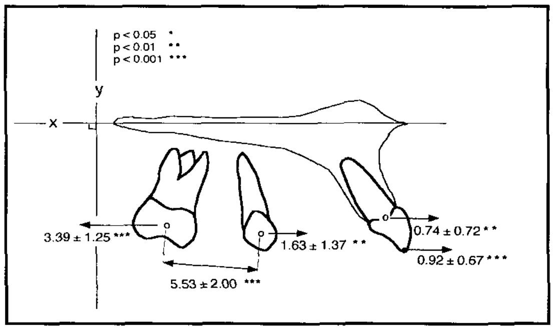


Figure 5B

**Figure 5A-B**
**A: Individual sagittal dental changes (mm) in 13 patients.**
**□ Maxillary incisor edge anterior movement (iex:) 0.92 ± 0.67**
**□ Maxillary incisor center anterior movement (ix): 0.74 ± 0.72**
**▩ Maxillary second premolar mesial movement (bx): 1.63 ± 1.37**
**▦ Maxillary distal movement (ms) 3.39 ± 1.25**
**B: Schematic illustration of sagittal dental changes (mm) and standard deviations (SD).**

Gianelly[14] also found that treatment time was increased with the presence of second molars, whereas Muse et al.[18] found that the presence of maxillary second molars did not correlate with the rate of maxillary first molar movement or with the amount of tipping that occurred. The findings of the present study were similar to those of Muse et al.[18]; no statistically significant differences in linear or angular changes were found among three groups of eruption stages of second molars. Therefore, the conclusions in this study were drawn from the sample as a whole and not differentiated by eruption subgroups.

Molar tipping, however, was very high (14.5°) in our sample when compared with the 7.4°, 8.0°, and 7.8° found in other studies.[12,13,18] Modifying the appliance used in their previous study, Bondemark et al.[16] later reported 1° of molar tipping. The trajectory of the TMA

**Figure 6A-B**
**A: Individual vertical changes of maxillary first molar and second premolar in relation to palatal plane (mm).**
**Maxillary first molar (myp:) -1.68 ± 1.33**
**Maxillarysecond premolar (byp): 0.78 ± 1.23**
**Maxillary incisor (iy): 0.45 ± 0.81**
**B: Schematic illustration of vertical dental changes (mm) and standard deviations (SD) in relation to palatal plane.**

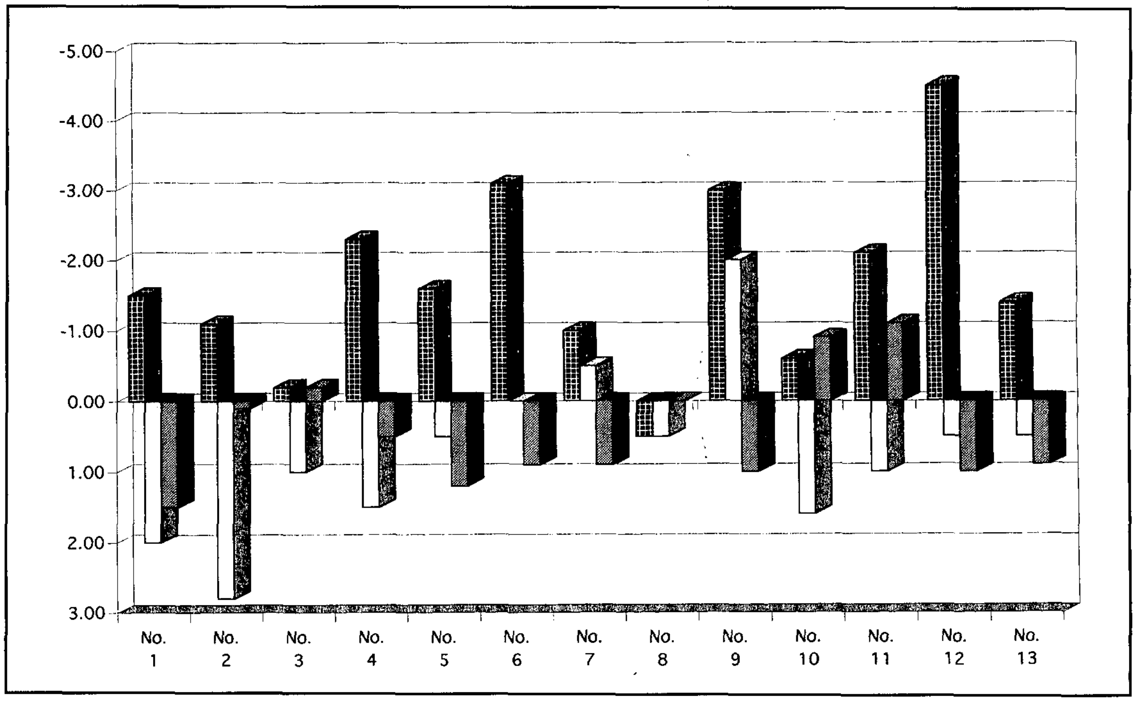


**Figure 6A**

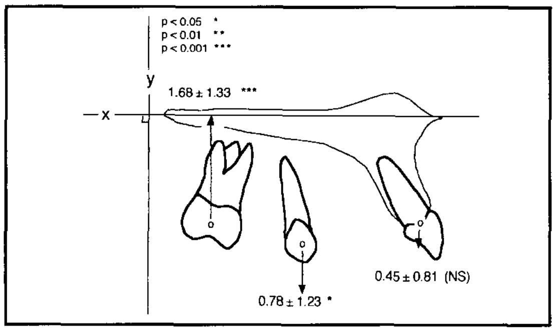


**Figure 6B**

springs may account for the excessive tipping found in this study.

Mean anterior movement of the center of the incisor crown was only 0.74 mm and movement at the incisor edge was only 0.92 mm. In other words, a mean of 1.71° of labial tipping was measured. Bondemark and Kurol[13] found an average of 1.8 mm of anterior movement of the incisor edge and 6° of anterior tipping of the same teeth, and Bondemark et al.[16] showed 1.5 to 2.0 mm and 4.4°, respectively.

**Anchorage loss**

Second premolar anchorage loss found in this study was 1.63 mm (±1.37 mm). Distal molar movement represented 71% of the space opened between molars and premolars. In case 1, the 4.85 mm anchorage loss on the second premolars could be explained by the extraction of the primary canines just before insertion of the pendulum appliance (Figure 5A). The excess of space mesial to the premolars probably caused more anchorage loss that apparently did not influence the anterior movement of the incisors. If this particular patient were excluded from the sample, the anchorage loss of the premolars in 12 remaining patients would be 1.34 mm, with 75% of the space created attributable to distal molar movement. Gianelly et al.[10] reported that 80% of the space created represented distal movement of the molars, while Itoh et al.[12] found 50% to 70%.

In order to support anchorage, the use of Class II elastics accompanied by magnets or coil springs is recommended.[9,14,15,18] Bondemark and Kurol[13] observed approximately 1.5 mm of premolar anchorage loss due to the mesially directed force component of the magnets. We hypothesize that even minimal expansion with the pendulum appliance might give a favorable transverse reinforcement of the lateral acrylic segments against the palate, thus improving anterior anchorage.

**Intrusion - extrusion**

Normal eruption of the maxillary molars around 11 to 12 years of age during a 4-month observation period was found to be approximately 0.23 mm when the palatal plane was used as the reference line.[32] Although the maxillary molars were moved quite rapidly in this study, no bite opening was detected. This was reflected by the absence of significant change in y-axis and PP/MP angle. The real amount of intrusion in relation to palatal plane (1.68 mm ± 1.33 mm; $p<0.001$) might have been bi-

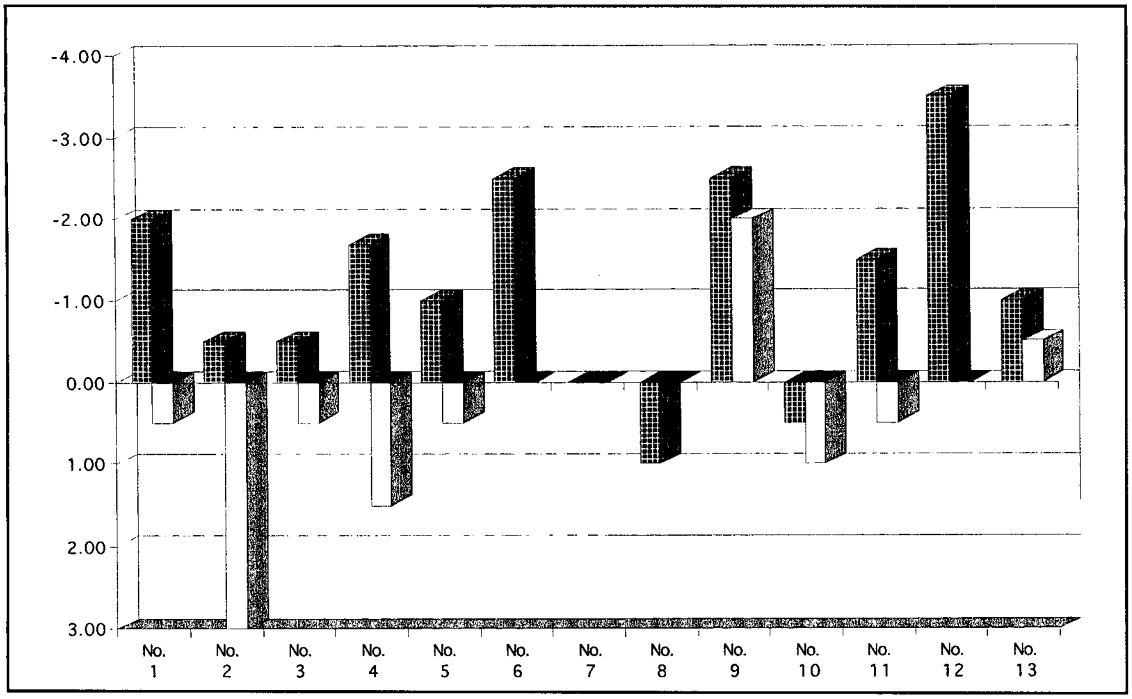


**Figure 6C**

**Figure 6C-D**
**C: Individual vertical changes of maxillary first molar and second premolar in relation to occlusal plane (mm).**
**▦ Maxillary first molar (myo:) -1.17 ± 1.29**
**☐ Maxillarysecond premolar (by): 0.42 ± 1.14**
**D: Schematic illustration of vertical dental changes (mm) and standard deviations (SD) in relation to occlusal plane.**

ased by the important amount of tipping found, which positioned the molar crown center closer to palatal plane. However, intrusion of the molar was also significant when the occlusal plane was used as the reference line (1.17 mm ± 1.29 mm; $p<0.01$). In any case, the amount of intrusion was sufficient not to change the y-axis and MP/PP angles, as bite opening is normally expected after distal movement and tipping of maxillary molars. In contrast, the work of Bondemark et al.[16] demonstrated a reduction in overbite of 3.6 mm due to changes in maxillary and mandibular molar heights, which increased by means of 2.0 mm and 1.8 mm respectively, which might be due to the use of an anterior bite plane in this study. As a consequence, the SN/MP angle tilted downward an average of 1.1°. In our sample, absence of maxillary first molar extrusion, and even intrusion (1.68 mm ± 1.33 mm), were observed. This positive finding can be related to prevention of dentoalveolar vertical growth by the rigid bonded appliance and/or by intrusive force exerted by the tongue. It could also be due to the design and activation trajectory of the TMA loop.

A small but significant amount of premolar extrusion (0.78 mm ± 1.23 mm) was found in relation to palatal plane, but there was no significant change in relation to the occlusal reference plane. This could mean that the occlusal plane represented a better reference line to evaluate vertical maxillary dental movements.

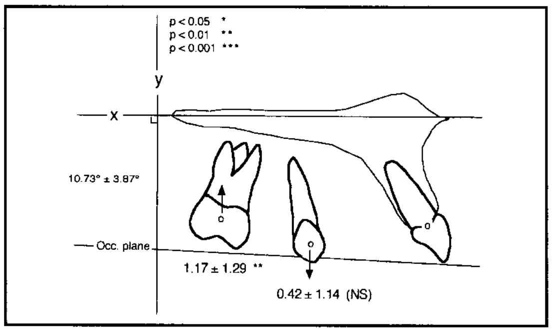


**Figure 6D**

In this study, the maxillary incisors showed no significant extrusion (0.45 mm ± 0.81 mm). Maxillary incisor extrusion in relation to palatal plane was calculated as approximately 0.1 mm for an observation period of 4 months between 11 and 12 years, referring to the norms of Riolo et al.[32] Muse et al.[18] found a mean of 1.6 mm of extrusion of the maxillary incisors, while Ngan et al.[25] found none. This could lead to a conclusion that the appliance itself might rotate with the teeth in the sagittal plane around a center of rotation between the molar and the second premolar, but without influencing the PP/MP angle.

**Skeletal changes**

With regard to skeletal changes of the maxilla, the SNA angle showed no statistical differences, confirming previous findings.[13,16,18] This observation may suggest that A-point was not affected by anteriorly oriented forces within a relatively short period of time. Thus, the ef-

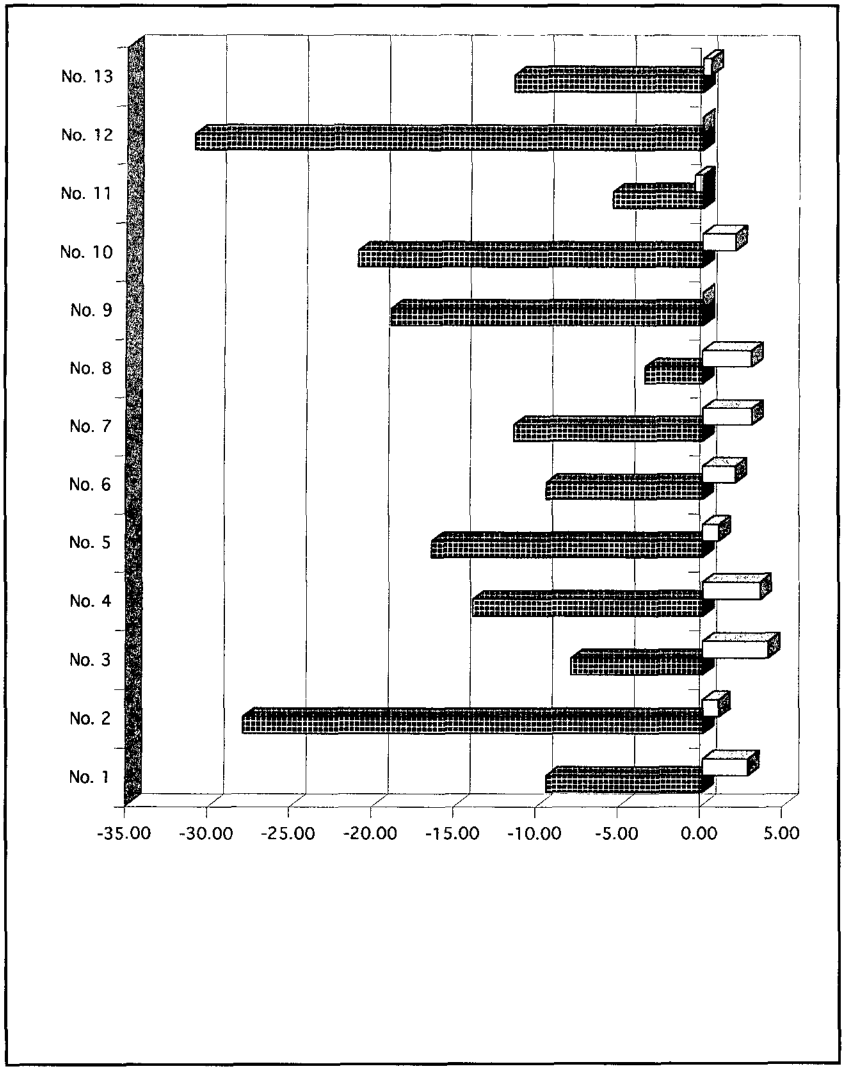


**Figure 7A**

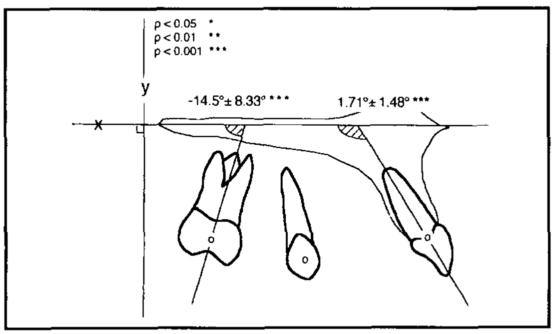


**Figure 7B**

**Figure 7A-B**
**A: Individual angular changes (°) in 13 patients.**
**☐ Maxillary second premolar mesial movement (γ): 1.63 ± 1.37**
**⊞ Maxillary molar distal movement (α) 3.39 ± 1.25**
**B: Schematic illustration of angular dental changes (°) and standard deviations (SD).**

fect was reflected by dental anchorage loss. Observation of the vertical changes revealed no significant change, as demonstrated by other studies,[13,18] except the findings of Bondemark et al.,[16] who used an anterior bite plane that probably stimulated vertical dentoalveolar adaptation.

In comparison with Hilgers' technique[19] where reactivation is rarely necessary, the springs in our study were activated only 45° initially with a clinically measured maximum initial force of 250 g, followed by one or two reactivations. This might explain the difference in treatment time with the pendulum appliance in our experiment (4.5 months) compared with Hilgers' (2 to 3 months).

Following removal of the pendulum appliance, the distally repositioned molars should be retained because relapse tendency is very high. We included a minimum of 3 months retention with the Nance palatal arch to allow spontaneous distal migration of the premolars (Figure 4D-I). Fixed appliance therapy was then initiated (Figure 4A-L).

The pendulum appliance should be used only in cases of moderate dental sagittal discrepancy and arch-length deficiency, but one should never forget that the pendulum appliance, as used here, does not have any corrective *skeletal* effect on Class II skeletal relations. Also, the acting forces produced by TMA springs cannot be easily directed in the vertical plane.

## Conclusions

The pendulum appliance for maxillary distal molar movement, developed by Hilgers, seems to be effective for everyday clinical application, particularly for noncooperative patients. The following conclusions have been drawn:

1. The pendulum appliance produces 3.39 mm ±1.25 mm distal molar movement with a mean bimolar intrusion of 1.17 mm ± 1.29 mm.
2. Maxillary expansion is possible for transverse deficiencies in combination with distal molar movement.
3. The pendulum appliance does not create dental or skeletal bite opening.

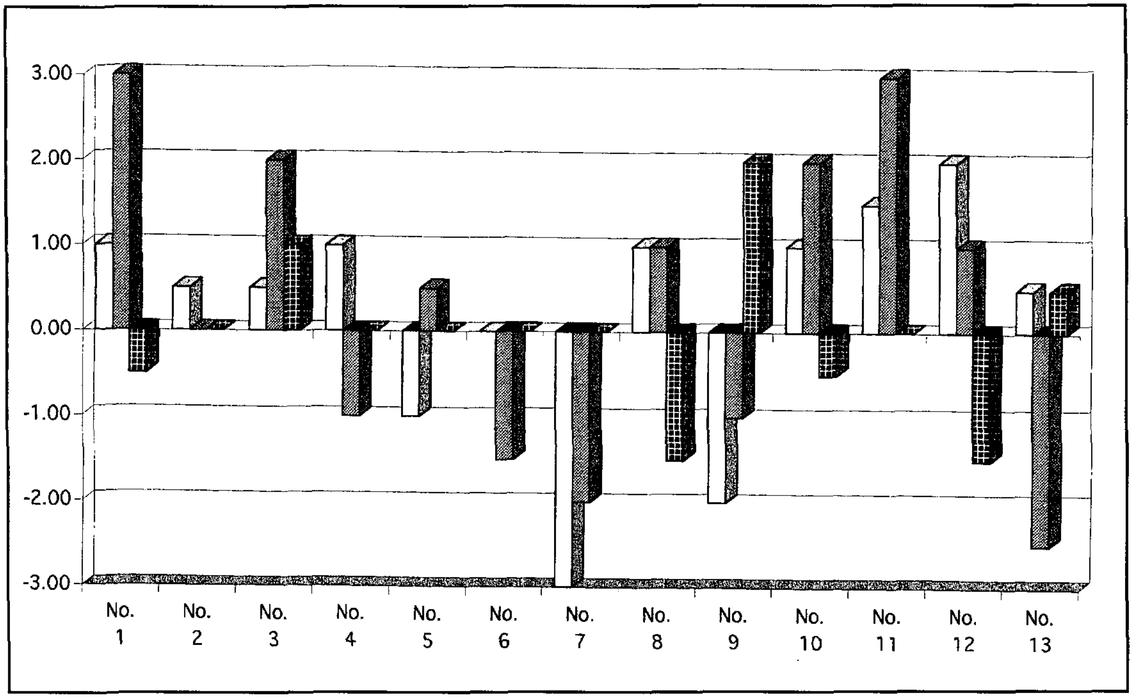


**Figure 8A**

**Figure 8A-B**
**A: Individual skeletal changes (°) in 13 patients.**
**B: Schematic illustration of angular changes (°) and standard deviations (SD) of palatal plane/mandibular plane, y-axis and SNA angle.**

4. Incisor anchorage loss is minimal.
5. Important molar distal tipping of 14.5° ± 8.33° should be taken into consideration.


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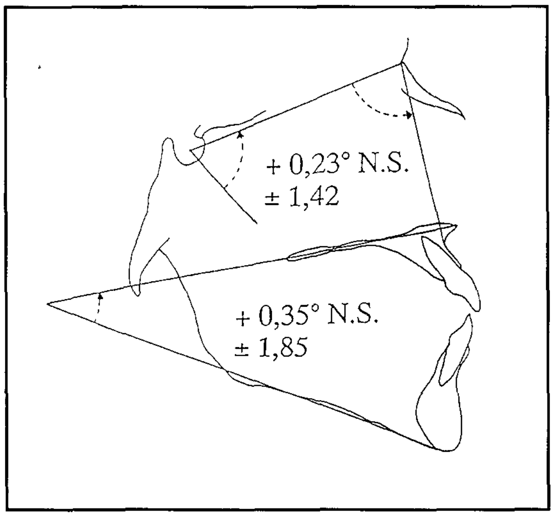


**Figure 8B**

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