



# Anchorage quality of deciduous molars versus premolars for molar distalization with a pendulum appliance

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**Purpose:** The aim of this study was to assess dental anchorage qualities when the pendulum appliance is used for distal molar movement. **Material:** Thirty adolescents in various dentition stages received a modified pendulum appliance with a distal screw and a specially preactivated pendulum spring for bilateral molar distalization in the maxilla. The subjects were subcategorized into 3 groups of 10 according to the dental anchorage used: deciduous molars, premolars and deciduous molars, or only premolars. Dentoalveolar effects and side effects in the anchorage unit and in the molar area were determined by cephalometric analysis. **Results:** Statistical analysis of the measurements showed significant differences between groups in the extent of molar distalization and the resulting incisor protrusion. Distal tipping of the 6-year molars was significantly less severe ( $2.3^\circ \pm 1.58^\circ$  to the palatal plane and  $2.55^\circ \pm 1.52^\circ$  to the anterior cranial base) in patients with premolar anchorage than in those with deciduous molar anchorage ( $6.15^\circ \pm 3.42^\circ$  and  $6.35^\circ \pm 3.46^\circ$ ). Incisor protrusion was significantly more pronounced in patients with deciduous molar anchorage ( $2.75 \pm 1.4$  mm) than in the other 2 groups ( $1.65 \pm 0.82$  mm, mixed deciduous molar and premolar anchorage, and  $1.75 \pm 0.75$  mm, premolar anchorage). Additionally, incisor protrusion was translatory compared with controlled tipping in subjects with deciduous molar anchorage or premolar and deciduous molar anchorage. **Conclusions:** Deciduous molars and premolars can be used for anchorage for molar distalization with a pendulum appliance; however, anchorage with premolars only results in the least pronounced dentoalveolar side effects. The anchorage quality of deciduous molar and mixed deciduous molar/premolar anchorage is limited. (*Am J Orthod Dentofacial Orthop* 2005;127:314-23)

In recent years, appliances largely independent of patient compliance increasingly have been used for maxillary molar distalization. Gianelly et al performed molar distalization with 2 appliances that had magnet modules<sup>1,2</sup> or nickel-titanium springs<sup>3,4</sup> as their active elements. The Jones jig,<sup>5</sup> the modified Nance appliance for unilateral molar distalization,<sup>6</sup> the fixed piston appliance,<sup>7</sup> the distal jet,<sup>8</sup> the edge-wise modified Nance appliance,<sup>9</sup> the first-class appliance,<sup>10</sup> and the Lokar distalizing appliance use buccally or palatally applied open coil springs for molar distalization. The buccally inserted K-loop<sup>11</sup> consists of rectangular springs made from titanium molybdenum alloy (TMA) wire. The intraoral bodily molar distalizer<sup>12</sup> has square TMA springs with 2

closed loops, whereas the pendulum appliance has TMA springs with a circular cross section and, as active elements, a closed and a U-shaped loop, each inserted palatally into the molar bands. The standard pendulum appliance was first described by Hilgers<sup>13</sup> in 1992 and was later subjected to numerous modifications.<sup>14-25</sup> Thus, open coil springs, intramaxillary magnet modules, or pendulum springs are used as active elements for noncompliance molar distalization appliances.

An intramaxillary anchorage unit is needed to counteract the reactive forces and moments in molar distalization. Aside from fixation with endosseous implants or anchorage support with miniscrews, the maxillary anchorage unit consists in general of a combination of dental anchorage and an additional intraoral anchorage aid: a number of teeth are linked with bands or occlusally bonded wires to a palatal button according to Nance to form an anchorage block.

In recent years, numerous clinical studies have been published on pendulum appliances, permitting a statement to be made on their efficiency.<sup>16,19,26-30</sup> Studies of our own pendulum-appliance modification have shown that the skeletal changes are negligible<sup>19</sup> and that the

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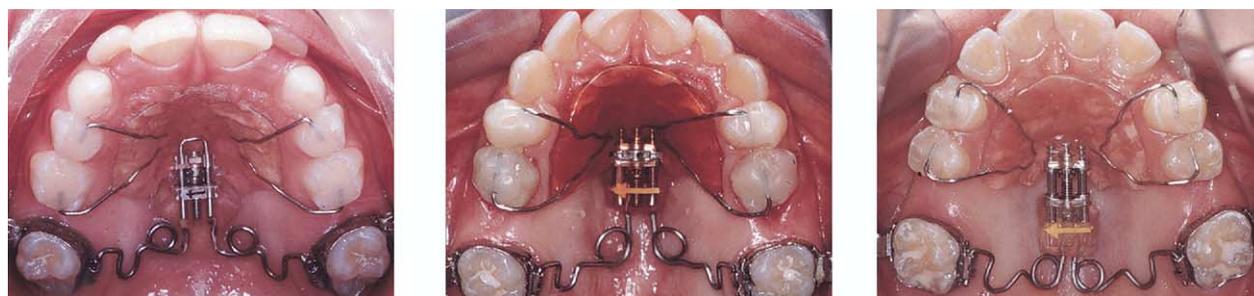
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**Table I.** Molar distalization with Pendulum K: patient groups, treatment duration, and intraoral activation of the distal screw

Patient group*	n	Mean age	Mean treatment duration (wk)	Mean activation of distal screw†
PG 1	10	9 y, 11 m	24.9	16.5
PG 2	10	11 y, 7 m	17.8	14
PG 3	10	12 y, 8 m	23.8	15.8
Total	30	11 y, 5 m	22.2	15.4

\*Patient group PG 1 = deciduous molar anchorage; bilateral distalization of first permanent molars; second molars are not yet erupted on either side. Patient group PG 2 = deciduous molar and premolar anchorage; bilateral distalization of first permanent molars; second molars are not yet erupted. Patient group PG 3 = premolar anchorage; bilateral distalization of first permanent molars; second molars are not yet erupted on either side.

†Ten turns of distal screw result in additional force application of 50 g; distal screw used: sectional screws with straight guidance (Forestadent, Article No. 134-1315).



**Fig 1.** Clinical examples of Pendulum K (pendulum appliance with distal screw and integrated uprighting activation and toe-in bend in region of pendulum springs for bilateral molar distalization in children and adolescents) at various anchorage stages. **A**, Anchorage with Nance holding arch and deciduous molars; **B**, anchorage with Nance holding arch and combination of premolars and deciduous molars; **C**, anchorage with Nance holding arch and premolars.

most favorable time for treatment with respect to the dentition stage in the molar area is during adolescence, before eruption of the 12-year molars.<sup>30</sup>

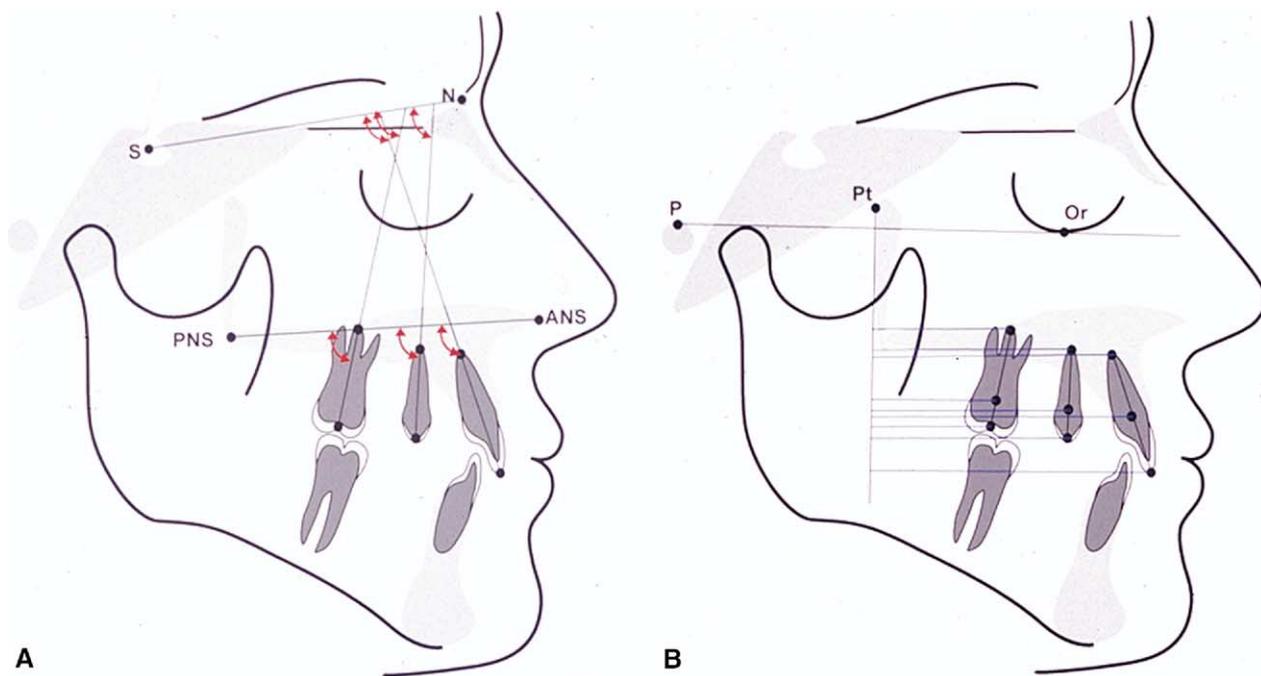
The aim of this study was to verify the dental anchorage quality for treatment with the pendulum appliance. It was to be clarified whether the initial or the advanced resorption of the deciduous molars in the mixed dentition provides adequate anchorage preparation for a pendulum appliance to counteract the reciprocally occurring forces and rotation moments. Conclusions were to be drawn as to the most favorable time for treatment with a pendulum appliance with respect to the dentition stage in the anchorage region, and the potential for a further increase in anchorage was to be discussed.

## MATERIAL AND METHODS

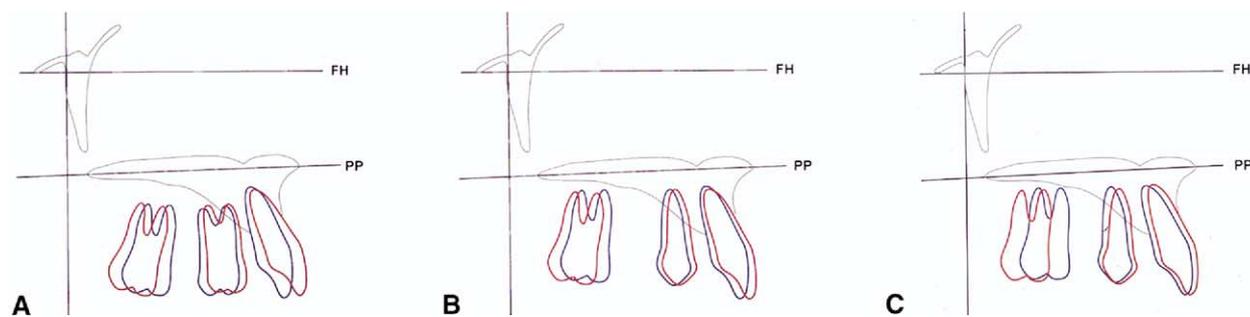
A modified pendulum appliance for bilateral molar distalization was placed in the maxillary arch of 30 patients (14 girls, 16 boys) with a mean age of 11 years 5 months. The mean treatment time was 22 weeks, during which the patients were on a monthly recall

schedule. At these recall sessions, the treating orthodontist adjusted the distal screw integrated into the Nance button a mean 15.4 times by a quarter turn. Although the dentition stage in the molar region was identical in all patients (first molar fully erupted, second and third molars not yet erupted), the patients were subcategorized into 3 equal-sized dentition groups (10 patients each) with respect to the anchorage unit (Table I). In patient group 1 (PG 1), only the first and second deciduous molars were used for anchorage purposes (Fig 1, A). The first premolars of the 10 patients of patient group 2 (PG 2) were erupted and were integrated into the anchorage unit with the second deciduous molars (Fig 1, B). In patient group 3 (PG 3), only the premolars were used for anchorage (Fig 1, C).

The pendulum appliance (Pendulum K) used in this study is a modification of the standard pendulum appliance according to Hilgers. Like the standard pendulum appliance, the Pendulum K consists of a Nance palatal button, occlusal onlays, and pendulum springs made of .032-in TMA. The occlusal onlays of the pendulum appliance consist of wires bonded to the



**Fig 2.** Cephalometric analysis: parameters measured on cephalometric radiographs taken before and after molar distalization (changes in sagittal plane are detailed in text). **A**, Measured angles; **B**, measured distances. S, sella; N, nasion; PNS, posterior nasal spine; ANS, anterior nasal spine; P, pogonion; Or, orbitale; Pt, pterygoid.



**Fig 3.** Average movement patterns of molars, deciduous molars, premolars, and incisors to illustrate dentoalveolar effects and side effects after treatment with pendulum appliance. **A**, Patient group 1; **B**, patient group 2; **C**, patient group 3. FH, Frankfort horizontal plane; PP, palatal plane.

fissures of the anchoring teeth with a temporary composite. A slight bite-opening effect in the molar region is achieved with the occlusal onlays, enabling more rapid distalization by eliminating occlusal interferences.<sup>19,24</sup> For better adherence to the deciduous molars, it is advisable to prepare an occlusal groove corresponding to the thickness of the onlay wire. The pendulum springs are activated before placement to provide for distalization (target force value: 180-200 g).

By adding a distal screw and by initially applying

an uprighting and a toe-in bend, the Pendulum K was further developed into an appliance with simple clinical handling characteristics. The treating orthodontist can reactivate the appliance at the recall appointments simply by adjusting the distal screw, without removing the pendulum springs from the palatal molar tubes.<sup>19,24</sup>

**Measuring the cephalometric radiographs**

The following parameters were measured on the cephalometric radiographs taken at the beginning of

treatment (T1) and after distalization (T2) to determine changes in the sagittal plane (Fig 2):

Angles:

- 1/ANS-PNS: angle between the maxillary central incisors and the palatal plane
- 1/SN: angle between the maxillary central incisors and the anterior cranial base
- 4/ANS-PNS: angle between either the first deciduous maxillary molar or the first maxillary premolar and the palatal plane
- 4/SN: angle between either the first deciduous maxillary molar or the first maxillary premolar and the anterior cranial base
- 6/ANS-PNS: angle between the first permanent maxillary molar and the palatal plane
- 6/SN: angle between the first permanent maxillary molar and the anterior cranial base.

Distances:

- 1-INC/PTV: distance between the incisal edge of the maxillary central incisors and the pterygoid vertical
- 1-CEJ/PTV: distance between the cementoenamel junction and the pterygoid vertical
- 1-AP/PTV: distance between the apical point of the maxillary incisor and the pterygoid vertical
- 4-COR/PTV: distance between the coronal point of either the first deciduous maxillary molar or the maxillary premolar and the pterygoid vertical
- 4-CEJ/PTV: distance between the cementoenamel junction of either the first deciduous maxillary molar or the maxillary premolar and the pterygoid vertical
- 4-AP/PTV: distance between the apical point of either the first deciduous maxillary molar or the maxillary premolar and the pterygoid vertical
- 6-COR/PTV: distance between the coronal point of the first permanent maxillary molar and the pterygoid vertical
- 6-CEJ/PTV: distance between the cementoenamel junction of the first maxillary molar and the pterygoid vertical
- 6-AP/PTV: distance between the apical point of the first maxillary molar and the pterygoid vertical
- 1-CEJ/ANS-PNS: distance between the maxillary central incisors and the palatal plane
- 4-CEJ/ANS-PNS: distance between either the first deciduous maxillary molar or the deciduous premolar and the palatal plane
- 6-CEJ/ANS-PNS: distance between the first permanent maxillary molar and the palatal plane.

In the sagittal plane, the relative mesial movement of the incisors, the first deciduous molars or premolars,

and the relative distal movement of the first molars to the pterygoid vertical (1-CEJ/PTV, 4-CEJ/PTV, and 6-CEJ/PTV, respectively) were measured.

The angles between the long axis of the tooth and the palatal plane or the anterior cranial base were used to determine the extent of labial tipping of the incisors, the tipping of the first deciduous molars or premolars, and the distal tipping of the molars.

In the vertical dimension, a potential intrusion or extrusion of the incisors, the first deciduous molars or premolars, and the first molars in relation to the palatal plane (1-CEJ/ANS-PNS, 4-CEJ/ANS-PNS, and 6-CEJ/ANS-PNS, respectively) was investigated. The reference point for these measurements was the point of intersection between the cementoenamel junction and the long axis of the tooth.

### Determination of the movement pattern

To determine and quantify the tooth movement for the permanent molars, premolars, deciduous molars, and incisors, the quotient of the moved distance of the apical point ( $S_{ap}$ ) and the moved distance of the incisal point ( $S_{inc}$ ) or of the coronal point ( $S_{cor}$ ) was calculated. If the apical point was moved in the opposite direction to the main movement direction of the tooth, the amount received a minus sign. The movement type of negative quotients ( $S_{ap}/S_{cor} < 0$ ) is uncontrolled tipping. The number 0 ( $S_{ap}/S_{cor} = 0$ ) means controlled tipping and the value 1 ( $S_{ap}/S_{cor} = 1$ ) translatory movement. Quotients between these 2 amounts represent a movement between controlled tipping and translation. Values greater than 1 ( $S_{ap}/S_{cor} > 1$ ) are a result of root movement.

The most occlusally located point on the constructed long axis was selected as the incisal or coronal point. The apical point was defined as the radiologic apex for single-rooted teeth. For 2-rooted teeth, the central point between the 2 apices was selected. For 3-rooted molars, the apical point was the central point of a line connecting the 2 buccal apices.

### Statistical analysis

For each variable of the model measurements and cephalometric radiographs, the arithmetic mean and the standard deviation were determined.

To assess the statistical significance of changes between the paired T1 and T2 cephalometric variables, an analysis of variance was performed (post hoc test: Tukey honestly significant difference). Differences with probabilities of less than 5% ( $P < .05$ ) were considered statistically significant.

The lateral cephalograms taken before and after pendulum appliance therapy were traced and measured twice, 4 weeks apart. The size of the total

**Table II.** Dental-linear changes (T1-T2, in millimeters) in sagittal plane (analysis of cephalometric radiographs)

Type of measurement	PG 1		PG 2		PG 3		Total		P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1-incisal/PTV (mm)	-2.75	1.40	-1.65	0.82	-1.75	0.75	-2.05	1.12	1-2*; 1-3*
1-CEJ/PTV	-1.55	0.80	-1.25	0.82	-1.20	0.59	-1.33	0.74	NS
1-apical/PTV	-0.10	1.37	-0.60	1.29	-0.60	1.60	-0.43	1.39	NS
1-CEJ/ANS-PNS	-0.60	0.91	-0.63	0.52	-0.60	0.74	-0.61	0.71	NS
4-coronal/PTV	-1.45	0.98	-1.20	1.70	-0.35	1.03	-1.00	1.33	NS
4-CEJ/PTV	-1.05	0.80	-1.40	1.79	-0.80	0.71	-1.08	1.19	NS
4-apical/PTV	-1.20	1.27	-1.45	1.98	-1.30	1.93	-1.32	1.70	NS
4-CEJ/ANS-PNS	-0.60	0.94	-0.60	0.97	-0.65	0.58	-0.62	0.82	NS
6-coronal/PTV	4.38	1.28	3.78	1.98	4.48	0.79	4.21	1.42	NS
6-CEJ/PTV	3.93	0.86	3.43	1.86	4.20	0.67	3.85	1.24	NS
6-apical/PTV	2.48	1.22	2.78	1.87	3.65	0.94	2.97	1.44	NS
6-CEJ/ANS-PNS	0.30	0.79	0.20	0.86	0.25	0.49	0.25	0.70	NS

\* $P < .05$ ; SD, standard deviation; NS, not significant.

**Table III.** Dental-angular changes (T1-T2, in degrees) in sagittal plane (analysis of cephalometric radiographs)

Type of measurement	PG 1		PG 2		PG 3		Total		P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1/ANS-PNS	-5.05	5.28	-2.60	5.62	-2.20	5.63	-3.28	5.47	NS
1/SN	-5.15	5.71	-2.15	5.75	-2.90	4.75	-3.40	5.39	NS
4/ANS-PNS	-1.75	6.20	1.00	3.72	2.05	5.61	0.43	5.35	NS
4/SN	-0.70	6.80	0.40	3.06	1.80	5.26	0.50	5.19	NS
6/ANS-PNS	6.15	3.42	4.10	3.75	2.30	1.58	4.18	3.36	1-3*
6/SN	6.35	3.46	5.05	3.97	2.55	1.52	4.65	3.45	1-3*

\* $P < .05$ .

measurement error (ME) was calculated with the formula  $ME = (\sum d^2/2n)$ , with  $d$  being the difference between 2 measurements and  $n$  the number of double measurements. The overall ME of the various measurements was no greater than 0.6 mm or  $0.8^\circ$ .

## RESULTS

### Analysis of the cephalometric radiographs

The mean values and standard deviations of the dental-linear and dental-angular changes are shown in Tables II and III. The extent of molar distalization and the reciprocal mesial movement of the first premolar or the deciduous molar and the incisor were compared (Fig 3), and the percentage of individual tooth movement in relation to the entire movement in the sagittal plane was calculated (values and formulae for calculation are given in Table IV).

The mean protrusion value of the maxillary central incisors in the area of the cementsoenamel junction for all groups was  $1.33 \pm 0.74$  mm, and the mean extrusion value was  $0.61 \pm 0.71$  mm. The extent of mean labial tipping was  $3.28^\circ \pm 5.47^\circ$  to the palatal plane and  $3.40^\circ \pm 5.39^\circ$  to the anterior cranial base.

The first premolars or deciduous molars were ac-

cordingly moved mesially by  $1.08 \pm 1.19$  mm and extruded by  $0.63 \pm 0.86$  mm. They were uprighted by a mean of  $0.43^\circ \pm 5.35^\circ$  to the palatal plane and  $0.50^\circ \pm 5.19^\circ$  to the anterior cranial base.

The 6-year molars underwent a mean distal tipping of  $4.18^\circ \pm 3.36^\circ$  in relation to the palatal plane and  $4.75^\circ \pm 3.44^\circ$  to the anterior cranial base. Their mean distalization was  $3.85 \pm 1.24$  mm and their intrusion to the palatal plane  $0.25 \pm 0.70$  mm.

According to the values of the 6-year molars and the incisors, the mean distalization of the molars was 74.18% of the total movement in the sagittal plane, whereas an anchorage loss of 25.82% resulted from a mean mesial movement of  $1.33 \pm 0.74$  mm of the incisors. Analogously, the values for the molars and first premolars or deciduous molars yielded a molar distalization of 76.29% and a mesial movement of the anchorage teeth of 23.71% of the total movement in the sagittal plane.

Significant differences between the 3 patient groups were observed in the dental-angular measurements with respect to the extent of molar tipping and incisor protrusion: the distal tipping of the 6-year molars was

**Table IV.** Proportion of molar distalization (T1-T2) in total movement in sagittal plane, in each case in relation to measurements taken in regions of incisors and either deciduous molars or premolars (molar distalization and mesial movement of anterior teeth or molar distalization and mesialization of either deciduous molars or premolars)

Type of measurement	PG 1		PG 2		PG 3		Total		P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Dental-linear									
1-CEJ/PTV (mm)	-1.55	0.80	-1.25	0.82	-1.20	0.59	-1.33	0.74	NS
4-CEJ/PTV (mm)	-1.05	0.80	-1.40	1.79	-0.80	0.71	-1.08	1.19	NS
6-CEJ/PTV (mm)	3.93	0.86	3.43	1.86	4.20	0.67	3.85	1.24	NS
Total movement in sagittal plane 1+6 <sup>†</sup> (mm)	5.48	1.13	4.68	1.89	5.40	0.66	5.18	1.33	NS
Total movement in sagittal plane 4+6 <sup>‡</sup> (mm)	4.98	0.92	4.83	1.76	5.00	0.88	4.93	1.21	NS
Calculation of relative movement									
Extent of molar distalization with respect to total movement 1+6 <sup>§</sup> (%)	72.24	11.16	72.36	22.84	77.95	10.10	74.18	15.48	NS
Extent of molar distalization with respect to total movement 4+6 <sup>  </sup> (%)	79.49	14.65	66.08	20.80	85.11	11.65	76.29	18.30	2-3*

\*P < .05.

<sup>†</sup>Total movement in sagittal plane 1+6 = [1-CEJ/PTV] + [6-CEJ/PTV].

<sup>‡</sup>Total movement in sagittal plane 4+6 = [4-CEJ/PTV] + [6-CEJ/PTV].

<sup>§</sup>Calculation of extent of molar distalization with respect to total movement 1+6:  $100 \times (6\text{-CEJ/PTV}) / ([1\text{-CEJ/PTV}] + [6\text{-CEJ/PTV}])$ .

<sup>||</sup>Calculation of extent of molar distalization with respect to total movement 4+6:  $100 \times (6\text{-CEJ/PTV}) / ([4\text{-CEJ/PTV}] + [6\text{-CEJ/PTV}])$ .

**Table V.** Method for characterization and quantification of the tooth movement (T1-T2) achieved with pendulum appliance treatment

Type of measurement	PG 1		PG 2		PG 3		Total		P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Incisors									
S <sub>ap</sub> /S <sub>inc</sub>	0.01	0.57	0.27	0.70	0.92	0.98	0.40	0.84	1-3*
Deciduous first molars/premolars									
S <sub>ap</sub> /S <sub>cor</sub>	0.66	0.86	1.10	0.81	1.67	2.52	1.14	1.61	NS
First molars									
S <sub>ap</sub> /S <sub>cor</sub>	0.54	0.31	0.67	0.53	0.83	0.24	0.68	0.39	NS

\*P < .05.

significantly less severe ( $2.3^\circ \pm 1.58^\circ$  to the palatal plane and  $2.55^\circ \pm 1.52^\circ$  to the anterior cranial base) in patients with premolar anchorage only, compared with deciduous molar anchorage ( $6.15^\circ \pm 3.42^\circ$  and  $6.35^\circ \pm 3.46^\circ$  in PG 1 to both reference planes).

The incisor protrusion relative to molar distalization was significantly more pronounced in PG 1, with a value of  $2.75 \pm 1.4$  mm, compared with the other 2 groups ( $1.65 \pm 0.82$  mm in PG 2 and  $1.75 \pm 0.75$  mm in PG 3).

#### Movement pattern of molars, premolars, and incisors

The type of tooth movement during treatment with the pendulum appliance varied not only with respect to the individual tooth types but also between patient groups (Table V). Although controlled tipping of the incisors was

observed among patients with deciduous molar anchorage only ( $S_{ap}/S_{inc} = 0.01$ ) and with mixed premolar and deciduous molar anchorage ( $S_{ap}/S_{inc} = 0.27$ ), the tooth movement was almost translatory in patients with premolar anchorage only ( $S_{ap}/S_{inc} = 0.92$ ;  $P = .039$ ). Three different movement patterns were observed in the anchorage unit. The first deciduous molars in PG 1 had a movement pattern between tipping and translation ( $S_{ap}/S_{cor} = 0.66$ ), whereas an almost translatory mesial movement ( $S_{ap}/S_{cor} = 1.10$ ) was observed for the first premolars in the mixed anchorage units of PG 2. In contrast, a root movement was observed for the premolars in PG 3 ( $S_{ap}/S_{cor} = 1.67$ ). The first molars in PG 1 underwent a combination of controlled tipping and translation during their distalization ( $S_{ap}/S_{cor} = 0.54$ ). In contrast, almost translatory distalization was observed for the molars of PG 3 ( $S_{ap}/S_{cor} = 0.83$ ).

## DISCUSSION

### Anchorage design of the pendulum appliance

With most pendulum appliances, as with almost all compliance-free appliances for molar distalization described to date, the anchorage block consists of a Nance palatal button and anchoring teeth in the same dental arch. The acrylic button fits tightly against the palatal mucosa in the region of the palatal rugae and is linked to the teeth with occlusally bonded onlays. After placement of the preactivated pendulum springs, the anchorage unit is designed to counteract the reactive forces and moments.

The anchorage effect of the anterior palatal plate to the resilient palatal mucosa might be due merely to hydrodynamic interactions and thus not represent true stationary anchorage.<sup>31</sup> However, additional vertical stabilization might result from tongue pressure while swallowing. Clinical studies have demonstrated that the anchorage value of the soft-tissue-supported Nance holding arch should not be overestimated.<sup>32,33</sup> Thus, the anchorage mainly depends on the dental anchorage quality of the teeth. The resistance potential of these anchorage teeth is determined by the size of the anchorage-relevant surfaces and thus by the number of teeth involved, by the root topography and the attachment level, and by the bone structure and the desmodontal reactive state.<sup>31</sup> The bone structure and attachment level can be regarded as almost constant among children and adolescents treated with pendulum appliances, but differences might occur with respect to the number of teeth, root topography, and desmodontal reactive state.

No root resorptions at permanent teeth were detectable on the panoramic radiographs.

### Number of anchorage teeth

Initially, Hilgers secured only the anterior part of the appliance, using bands on the maxillary first premolars or deciduous molars and a holding arch to the Nance button. However, with this anchorage preparation, Hilgers observed that, after placing the springs, the Nance buttons tended to lift, the premolars tipped, and pressure points resulted from settling of the button margin.<sup>13</sup> Therefore, he recommended that supporting elements should be bonded occlusally to the maxillary second premolars or second deciduous molars for additional stability. In their reports of pendulum appliance modification for adult treatment, Kinzinger et al<sup>23,25</sup> described the additional bonding of occlusal onlays to the canines to obtain additional anchorage support.

Studies of other intraoral distalizing appliances

have shown that a marked loss of anchorage occurs if only 2 teeth are included in the anchorage unit.<sup>12,34</sup>

Consequently, the reactive segment should consist of as many anchorage teeth as possible, which are combined to form a "multi-rooted anterior anchorage unit" with occlusal onlays and the Nance button, and therefore permit uniform periodontal pressure distribution.

### Anchorage quality of deciduous molars and premolars, root topography

The desmodontal anchorage quality of the anchoring teeth depends largely on their root surfaces and root topography. There are no sound indications in the literature with respect to the root surface of deciduous molars. Even if the root surface of deciduous molars and premolars can be assumed to be almost identical, the anchorage quality of the deciduous molars undergoes a constant decrease during physiologic resorption, resulting in an imbalance in favor of the premolars.

The results of this study demonstrate that both the extent and the quality of molar distalization are better and that side effects are less pronounced in the anchorage and incisor region if premolars alone are used for anchorage. In this respect, more severe side effects must be expected when anchorage is performed with deciduous molars or with both premolars and deciduous molars. It is advisable to perform an initial test for increased tooth mobility, especially when using deciduous molars for anchorage, to avoid having to remove the appliance prematurely when the anchorage quality has been overestimated.

A panoramic radiograph also provides information on the extent of root resorption in deciduous molars and thus indirectly on the quality of such teeth for anchorage purposes during pendulum appliance therapy.

### Desmodontal reactive state, potential causes of reduced anchorage

The primarily unmoved tooth in a desmodontal resting state offers the best tissue resistance.<sup>35,36</sup> Initial leveling increases the proliferation rate of cells relevant to the remodeling process in the anchorage unit and increases the readiness for reactive movement.<sup>37</sup> Therefore, initial leveling should not be performed in the region of the anchorage unit when placing a pendulum appliance. When using a pendulum appliance and a multibracket appliance simultaneously in the anterior segment, the segmented archwire should be of passive design.

Grummons<sup>22</sup> used pendulum appliance modifications in which a palatal button is not incorporated. Although the anchorage effect of the Nance anterior

palatal plate on the resilient palatal mucosa should not be overrated, its omission is most likely to result in an increased loss of anchorage.

### Potential measures for increased anchorage

When an endosseous implant is used in the region of the hard palate or miniscrews, stationary intraoral anchorage can be achieved without teeth being incorporated. Individual case studies have shown that combinations of palatal implant and pendulum appliance,<sup>25</sup> miniscrews, anchoring plate, and pendulum appliance,<sup>21</sup> or anchoring screws and distal jet<sup>38</sup> can offer reasonable alternatives for anchorage. The fixing of a pendulum appliance to an osseointegrated palatal implant of the Orthosystem (Institut Straumann, Waldenburg, Switzerland) not only represents a significant improvement in anchorage quality during molar distalization but also permits stationary anchorage with a transpalatal arch during the subsequent distal guidance of the premolars and canines. However, these anchorage options cannot be considered for typical patients. They represent a reasonable treatment alternative only in exceptional cases, such as adults with problematic periodontal anchorage or in mixed dentitions with early loss of the deciduous molars.

Favero<sup>17</sup> described another means of increasing anchorage: his modified pendulum appliance for the lingual technique. In the Pendulum F, the acrylic portion of the Nance button has a larger dimension than in other pendulum appliances and can accommodate in the anterior region a segmented wire, which is inserted in the lingual brackets of the incisors.

An increase in biological anchorage quality is also conceivable: occlusal forces can be used therapeutically for increased anchorage if the composite onlays to which the wires are attached are formed with an occlusal relief. However, this method can be applied only if the mandibular arch has sufficient teeth, which are in a stable position (ie, no orthodontic treatment is performed simultaneously in the mandible).

### Distal tipping of the first molars

In a clinical study by the present authors,<sup>30</sup> the efficiency of a pendulum appliance for first molar distalization related to the second and third molar eruption stage was investigated in 36 patients. The results showed that, in the distalization direction, a tooth germ acts as a fulcrum for the mesially adjacent tooth: the tipping of the first molars was notably greater when the 12-year molar was still at the germ stage. However, when second molars were completely erupted, the first molar distalization was almost bodily. In the present study, all second molars were still at the germ stage. The root growth of patients with premolar

anchorage only was more advanced than that of those with deciduous molar anchorage. This topographic relationship might account for the distal tipping of the first molars having been significantly less pronounced in patients with premolar anchorage only.

### Comparison with other studies of treatment with pendulum appliances

A tendency toward the same effects of dental-linear and dental-angular changes is reported in all studies published to date on treatment with a pendulum appliance.<sup>16,19,26-30</sup> For indirect effects on the incisors (mesial drift and labial tipping), values between 0.75 mm/1.7°<sup>27</sup> and 3.7 mm/4.9°<sup>29</sup> were observed. A potential effect on the premaxilla cannot be ruled out, although published studies<sup>16,19,26-30</sup> have indicated that no skeletal changes occur in the region of the maxilla (no shift of the A-point to ventral), even when children and adolescents are treated with a pendulum appliance. This might also be due to the short treatment time.

With respect to the anchorage block, the mean values measured for linear mesialization and mesial tipping of the premolars and deciduous molars were between 1.08 mm/0.43° (present study) and 2.55 mm<sup>26</sup> or 1.5°.<sup>28</sup> The greatest differences are observed in the quality of molar movement with a pendulum appliance. In the 2 previous studies<sup>19,30</sup> and in this study, the Pendulum K, with its integrated uprighting and toe-in bends, enabled almost translatory molar distalization, with distal tipping between 3° and 4.65°. Distal tipping of the first molar reached only 6° when a standard pendulum appliance with subsequent uprighting activation was used.<sup>16</sup> When the standard pendulum appliance according to Hilgers was used without uprighting activation in the region of the pendulum springs, pronounced tipping of the molars by up to 14.5°<sup>27</sup> and 15.7°<sup>29</sup> was observed. The proportion of molar distalization in relation to the total movement varied between 57%<sup>26</sup> and 76% (present study and Bussick and McNamara<sup>28</sup>).

No reactive extrusion of the teeth in the anchorage region was observed in this study and others<sup>16,19,30</sup> when pendulum appliance types with uprighting activations in the region of the pendulum springs were used.

With the exception of the present study, only Bussick and McNamara<sup>28</sup> and Kinzinger et al<sup>19</sup> differentiated the anchorage units with respect to the integration of deciduous molars and divided the patients into 2 groups. This showed no significant differences in the dental-linear and dental-angular measurements in the maxillary region between the patients with mixed premolar/deciduous molar an-

chorage<sup>28</sup> or with mixed premolar/deciduous molar anchorage and deciduous molar anchorage only<sup>19</sup> and patients with premolar anchorage only. However, tendencies observed, especially in the latter study, are supported by the findings of the present study, in which the patient groups were subdivided into 3 dentition stages. In neither of the previous studies<sup>19,28</sup> was any distinction made with respect to the developmental and eruption stages of the molars. In its methodology (identical dentition in the molar region: first molar fully erupted, second and third molars not erupted), the present study therefore seems more suitable for drawing conclusions about the most favorable treatment time with respect to the dentition stage in the anchorage region.

### CONCLUSIONS

The findings of this clinical study demonstrate that both deciduous molars and premolars are fundamentally suitable for intraoral anchorage when a pendulum appliance is used for molar distalization. When only premolars are used for anchorage, the dentoalveolar side effects are least pronounced in the region of the incisors and premolars, and the effects are most favorable in the molar region.

Our results show clear-cut tendencies between the groups differentiated with respect to the dentition in the anchorage region: in patients in whom only premolars were used for desmodontal anchorage, the extent of molar distalization was greatest, the distal tipping was least pronounced, and the type of tooth movement was almost translatory. In contrast, the distal tipping of the molars and the protrusions of the incisors were most pronounced in the youngest patients, who had deciduous molar anchorage only. A limitation of this study is that the number of patients in each group was relatively small.

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