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Treatment effects of intraoral appliances with conventional anchorage designs for non-compliance maxillary molar distalization. A literature review

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SUMMARY Since the end of the 1970s, various appliances with intramaxillary anchorage for distalization of the upper molars have been described as an alternative to headgear. The major advantages of these innovative appliances are that they act permanently and are independent of patient compliance. The purpose of this study was to compare the efficiency, both quantitatively and qualitatively, of various appliance types with intramaxillary anchorage for non-compliance molar distalization. Eighty-five papers were reviewed, and 22 were identified as being suitable for inclusion. The selection was based on compliance with the following criteria: treatment group with at least 10 non-syndromal patients, conventional intraoral anchorage design using a palatal button and anchorage teeth, consistent cephalometric measurements in clinical–epidemiological studies, exact data on the course of treatment, and statistical presentation of the measured outcomes and their standard deviations.

The results show that non-compliance molar distalization is possible with numerous different appliances. While molar distalization with standard pendulum appliances exhibited the largest values for dental-linear distalization, it also resulted in concurrent, substantial therapeutically undesirable distal tipping. However, specific modifications to the pendulum appliance allow achievement of almost bodily molar distalization. Different outcomes are quoted in the studies for the efficiency of loaded spring systems for distal molar movement, but it seems that the first class appliance and the palatal distal jet are more efficient than the vestibular Jones Jig.

The studies identify anchorage loss as being found in the area of the incisors rather than the area of the first premolars. There was a trend for more substantial reciprocal side-effects to occur when only two teeth were included in the anchorage unit. Vertical components acting on the molars, premolars, and incisors, such as intrusion and extrusion, tended to be of secondary importance and, therefore, may be disregarded.

Introduction

In the course of orthodontic treatment, distalization of the maxillary molars is often indicated to gain space in the upper dental arch and/or to correct distal tooth malpositions. Multiple treatment methods and appliances for molar distalization have been described. In addition to the traditionally used headgear types and removable active plates, a trend has been seen since the end of the 1970s which favours distalization appliances with intramaxillary anchorage. The efficiency of these innovative appliances does not depend on patient compliance. Their design includes two fundamental elements: the active components that distalize the molars and an anchorage unit that compensates the reciprocally acting force systems. The anchorage unit (combinations of dental anchorage and soft tissue rests) is almost identical between intraoral appliances for non-compliance molar distalization, although absolute and supportive anchorage designs with palatal implants and miniscrews have been described (Männchen, 1999; Byloff *et al.*, 2000; Karaman *et al.*, 2002; Kinzinger and Diedrich, 2002, Favero *et al.*, 2003; Keles *et al.*, 2003; Kyung *et al.*, 2003; Gelgör *et al.*, 2004; Kinzinger *et al.*, 2004b, 2006; Kircelli *et al.*, 2005; Escobar *et al.*, 2007; Öncag *et al.*, 2007). The principal differences can be found in the material and the type of application of the molar-distalizing components.

The active components of the standard pendulum appliance described by Hilgers (1992) are two pendulum springs anchored to the dorsal portion of the button, made of 0.032 inch titanium molybdenum alloy wire, which are inserted in the pre-activated state into palatal sheaths of the molar bands. Various modifications of the appliance (Byloff *et al.*, 1997; Kinzinger *et al.*, 2000, Kinzinger and Diedrich, 2007) are reported to counteract tipping and palatal movements which may occur because of the arch-like radius of the pendulum springs in order to make tooth movement as translatory as possible.

The principle of force application in distalization appliances with magnets (Itoh *et al.*, 1991; Bondemark and Kurol, 1992) relies on the force of repulsion found between two homopolar samarium/cobalt magnets. The magnets are attached buccally with ribbon arches, the distal magnet being fitted directly to the headgear tube of the first molar. Bondemark *et al.* (1994), Bondemark and Kurol (1998), and Bondemark (2000) combined the Nance button with open nickel titanium (NiTi) springs. These coil springs are fitted to vestibular arch sections. In the Jones Jig appliance (Jones and White, 1992), the NiTi coil springs are on an arch section-like structure that is fitted to buccal tubes of the molars.

The distal jet (Carano and Testa, 1996; Bowman, 1998) has a force-applying component that, unlike the Jones Jig, is in a palatal location. Two tubes that are incorporated bilaterally into the Nance button are end points to open NiTi coil springs which, through a bayonet bend, can deliver a distalization force to the tubes located palatally on the upper molar bands. On account of their fundamental components, the Jones Jig and the distal jet may be considered design variants. Differences exist only in the location of force application: vestibularly in one and palatally in the other.

The first class appliance (Fortini *et al.*, 1999) may be considered as a specialized design: a formative screw that is fitted buccally to the molar tubes and premolars is the distalizing component. The NiTi springs are fitted palatally to spring-loaded splints, counteracting the appliance-related rotational moments. The Nance button has a butterfly-shaped design fitted to premolar bands and, through the spring splint, to the molar bands.

Clinical trials and case studies have shown that in principle all quoted appliances will achieve successful molar distalization in the upper jaw. However, success must not be exclusively with the clinical criterion of space gained between the first molar and second premolar or a primary

Table 1 Studies using various appliances for distalization of the upper molars: number of treatment cases and treatment duration (w = week, m = month), intraoral anchorage designs of the different upper molar distalization appliances, NAB: Nance acrylic button, B: retaining wire soldered to bands; OR: wires bonded as occlusal rests.

Authors	Distalization appliance used	Initial distalization force/quadrant (cN/g)	Number of cases	Mean treatment duration	Soft-tissue rest	Dental anchorage
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	Not available	26	6.5 m	NAB	Two B first premolars
Bussick and McNamara (2000)	Hilgers pendulum	200–250	101	7 ± 2 m	NAB	Four OR premolars/ primary molars
Byloff and Darendeliler (1997)	Hilgers pendulum	200–250	13	16.6 ± 7 w	NAB	Four OR premolars/ primary molars
Byloff *et al.* (1997)	Hilgers pendulum with uprighting activation	200–250	20	27.25 ± 7.12 w	NAB	Four OR
Chiu *et al.* (2005)	Hilgers pendulum/ Distal Jet	230/240	32/32	7 m/10 m	NAB	Four OR/2 B second premolars
Ghosh and Nanda (1996)	Hilgers pendulum	230	41	6.21 ± 1.44 m	NAB	Four OR
Kinzinger *et al.* (2000)	Pendulum K	200–250	50	22.49 w	NAB	Four OR
Kinzinger *et al.* (2004a)	Pendulum K	180–200	36	21.86 w	NAB	Four OR
Kinzinger *et al.* (2005a)	Pendulum K	180–200	30	22.2 w	NAB	Four OR premolars/ primary molars
Kinzinger *et al.* (2005b)	Pendulum K	180–200	66	22 w	NAB	Four OR
Bondemark and Kurol (1992)	Magnets	215	10/10	16.6 w	NAB	Two B second premolars
Bondemark *et al.* (1992)	Magnets/supercoils	225/225	18/18	6 m	NAB + anterior bite plane	Two B second premolars
Bondemark and Kurol (1998)	Magnets/supercoils	Not available	18/18	6 m	NAB + anterior bite plane	Two B second premolars
Bondemark (2000)	Magnets/nickel titanium coils	225/180–200	21/21	5.8 ± 0.97 m, 6.5 ± 1.36 m	NAB	Two B second premolars
Brickman *et al.* (2000)	Jones Jig	70–75	72	6.35 ± 2.75 m	NAB	Two B second premolars
Gulati *et al.* (1998)	Jones Jig	150	10	12 w	NAB	Four B first and second premolars
Haydar and Üner (2000)	Jones Jig	75	10	2.5 m	NAB	Two B second premolars
Mavropoulos *et al.* (2005)	Jones Jig	80	10	17.5 w	NAB	Two B second premolars
Papadopoulos *et al.* (2004)	Modified Jig	80	14	16.5 w	NAB	Two B second premolars
Bolla *et al.* (2002)	Distal Jet	180–240	20	5 m	NAB	Two B first premolars
Ngantung *et al.* (2001)	Distal Jet	240	33	6.7 ± 1.7 m	NAB	Two B second premolars
Fortini *et al.* (2004)	First class appliance	Not available	17	2.4 m	NAB	Two B second premolars/second primary molars

molar, for the force applied to the molars by the appliance is also, and to the same extent, applied reactively, within the individual biomechanical system, to the anchorage unit. The resultant anchorage loss results in a mesialization effect on the anchorage components. Depending on the stage of the dentition, these components are either premolars or primary molars. The anchorage loss also has an effect on the anterior teeth, either indirectly or directly (e.g. through multi-band arch sections). Furthermore, the desired translatory movement of the maxillary molar in the spongious bone may be subjected to deviations in all dimensions while force is being applied, and this may result in tipping, intrusion, and extrusion. Therefore, the objective of this study was to compare, both quantitatively and qualitatively, the molar distalization and anchorage loss effects associated with various appliance types with intramaxillary and conventional anchorage designs. The study investigated the effects on the molars, premolars, and incisors (extent of tooth movements in the sagittal and vertical dimensions, extent of tipping or protrusion). Knowledge of the obtained treatment effects allowed subsequent assessment of the efficiency of the different appliances.

Materials and methods

Using a Medline literature research, 85 papers were selected for further assessment, then examined, and evaluated for suitability by two reviewers (GSMK and ME). These publications included specialized papers on molar distalization in general, clinical studies, and presentations of new appliances as well as case studies. In the course of this research, 22 papers were identified as being suitable (Table 1). The selection of the papers was based on compliance with the following criteria: treatment group with at least 10 non-syndromal patients, 'conventional' intraoral anchorage design with a palatal button and two or four anchorage teeth, i.e. no supportive or absolute anchorage design with miniscrews or implants, consistent cephalometric measurements in clinical–epidemiological studies, exact data on the course of treatment, statistical presentation of the measured outcomes, and their standard deviations.

The most important parameter in the studies (the main effect) with respect to the review was the distalization of the upper 6-year molars induced by the various appliances. Among the papers not considered were, in particular, those

Table 2 Dental-linear distalization of the molars: appliances, reference planes, distalization of the molars (Dis Mov Mol; in mm + standard deviation), and corresponding standard treatment effect (STE Dis Mov Mol; with deviations per 95 per cent confidence interval); PTV = pterygoid vertical, OLp V = occlusal line perpendicular, vertical from the sella landmark, RD1 = line perpendicular to CT plane at point T.

Authors	Appliance	Reference plane	Dis Mov Mol (mm)	Standard treatment effect (STE Dis Mov Mol)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PTV	5.31 ± 1.52	3.49 ± 0.44
Bussick and McNamara (2000)	Hilgers pendulum	PTV	5.70 ± 1.90	3.00 ± 0.41
Byloff and Darendeliler (1997)	Hilgers pendulum	PTV	3.39 ± 1.25	2.71 ± 1.06
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PTV	4.14 ± 1.61	2.57 ± 0.84
Chiu *et al.* (2005)	Hilgers pendulum	PTV	6.1 ± 1.8	2.55 ± 0.66
Ghosh and Nanda (1996)	Hilgers pendulum	PTV	3.37 ± 2.10	1.60 ± 0.49
Kinzinger *et al.* (2000)	Pendulum K	PTV	2.88 ± 1.59	1.81 ± 0.47
Kinzinger *et al.* (2004a)	Pendulum K	PTV	3.14 ± 0.92	3.41 ± 0.73
Kinzinger *et al.* (2005a)	Pendulum K	PTV	3.85 ± 1.24	3.10 ± 0.74
Kinzinger *et al.* (2005b)	Pendulum K	PTV	3.46 ± 1.80	1.92 ± 0.41
Bondemark and Kurol (1992)	Magnets	OLp V	4.20 ± 0.92	4.57 ± 1.18
Bondemark *et al.* (1994)	Magnets	OLp V	2.02± 0.94	2.34 ± 0.84
Bondemark *et al.* (1994)	Supercoils	OLp V	3.20 ± 1.09	2.94 ± 0.94
Bondemark and Kurol (1998)	Magnets	OLp V	2.20 ± 1.05	2.10 ± 0.82
Bondemark and Kurol (1998)	Supercoils	OLp V	2.60 ± 1.17	2.22 ± 0.82
Bondemark (2000)	Magnets	OLp V	2.60 ± 0.51	5.10 ± 1.25
Bondemark (2000)	Nickel titanium coils	OLp V	2.50 ± 0.69	3.62 ± 0.98
Brickman *et al.* (2000)	Jones Jig	PTV	2.51 ± 1.35	1.86 ± 0.57
Gulati *et al.* (1998)	Jones Jig	OLp V	2.75 ± 0.85	3.24 ± 2.29
Gulati *et al.* (1998)	Jones Jig	PTV	2.95 ± 0.76	3.88 ± 1.49
Haydar and Üner (2000)	Jones Jig	RD1	2.80 ± 0.79	3.54 ± 1.00
Mavropoulos *et al.* (2005)	Jones Jig	PTV	1.90 ± 2.12	0.90 ± 0.92
Papadopoulos *et al.* (2004)	Modified Jig	PTV	1.40 ± 2.06	0.68 ± 0.76
Bolla *et al.* (2002)	Distal Jet	PTV	3.20 ± 1.40	2.29 ± 0.80
Chiu *et al.* (2005)	Distal Jet	PTV	2.8 ± 1.1	2.55 ± 0.66
Ngantung *et al.* (2001)	Distal Jet	PTV	2.12 ± 1.84	1.15 ± 0.52
Fortini *et al.* (2004)	First class appliance	Olp-S	4.00 ± 1.50	2.67 ± 0.92

Table 3 Intrusion and extrusion of the molars during distalization: appliances, reference planes, intrusion (−)/extrusion (+) of the molars (In/Ex Mol; in mm + standard deviation), and corresponding standard treatment effect (STE In/Ex Mol; with deviations per 95 per cent confidence interval); PP = palatal plane, SN = anterior cranial base, OL = occlusal line, NA = not available.

Authors	Appliance	Reference plane	In/Ex Mol (mm)	Standard treatment effect (STE In/Ex Mol)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PP	−1.20 ± 1.37	−0.88 ± 0.57
Bussick and McNamara (2000)	Hilgers pendulum	PP	0.10 ± 1.30	0.08 ± 0.27
Byloff and Darendeliler (1997)	Hilgers pendulum	PP	−1.68 ± 1.33	−1.95 ± 0.94
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PP	−1.42 ± 0.87	−1.60 ± 0.71
Chiu *et al.* (2005)	Hilgers pendulum	PP	0.5 ± 1.1	0.45 ± 0.50
Ghosh and Nanda (1996)	Hilgers pendulum	PP	−0.10 ±1.29	−0.08 ± 0.43
Kinzinger *et al.* (2000)	Pendulum K	PP	0.37 ± 0.56	0.66 ± 0.41
Kinzinger *et al.* (2004a)	Pendulum K	PP	0.63 ± 0.70	0.90 ± 0.49
Kinzinger *et al.* (2005a)	Pendulum K	PP	−0.25 ± 0.70	−0.36 ± 0.51
Kinzinger *et al.* (2005b)	Pendulum K	PP	0.39 ± 0.80	0.49 ± 0.35
Bondemark and Kurol (1992)	Magnets	—	NA	NA
Bondemark *et al.* (1994)	Magnets	PP	0.80 ± 0.66	1.21 ± 0.71
Bondemark *et al.* (1994)	Supercoils	PP	0.80 ± 0.66	1.21 ± 0.71
Bondemark and Kurol (1998)	Magnets	PP	1.10 ± 0.61	1.80 ± 0.78
Bondemark and Kurol (1998)	Supercoils	PP	1.10 ± 0.61	1.80 ± 0.78
Bondemark (2000)	Magnets	—	NA	NA
Bondemark (2000)	Nickel titanium coils	—	NA	NA
Brickman *et al.* (2000)	Jones Jig	PP	0.14 ± 1.39	0.10 ± 0.33
Gulati *et al.* (1998)	Jones Jig	OL	1.60 ± 1.25	1.28 ± 0.96
Haydar and Üner (2000)	Jones Jig	SN	0.95 ± 0.83	1.14 ± 0.67
Mavropoulos *et al.* (2005)	Jones Jig	PP	−0.63 ± 0.90	0.7 ± 0.90
Papadopoulos *et al.* (2004)	Modified Jig	PP	−0.40 ± 1.27	0.31 ± 0.74
Bolla *et al.* (2002)	Distal Jet	PP	0.50 ± 1.50	0.33 ± 0.62
Chiu *et al.* (2005)	Distal Jet	PP	1.0 ± 1.1	0.91 ± 0.51
Ngantung *et al.* (2001)	Distal Jet	PP	0.01 ± 1.72	0.01 ± 0.48
Fortini *et al.* (2004)	First class appliance	SN	1.20 ± 2.00	0.60 ± 0.69

which did not report any data on anchorage loss since this side-effect, which results clinically in mesialization and/or tipping of the premolars and incisors, is an important aspect that needs consideration. Therefore, it is an essential part of the qualitative assessment of the relationship between the main and side-effects. Case studies that described the treatment of only a few patients were not considered in the review even when their data were correct and appropriately documented by the above criteria because these data are not quantitatively representative. Finally, publications that did not contain any data or only inexact ones on standard deviations were not taken into account as this value is necessary for computing the treatment effect.

To determine the treatment-related horizontal, vertical, and angular movements of the molars, premolars, and incisors, the lateral cephalographic images pre- and post-treatment presented in the individual studies were registered according to defined landmarks and standardized planes in order to calculate the outcome as the difference between them. As to the sagittal dental-linear parameters, analyses in which the OLp vertical (perpendicular from sella to the occlusal line) and the pterygoid vertical [PTV; perpendicular from the pterygoid landmark to the Frankfort horizontal (FH) plane] were used as reference planes were preferred. The reference planes for the vertical dental-linear parameters were the palatal plane (PP) and the anterior cranial base (SN). Angular measurements were taken in relation to the anterior cranial base (SN), the PP, and the FH plane. For dental measurements, different landmarks were used according to the chosen analytical method. For instance, the mesial or distal cusps, the mesial or distal approximal surfaces, or the centroid of the tooth were used as points of measurement for the first molar. Provided the relationship between the movement-induced differences remains constant and can be considered an absolute value for computing the effects, the individual location of the respective points of measurement and their reference plane can be neglected.

A method described by Hedges and Olkin (1985) to assess treatment effects was used. To ensure mathematically correct processing of the results of the individual studies, the individual cephalometric data were computed to obtain the standardized treatment effects. The appropriate formula was

Standard treatment effect $d(s) = [M\text{ (post-treatment)} - M\text{ (pre-treatment)}]/\text{SD (pooled)}$,

where M (pre-treatment) is the value measured before, M (post-treatment) the value measured after force application,

Table 4 Distal tipping of the molars: appliances, reference planes, molar tipping (Dis Tip Mol; in degrees + standard deviation), and corresponding standard treatment effect (STE Dis Tip Mol; with deviations per 95 per cent confidence interval); SN=anterior cranial base, FH=Frankfurt horizontal, PP=palatal plane, NA=not available.

Authors	Appliance	Reference plane	Dis Tip Mol (degrees)	Standard treatment effect (STE Dis Tip Mol)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	SN	13.06 ± 7.52	1.74 ± 0.64
Bussick and McNamara (2000)	Hilgers pendulum	FH	10.60 ± 5.60	1.89 ± 0.33
Byloff and Darendeliler (1997)	Hilgers pendulum	PP	14.50 ± 8.33	1.74 ± 0.90
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PP	6.07 ± 5.15	1.18 ± 0.67
Chiu *et al.* (2005)	Hilgers pendulum	FH	10.7 ± 5.5	1.95 ± 0.60
Ghosh and Nanda (1996)	Hilgers pendulum	SN	8.36 ± 8.37	0.99 ± 0.45
Kinzinger *et al.* (2000)	Pendulum K	SN	3.24 ± 4.28	0.76 ± 0.41
Kinzinger *et al.* (2000)	Pendulum K	PP	3.14 ± 3.99	0.79 ± 0.41
Kinzinger *et al.* (2004a)	Pendulum K	SN	3.07 ± 4.02	0.76 ± 0.47
Kinzinger *et al.* (2004a)	Pendulum K	PP	3.29 ± 4.31	0.76 ± 0.47
Kinzinger *et al.* (2005a)	Pendulum K	SN	4.65 ± 3.45	1.35 ± 0.57
Kinzinger *et al.* (2005a)	Pendulum K	PP	4.18 ± 3.36	1.24 ± 0.55
Kinzinger *et al.* (2005b)	Pendulum K	SN	4.24 ± 4.67	0.91 ± 0.35
Kinzinger *et al.* (2005b)	Pendulum K	PP	4.75 ± 4.50	1.10 ± 0.37
Bondemark and Kurol (1992)	Magnets	SN	8.00 ± 3.53	2.27 ± 0.80
Bondemark *et al.* (1994)	Magnets	SN	1.00 ± 1.39	0.72 ± 0.67
Bondemark *et al.* (1994)	Supercoils	SN	1.00 ± 1.38	0.72 ± 0.67
Bondemark and Kurol (1998)	Magnets	—	NA	NA
Bondemark and Kurol (1998)	Supercoils	—	NA	NA
Bondemark (2000)	Magnets	PP	2.20 ± 2.53	0.87 ± 0.63
Bondemark (2000)	Nickel titanium coils	PP	8.80 ± 2.82	3.12 ± 0.90
Brickman *et al.* (2000)	Jones Jig	SN	7.53 ± 4.57	1.65 ± 0.53
Gulati *et al.* (1998)	Jones Jig	SN	3.50 ± 1.85	1.89 ± 1.06
Haydar and Üner (2000)	Jones Jig	SN	7.85 ± 5.18	1.52 ± 0.71
Mavropoulos *et al.* (2005)	Jones Jig	SN	6.8 ± 4.8	1.42 ± 0.98
Papadopoulos *et al.* (2004)	Modified Jig	SN	6.80 ± 5.91	1.15 ± 0.80
Bolla *et al.* (2002)	Distal Jet	SN	3.10 ± 2.80	1.11 ± 0.67
Chiu *et al.* (2005)	Distal Jet	FH	5.0 ± 3.6	1.39 ± 0.55
Ngantung *et al.* (2001)	Distal Jet	SN	3.26 ± 3.68	0.89 ± 0.51
Fortini *et al.* (2004)	First class appliance	SN	4.60 ± 2.60	1.77 ± 0.78

and SD (pooled) the appropriate standard deviation. No control groups were reported in the available studies. Thus, the effect was considered to be the difference between pre- and post-treatment. This resulted in the following modification of the above formula:

Standard treatment effect $d(s) = M$ (effect)/SD (effect)

The confidence interval δ was computed as follows:

$\delta(u) = d(s) - [C(\alpha/2) \times \hat{o}(d)]$ and $\delta(u) = d(s) + [C(\alpha/2) \times \hat{o}(d)]$

where $C(\alpha/2)$ is 1.96 [for a $(1 - \alpha/2)$ quantile at 95 per cent with a probability of error amounting to $\alpha = 5\%$]; and where $\hat{o}(d)$ is the standard deviation of the standard treatment effect, which was computed as follows:

$$\hat{o}(d) = \sqrt{(8 + d^2)/4n}$$

where n is the number of investigated items.

In some of the selected papers, data on the percentage share of molar distalization in the total movement in the sagittal dimension were reported as an addition to the distalization measurements. These data were included as reported by the respective authors. For papers in which no data on the percentage of molar distalization in the total was published, this share was computed as follows:

Distalization 6-years (in mm) x 100%/[Distalization 6-years (in mm) + Mesialization premolars and incisors (in mm)].

Studies on the effects of appliances for non-compliance molar distalization do not use a control group because the treatment period is too short (see Table 1) for normal growth processes to play a significant role in the changes (Fuziy *et al.*, 2006).

Results

Effects on the molars

The longest linear distalization measurements for the molars (Table 2) were reported in studies in which molars were

Table 5 Dental-linear mesialization of the premolars: appliances, reference planes, mesialization of the premolars (Mes Mov PM; in mm + standard deviation), and corresponding standard treatment effect (STE Mes Mov PM; with deviations per 95 per cent confidence interval); PTV=pterygoid vertical, OLp V=occlusal line perpendicular, vertical from the sella landmark, RD1=line perpendicular to CT plane at point T, NA=not available.

Authors	Appliance	Reference plane	Mes Mov PM (mm)	Standard treatment effect (STE Mes Mov PM)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PTV	2.21 ± 1.3	1.70 ± 0.63
Bussick and McNamara (2000)	Hilgers pendulum	PTV	1.80 ± 2.00	0.90 ± 0.33
Byloff and Darendeliler (1997)	Hilgers pendulum	PTV	1.63 ± 1.37	1.19 ± 0.84
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PTV	2.22 ± 0.98	2.27 ± 0.8
Chiu *et al.* (2005)	Hilgers pendulum	PTV	1.4 ± 1.9	0.74 ± 0.51
Ghosh and Nanda (1996)	Hilgers pendulum	PTV	2.55 ± 1.90	1.34 ± 0.47
Kinzinger *et al.* (2000)	Pendulum K	PTV	NA	NA
Kinzinger *et al.* (2004a)	Pendulum K	PTV	NA	NA
Kinzinger *et al.* (2005a)	Pendulum K	PTV	1.08 ± 1.19	0.91 ± 0.53
Kinzinger *et al.* (2005b)	Pendulum K	PTV	NA	NA
Bondemark and Kurol (1992)	Magnets	OLp V	NA	NA
Bondemark *et al.* (1994)	Magnets	OLp V	NA	NA
Bondemark *et al.* (1994)	Supercoils	OLp V	NA	NA
Bondemark and Kurol (1998)	Magnets	OLp V	NA	NA
Bondemark and Kurol (1998)	Supercoils	OLp V	NA	NA
Bondemark (2000)	Magnets	OLp V	1.80 ± 0.86	2.09 ± 0.74
Bondemark (2000)	Nickel titanium coils	OLp V	1.20 ± 1.01	1.19 ± 0.33
Brickman *et al.* (2000)	Jones Jig	PTV	2.00 ± 1.99	1.01 ± 0.37
Gulati *et al.* (1998)	Jones Jig	OLp V	1.10 ± 0.87	1.26 ± 0.96
Gulati *et al.* (1998)	Jones Jig	PTV	1.05 ± 0.83	1.27 ± 1.96
Haydar and Üner (2000)	Jones Jig	RD1	3.35 ± 2.69	1.25 ± 0.96
Mavropoulos *et al.* (2005)	Jones Jig	PTV	2.08 ± 2.04	1.02 ± 0.98
Papadopoulos *et al.* (2004)	Modified Jig	PTV	2.60 ± 1.70	1.53 ± 0.80
Bolla *et al.* (2002)	Distal Jet	PTV	1.30 ± 1.50	0.87 ± 0.65
Chiu *et al.* (2005)	Distal Jet	PTV	2.60 ± 1.1	2.36 ± 0.64
Ngantung *et al.* (2001)	Distal Jet	PTV	2.60 ± 1.97	1.32 ± 0.53
Fortini *et al.* (2004)	First class appliance	Olp-S	1.70 ± 1.50	1.13 ± 0.73

distalized with a Hilgers pendulum. The largest effects (standard treatment effect) were achieved by Bondemark (2000) and Bondemark and Kurol (1992) using magnets. In comparison, the shortest linear distalization measurements were reported by Papadopoulos *et al.* (2004) using a modified jig. When using the distalization appliances described above, along with a sagittally distalizing movement, vertical movements of the molars occur to a smaller extent (Table 3). The lowest vertical side-effects were recorded in the distal jet study by Ngantung *et al.* (2001) and highest, in the form of molar intrusion, in the comparative pendulum studies of Byloff and Darendeliler (1997) and Byloff *et al.* (1997). The highest extrusive effect was reported by Gulati *et al.* (1998) with a Jones Jig. The investigated distalization appliances do not result in a purely translatory movement but also, because force is applied in general coronally from the centre of resistance, in controlled tipping (Table 4). Depending on the appliance, the extent to which this side-effect occurs varies substantially. The highest extent of tipping was recorded for distalization with a Hilgers pendulum. Still, Kinzinger *et al.* (2004a, 2005a,b) achieved molar distalization with less tipping with a modified pendulum appliance. The smallest amount of tipping and the most desirable standard treatment effect was achieved by Bondemark *et al.* (1992) in a study using supercoils.

Effects on the premolars

In the studies by Gulati *et al.* (1998) and Kinzinger *et al.* (2005a), the smallest amount of anchorage loss was reported (Table 5). Low standard treatment effects were achieved with two anchorage teeth in the distal jet study (Bolla *et al.*, 2002) and with four anchorage teeth, different from the pendulum studies of Chiu *et al.* (2005), Bussick and McNamara (2000), and Kinzinger *et al.* (2005a). The least vertical side effects (Table 6) were reported by Papadopoulos *et al.* (2004). The highest side-effects in the form of premolar extrusion were observed in the Jones Jig study by Brickman *et al.* (2000), while the pendulum appliance study (Ghosh and Nanda, 1996) resulted in the highest standard treatment. The smallest extent of tipping (Table 7) was reported by Chiu *et al.* (2005) with the distal jet and Kinzinger *et al.* (2005a) with the pendulum appliance. In comparison, the

Table 6 Intrusion and extrusion of the premolars during distalization: appliances, reference planes, intrusion (−)/extrusion (+) of the premolars (In/Ex PM; in mm + standard deviation), and corresponding standard treatment effect (STE In/Ex PM; with deviations per 95 per cent confidence interval); PP = palatal plane, SN = anterior cranial base, NA = not available.

Authors	Appliance	Reference plane	In/Ex PM (mm)	Standard treatment effect STE In/Ex PM
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PP	1.18 ± 1.36	0.87 ± 0.57
Bussick and McNamara (2000)	Hilgers pendulum	PP	1.10 ± 1.20	0.92 ± 0.33
Byloff and Darendeliler (1997)	Hilgers pendulum	PP	0.78 ± 1.23	0.63 ± 0.78
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PP	1.41 ± 1.19	1.18 ± 0.67
Chiu *et al.* (2005)	Hilgers pendulum	PP	1.2 ± 1.1	1.09 ± 0.53
Ghosh and Nanda (1996)	Hilgers pendulum	PP	1.70 ± 1.36	1.25 ± 0.47
Kinzinger *et al.* (2000)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2004a)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2005a)	Pendulum K	PP	0.62 ± 0.82	0.76 ± 0.45
Kinzinger *et al.* (2005b)	Pendulum K	NA	NA	NA
Bondemark and Kurol (1992)	Magnets	NA	NA	NA
Bondemark *et al.* (1994)	Magnets	NA	NA	NA
Bondemark *et al.* (1994)	Supercoils	NA	NA	NA
Bondemark and Kurol (1998)	Magnets	NA	NA	NA
Bondemark and Kurol (1998)	Supercoils	NA	NA	NA
Bondemark (2000)	Magnets	NA	NA	NA
Bondemark (2000)	Nickel titanium coils	NA	NA	NA
Brickman *et al.* (2000)	Jones Jig	PP	1.88 ± 1.56	1.21 ± 0.36
Gulati *et al.* (1998)	Jones Jig	NA	NA	NA
Haydar and Üner (2000)	Jones Jig	SN	0.95 ± 0.96	0.99 ± 0.93
Mavropoulos *et al.* (2005)	Jones Jig	PP	0.72 ± 0.56	1.29 ± 0.96
Papadopoulos *et al.* (2004)	Modified Jig	PP	0.60 ± 1.57	0.38 ± 0.74
Bolla *et al.* (2002)	Distal Jet	PP	1.10 ± 1.60	0.69 ± 0.65
Chiu *et al.* (2005)	Distal Jet	PP	1.3 ± 1.2	1.08 ± 0.52
Ngantung *et al.* (2001)	Distal Jet	PP	1.63 ± 1.59	1.03 ± 0.51
Fortini *et al.* (2004)	First class appliance	SN	1.00 ± 1.70	0.59 ± 0.69

greatest amount of tipping was reported by Papadopoulos *et al.* (2004) and Mavropoulos *et al.* (2005).

Effects on the incisors

Incisor mesialization (Table 8) was lowest with a Jones Jig (Haydar and Üner, 2000). The most significant side-effects in the form of incisor mesialization were measured in the distal jet study by Chiu *et al.* (2005), using two anchorage teeth. In their pendulum study, Chiu *et al.* (2005) reported the least vertical side-effects. The greatest side-effect, in the form of extrusion, occurred with the Jones Jig (Haydar and Üner, 2000; Table 9). The smallest incisor protrusion values (Table 10) were reported with the Jones Jig (Haydar and Üner, 2000) and with the pendulum appliance (Byloff and Darendeliler, 1997). Compared with this, the largest protrusion values occurred in the distal jet studies of Chiu *et al.* (2005) and Ngantung *et al.* (2001).

Share of molar distalization in the total movement in the sagittal dimension

With pendulum appliances and an anchorage design with four anchorage teeth, Chiu *et al.* (2005), at 81 per cent, Kinzinger *et al.* (2005a), at 76.3 per cent, and Bussick and McNamara (2000), at 76 per cent, achieved the highest share of effective molar distalization. Fortini *et al.* (2004), using the first class appliance (76.5 and 70 per cent), and Bondemark and Kurol (1992), using magnets (70 per cent), achieved comparable shares with anchorage designs with two teeth. In studies with the pendulum appliances (four anchorage teeth), the share of molar distalization in the total movement in the sagittal dimension was between 56.9 and 81 per cent, with magnets (two anchorage teeth) between 53.7 and 70 per cent, with coil springs (two anchorage teeth) between 59 and 67.6 per cent, with Jones Jigs or modified jigs (two or four anchorage teeth) between 35 and 55.7 per cent, and with distal jets (two anchorage teeth) between 45 and 71.1 per cent (Table 11).

Discussion

Effects on the molars

The dental-linear outcomes from molar distalization suggest that greater distalization can be achieved using pendulum appliances. However, the fact that part of the distalization, in particular when using the standard Hilgers pendulum, is

Table 7 Tipping of the premolars: appliances, reference planes, tipping of the premolars (Tip PM; in degrees + standard deviation), and corresponding standard treatment effect (STE Tip PM; with deviations per 95 per cent confidence interval); SN = anterior cranial base, FH = Frankfort horizontal, PP = palatal plane, NA = not available.

Authors	Appliance	Reference plane	Tip PM (degrees)	Standard treatment effect STE Tip PM
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	SN	4.84 ± 3.84	1.26 ± 0.59
Bussick and McNamara (2000)	Hilgers pendulum	FH	1.50 ± 4.30	0.35 ± 0.31
Byloff and Darendeliler (1997)	Hilgers pendulum	NA	NA	NA
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	NA	NA	NA
Chiu *et al.* (2005)	Hilgers pendulum	FH	−1.7 ± 4.7	−0.36 ± 0.49
Ghosh and Nanda (1996)	Hilgers pendulum	SN	1.29 ± 7.52	0.17 ± 0.43
Kinzinger *et al.* (2000)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2000)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2004a)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2004a)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2005a)	Pendulum K	SN	−0.50 ± 5.19	−0.10 ± 0.51
Kinzinger *et al.* (2005a)	Pendulum K	PP	−0.43 ± 5.35	−0.08 ± 0.39
Kinzinger *et al.* (2005b)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2005b)	Pendulum K	NA	NA	NA
Bondemark and Kurol (1992)	Magnets	NA	NA	NA
Bondemark *et al.* (1994)	Magnets	NA	NA	NA
Bondemark *et al.* (1994)	Supercoils	NA	NA	NA
Bondemark and Kurol (1998)	Magnets	NA	NA	NA
Bondemark and Kurol (1998)	Supercoils	NA	NA	NA
Bondemark (2000)	Magnets	PP	6.70 ± 2.95	2.27 ± 0.78
Bondemark (2000)	Nickel titanium coils	PP	2.10 ± 2.75	0.76 ± 0.63
Brickman *et al.* (2000)	Jones Jig	SN	4.76 ± 4.74	1.00 ± 0.35
Gulati *et al.* (1998)	Jones Jig	SN	2.60 ± 1.17	2.22 ± 1.11
Haydar and Üner (2000)	Jones Jig	SN	6.05 ± 5.56	1.09 ± 0.94
Mavropoulos *et al.* (2005)	Jones Jig	SN	7.50 ± 5.90	1.27 ± 0.96
Papadopoulos *et al.* (2004)	Modified Jig	SN	8.10 ± 5.14	1.57 ± 0.85
Bolla *et al.* (2002)	Distal Jet	SN	−2.80 ± 4.00	0.70 ± 0.65
Chiu *et al.* (2005)	Distal Jet	FH	0.3 ± 4.9	0.06 ± 0.49
Ngantung *et al.* (2001)	Distal Jet	SN	−4.33 ± 5.21	−0.83 ± 0.50
Fortini *et al.* (2004)	First class appliance	SN	2.20± 2.20	1.00 ± 0.71

achieved by distal tipping must not go unnoticed. Subsequent molar uprighting by mesial tipping of the crown during the levelling stage reduces the space gained by the distalization. Chaques-Asensi and Kalra (2001), Bussick and McNamara (2000), Byloff and Darendeliler (1997), Chiu *et al.* (2005) as well as Joseph and Butchart (2000) reported mean mesial tipping values of more than 10 degrees for the molars with the pendulum appliances. This would infer that purely translatory force application to the maxillary molars is not possible with pendulum appliances and that this is built into their design. Byloff *et al.* (1997) were able to substantially reduce the side-effects of molar tipping by inserting uprighting activators, in a second treatment stage, in the area of the pendulum springs. Kinzinger *et al.* (2000, 2003, 2004a or b, 2005a,b; Kinzinger and Diedrich, 2007) were able to show, furthermore, that specific modifications to the pendulum appliance (uprighting bend, toe-in bend, and incorporation of a distal screw) allowed immediate molar distalization with low distal tipping effects.

The influence of the second molars on the quantity and quality of molar distalization has been a subject of controversy. Worms *et al.* (1973) reported that second molars touching the first molars constituted a resistance for distal movement. When first molars move distally, they move the second molars too, no matter whether or not these latter have already erupted. Second and third molars experience the same type of influence: they move distally when the first or second molar moves towards their location. Modelling processes occur in the area of the tuberosity to allow distal movement of the molars. Ghosh and Nanda (1996) showed that the second molars do not exercise a significant effect, neither on the distalization of the first molars nor on anchorage loss. The same opinion was put forward by Muse *et al.* (1993), Byloff and Darendeliler (1997), and Joseph and Butchart (2000). In a clinical study, Kinzinger *et al.* (2004a) showed that there was a more marked trend for distal crown tipping in the 6-year molars when the second molars were unerupted (the so-called hypomochlion effect). Bondemark *et al.* (1992), also, identified a strong influence of erupted second molars on the distalization of first molars. According to Hilgers (1992), second molars do not hamper first molar distalization, but

Table 8 Dental-linear mesialization of the incisors: appliances, reference planes, mesialization of the incisors (Mes Mov Inc; in mm + standard deviation), and corresponding standard treatment effect STE Mes Mov Inc (with deviations per 95 per cent confidence interval); PTV = pterygoid vertical, OLp V = occlusal line perpendicular, vertical from the sella landmark, RD1 = line perpendicular to CT plane at point T, NA = not available.

Authors	Appliance	Reference plane	Mes Mov Inc (mm)	Standard treatment effect (STE Mes Mov Inc)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PTV	2.09 ± 0.72	2.90 ± 0.78
Bussick and McNamara (2000)	Hilgers pendulum	PTV	1.40 ± 1.50	0.93 ± 0.29
Byloff and Darendeliler (1997)	Hilgers pendulum	PTV	0.92 ± 0.67	1.37 ± 0.86
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PTV	1.54 ± 0.88	1.75 ± 0.73
Chiu *et al.* (2005)	Hilgers pendulum	PTV	1.1 ± 1.2	0.92 ± 0.52
Ghosh and Nanda (1996)	Hilgers pendulum	PTV	NA	NA
Kinzinger *et al.* (2000)	Pendulum K	PTV	1.06 ± 1.03	1.03 ± 0.41
Kinzinger *et al.* (2004a)	Pendulum K	PTV	1.33 ± 0.85	1.56 ± 0.53
Kinzinger *et al.* (2005a)	Pendulum K	PTV	1.33 ± 0.74	1.8 ± 0.61
Kinzinger *et al.* (2005b)	Pendulum K	PTV	1.26 ± 0.71	1.77 ± 0.39
Bondemark and Kurol (1992)	Magnets	OLp V	1.80 ± 0.75	2.40 ± 1.15
Bondemark *et al.* (1994)	Magnets	OLp V	1.90 ± 0.41	4.63 ± 1.25
Bondemark *et al.* (1994)	Supercoils	OLp V	1.90 ± 0.41	4.63 ± 1.25
Bondemark and Kurol (1998)	Magnets	OLp V	1.80 ± 0.91	1.98 ± 0.81
Bondemark and Kurol (1998)	Supercoils	OLp V	1.80 ± 0.91	1.98 ± 0.81
Bondemark (2000)	Magnets	OLp V	1.90 ± 0.64	2.97 ± 0.88
Bondemark (2000)	Nickel titanium coils	OLp V	1.50 ± 0.92	1.63 ± 0.71
Brickman *et al.* (2000)	Jones Jig	PTV	NA	NA
Gulati *et al.* (1998)	Jones Jig	OLp V	NA	NA
Gulati *et al.* (1998)	Jones Jig	PTV	NA	NA
Haydar and Üner (2000)	Jones Jig	RD1	0.25 ± 1.09	0.23 ± 0.88
Mavropoulos *et al.* (2005)	Jones Jig	PTV	1.8 ± 2.86	0.63 ± 0.90
Papadopoulos *et al.* (2004)	Modified Jig	PTV	2.30 ± 2.25	1.02 ± 0.78
Bolla *et al.* (2002)	Distal Jet	PTV	NA	NA
Chiu *et al.* (2005)	Distal Jet	PTV	3.7 ± 1.7	2.18 ± 0.62
Ngantung *et al.* (2001)	Distal Jet	PTV	NA	NA
Fortini *et al.* (2004)	First class appliance	Olp-S	1.30± 1.30	1.0 ± 0.71

he suggested that distalization treatment was more efficient before eruption. Gianelly (1990) and Kinzinger *et al.* (2004a) pointed out that the treatment would in any case take longer when the second molars were erupted. In this respect, it should be noted that most of the authors provided exact data on dentition stages in the area of the molars (Bondemark and Kurol 1992, 1998; Bondemark *et al.*, 1992; Ghosh and Nanda, 1996; Byloff and Darendeliler, 1997; Byloff *et al.*, 1997; Gulati *et al.*, 1998; Bondemark 2000; Bussick and McNamara, 2000; Bolla *et al.*, 2002; Fortini *et al.*, 2004; Kinzinger *et al.*, 2004a, 2005b; Papadopoulos *et al.*, 2004; Mavropoulos *et al.*, 2005), but only a few (Bussick and McNamara, 2000; Kinzinger *et al.*, 2004a, 2005b) subdivided their patient sample by dentition stages and performed statistical analyses across subsamples.

Aspects of vertical movement have only a minor part in maxillary molar distalization. When breaking down the intrusion and extrusion outcomes according to the specific appliances, it can be seen that, as opposed to all other treatment appliances, the standard pendulum appliance tends to cause maxillary molar intrusion.

Effects on the premolars and incisor/anchorage unit

Conventional anchorage designs exclusively for intraoral anchorage of non-compliance molar distalization appliances use an acrylic button placed onto the palatal mucosa in the area of the palatal rugae and, in general, anchored to two or four primary molars or permanent premolars through occlusally attached to rests or prefabricated bands. The forces and moments exercised by the activators of the distalization appliances act reciprocally and to the same extent on the anchorage unit. Depending on the design of the appliance, these reactive forces and moments are compensated only partially and may therefore result in side-effects expressed by movements in the system component located mesial from the force application. These effects, which are commonly called anchorage loss, cause the immediate anchorage teeth, i.e. the primary molars or permanent premolars, and furthermore, indirectly, the incisors to move mesially. Such mesial tipping is undesirable in general and has to be corrected during the levelling stage. Therefore, it is of therapeutic interest to know the extent of these side-effects.

Table 9 Intrusion and extrusion of the incisors during distalization: appliances, reference planes, intrusion (−)/extrusion (+) of the incisors (In/Ex Inc; in mm + standard deviation), and corresponding standard treatment effect (STE In/Ex Inc; with deviations per 95 per cent confidence interval); PP=palatal plane, SN=anterior cranial base, NA=not available.

Authors	Appliance	Reference plane	In/Ex Inc (mm)	Standard treatment effect (STE In/Ex Inc)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PP	0.75 ± 1.12	0.67 ± 0.57
Bussick and McNamara (2000)	Hilgers pendulum	PP	0.90 ± 1.20	0.75 ± 0.33
Byloff and Darendeliler (1997)	Hilgers pendulum	PP	0.45 ± 0.81	0.56 ± 0.78
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PP	0.54 ± 0.87	0.62 ± 0.63
Chiu *et al.* (2005)	Hilgers pendulum	PP	−0.1 ± 0.9	−0.11 ± 0.49
Ghosh and Nanda (1996)	Hilgers pendulum	PP	0.65 ± 1.07	0.61 ± 0.45
Kinzinger *et al.* (2000)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2004a)	Pendulum K	NA	NA	NA
Kinzinger *et al.* (2005a)	Pendulum K	PP	0.61 ± 0.71	0.86 ± 0.53
Kinzinger *et al.* (2005b)	Pendulum K	NA	NA	NA
Bondemark and Kurol (1992)	Magnets	NA	NA	NA
Bondemark *et al.* (1994)	Magnets	PP	0.20 ± 0.38	0.53 ± 0.67
Bondemark *et al.* (1994)	Supercoils	PP	0.20 ± 0.38	0.53 ± 0.67
Bondemark and Kurol (1998)	Magnets	PP	0.20 ± 0.4	0.50 ± 0.67
Bondemark and Kurol (1998)	Supercoils	PP	0.20 ± 0.4	0.50 ± 0.67
Bondemark (2000)	Magnets	NA	NA	NA
Bondemark (2000)	Nickel titanium coils	NA	NA	NA
Brickman *et al.* (2000)	Jones Jig	PP	0.14 ± 0.87	0.16 ± 0.33
Gulati *et al.* (1998)	Jones Jig	NA	NA	NA
Haydar and Üner (2000)	Jones Jig	SN	1.95 ± 1.04	1.88 ± 1.05
Mavropoulos *et al.* (2005)	Jones Jig	NA	NA	NA
Papadopoulos *et al.* (2004)	Modified Jig	PP	0.30 ± 0.56	0.54 ± 0.74
Bolla *et al.* (2002)	Distal Jet	PP	0.60 ± 0.90	0.67 ± 0.63
Chiu *et al.* (2005)	Distal Jet	PP	−1.5 ± 1.6	−0.94 ± 0.52
Ngantung *et al.* (2001)	Distal Jet	PP	−1.0 ± 1.83	−0.55 ± 0.49
Fortini *et al.* (2004)	First class appliance	NA	NA	NA

In the investigated studies, anchorage loss occurred more markedly in the area of the incisors compared with that of the first premolars. This might be explained by the fact that the reciprocal force reacting to the distalization force is a compound of the following components in the area of the anterior teeth: the force relayed by the dental arch itself in the area of the approximal contacts from the premolars to the canines and to the anterior teeth and the Nance button relaying hydrodynamically the forces to the anterior portion of the palate and, thereby, indirectly to the area of the anterior teeth.

Conventional anchorage designs of non-compliance molar distalization appliances have, in principle, stood the test of clinical practice, but it has to be acknowledged that a Nance-type anterior palatal button, when considered in isolation, may achieve the anchoring effect on the resilient palatal mucosa only by hydrodynamic interaction, which is by no means a stationary anchorage. Furthermore, individual characteristics, such as palatal mucosa thickness and depth and width of the palatal vault, deserve discussion. Moreover, it has been reported that the mucosa is adversely affected by the restrictions to mouth hygiene, as errors of manufacture in the dental laboratory and exaggerated activation of the active components may result in pressing into the palatal mucosa, causing pressure-induced ulcers (Bondemark and Kurol, 1992; Hilgers, 1992; Kinzinger *et al.*, 2000; Escobar *et al.*, 2007).

The quality of anchorage is mainly based on the amount of periodontal tissue interface. The resistive potential of the anchorage teeth is determined by the size of the surface relevant for the anchorage, i.e. the number of teeth included, their root topography and level of attachment, the bone structure, and the desmodontal response. In children and adolescents treated with non-compliance molar distalization appliances, the bone structure and the attachment level can be considered to be virtually identical. Differences may result from the number of teeth, the root topography, and the desmodontal responsiveness. Although outcomes are not fully consistent with each other, the side-effects in relation to anchorage occurred most often in studies in which only two teeth were part of the anchorage design. Therefore, the reactive portion should include as many anchorage teeth as possible.

Few clinical studies have investigated the efficiency of non-compliance molar distalization appliances in the mixed dentition (Bussick and McNamara, 2000; Kinzinger *et al.*, 2000, 2003, 2005a). In terms of anchorage, they found that primary molars, just as permanent premolars, were suitable

Table 10 Protrusion of the incisors: appliances, reference planes, the incisors (Prot Inc; in degrees + standard deviation), and corresponding standard treatment effect (STE Prot Inc; with deviations per 95 per cent confidence interval); SN=anterior cranial base, FH=Frankfort horizontal, PP=palatal plane, NA=not available.

Authors	Appliance	Reference plane	Prot Inc (degrees)	Standard treatment effect (STE Prot Inc)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	SN	5.14 ± 4.01	1.28 ± 0.59
Bussick and McNamara (2000)	Hilgers pendulum	FH	3.60 ± 8.40	0.43 ± 0.29
Byloff and Darendeliler (1997)	Hilgers pendulum	PP	1.71 ± 1.48	1.16 ± 0.82
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PP	3.20 ± 3.02	1.06 ± 0.67
Chiu *et al.* (2005)	Hilgers pendulum	FH	3.1 ± 4.1	0.76 ± 0.51
Ghosh and Nanda (1996)	Hilgers pendulum	SN	2.40 ± 4.57	0.53 ± 0.43
Kinzinger *et al.* (2000)	Pendulum K	SN	3.93 ± 5.66	0.69 ± 0.41
Kinzinger *et al.* (2000)	Pendulum K	PP	4.10 ± 5.53	0.74 ± 0.41
Kinzinger *et al.* (2004a)	Pendulum K	SN	4.51 ± 3.60	1.25 ± 0.51
Kinzinger *et al.* (2004a)	Pendulum K	PP	4.39 ± 2.87	1.53 ± 0.53
Kinzinger *et al.* (2005a)	Pendulum K	SN	3.40 ± 5.39	0.63 ± 0.51
Kinzinger *et al.* (2005a)	Pendulum K	PP	3.28 ± 5.47	0.60± 0.51
Kinzinger *et al.* (2005b)	Pendulum K	SN	3.74 ± 5.11	0.73 ± 0.35
Kinzinger *et al.* (2005b)	Pendulum K	PP	3.13 ± 4.88	0.64 ± 0.35
Bondemark and Kurol (1992)	Magnets	SN	5.80 ± 2.88	2.01 ± 1.08
Bondemark *et al.* (1994)	Magnets	SN	4.40 ± 1.97	2.23 ± 0.83
Bondemark *et al.* (1994)	Supercoils	SN	4.40 ± 1.97	2.23 ± 0.83
Bondemark and Kurol (1998)	Magnets	NA	NA	NA
Bondemark and Kurol (1998)	Supercoils	NA	NA	NA
Bondemark (2000)	Magnets	PP	5.50 ± 2.52	2.18 ± 0.76
Bondemark (2000)	Nickel titanium coils	PP	4.70 ± 3.65	1.29 ± 0.67
Brickman *et al.* (2000)	Jones Jig	SN	2.40 ± 3.46	0.69 ± 0.34
Gulati *et al.* (1998)	Jones Jig	SN	NA	NA
Haydar and Üner (2000)	Jones Jig	SN	1.00 ± 1.56	0.64 ± 0.90
Mavropoulos *et al.* (2005)	Jones Jig	SN	5.16 ± 3.44	1.50 ± 0.99
Papadopoulos *et al.* (2004)	Modified Jig	SN	4.80 ± 3.23	1.49 ± 0.84
Bolla *et al.* (2002)	Distal Jet	SN	0.60 ± 5.30	0.11 ± 0.63
Chiu *et al.* (2005)	Distal Jet	FH	13.7 ± 8.0	1.71 ± 0.57
Ngantung *et al.* (2001)	Distal Jet	SN	12.16 ± 10.72	1.13 ± 0.52
Fortini *et al.* (2004)	First class appliance	SN	2.60 ± 1.00	2.60 ± 0.92

in principle for constructing the anchorage of a pendulum appliance for molar distalization, but that anchorage exclusively to primary molars or to a mix of primary molars and permanent premolars resulted in reduced anchorage quality.

Conventional anchorage designs deserve critical discussion. On the one hand, the anchoring effect of a palatal button is uncertain, while restricted mouth hygiene because of the temporal partial coverage of the palate has been an acknowledged problem. On the other hand, mesial migration of the anterior dentition has to be taken into consideration, as the outcomes of all studies illustrate. In the final analysis, certain dentitional stages and certain periodontal situations do not allow constructing sufficient anchorage on the patient's own dentition. Recently, alternative anchorage designs using implants or miniscrews have been described (Männchen, 1999; Byloff *et al.*, 2000; Kinzinger and Diedrich, 2002; Karaman *et al.*, 2002; Favero *et al.*, 2003; Keles *et al.*, 2003; Kyung *et al.*, 2003; Gelgör *et al.*, 2004; Kinzinger *et al.*, 2004b, 2006; Kircelli *et al.*, 2005; Escobar *et al.*, 2007; Öncag *et al.*, 2007). Future research will have to comparatively assess their efficiency.

Percentage of molar distalization in total movement in the sagittal dimension

In relation to total movement in the sagittal dimension, i.e. cumulative molar distalization and reciprocal premolar and incisor mesialization, Gianelly (1990) suggested that a minimum molar distalization of 66 per cent and, reciprocally, a maximum anchorage loss of 33 per cent were efficient. Anchorage loss below 33 per cent would be acceptable and easily corrected therapeutically. In none of the studies in which jig appliances were used, in only two out of seven in which magnets and coil spring systems were used, in one out of three in which distal jets were used, and in a total eight out of 10 in which pendulum appliances were used, was this requirement complied with. In seven out of 11 studies in which the proportion of molar distalization exceeded 70 per cent, four teeth were included in the anchorage design.

Table 11 Percentage of molar distalization in total movement in the sagittal dimension: reference (Inc = incisors, PM = premolar).

Authors	Appliance	Anchorage reference tooth	Total sagittal 6-year molar (in %)
Chaques-Asensi and Kalra (2001)	Hilgers pendulum	PM	70.6
		Inc	71.8
Bussick and McNamara (2000)	Hilgers pendulum	PM	76.0
Byloff and Darendeliler (1997)	Hilgers pendulum	PM	70.9
Byloff *et al.* (1997)	Hilgers pendulum, uprighting activation	PM	64.2
Chiu *et al.* (2005)	Hilgers pendulum	PM	81.0
Ghosh and Nanda (1996)	Hilgers pendulum	PM	56.9
Kinzinger *et al.* (2000)	Pendulum K	Inc	72.5
Kinzinger *et al.* (2004a)	Pendulum K	Inc	70.2
Kinzinger *et al.* (2005a)	Pendulum K	PM	76.3
		Inc	74.2
Kinzinger *et al.* (2005b)	Pendulum K	Inc	73.5
Bondemark and Kurol (1992)	Magnets	Inc	70.0
Bondemark *et al.* (1994)	Magnets	Inc	53.7
Bondemark *et al.* (1994)	Supercoils	Inc	62.7
Bondemark and Kurol (1998)	Magnets	Inc	55.0
Bondemark and Kurol (1998)	Supercoils	Inc	59.0
Bondemark (2000)	Magnets	PM	59.1
		Inc	57.8
Bondemark (2000)	Nickel titanium coils	PM	67.6
		Inc	61.9
Brickman *et al.* (2000)	Jones Jig	PM	55.7
Gulati *et al.* (1998)	Jones Jig	PM	55.0
Haydar and Üner (2000)	Jones Jig	PM	45.0
Mavropoulos *et al.* (2005)	Jones Jig	PM	46.0
Papadopoulos *et al.* (2004)	Modified Jig	PM	35.0
		Inc	37.8
Bolla *et al.* (2002)	Distal Jet	PM	71.1
Chiu *et al.* (2005)	Distal Jet	PM	52.0
Ngantung *et al.* (2001)	Distal Jet	PM	45.0
Fortini *et al.* (2004)	First class appliance	PM	70.0
		Inc	76.5

Appliance efficiency

Based on the results of the reviewed studies, a final evaluation of the efficiency of the appliances that could be recommended can be given only to a limited extent. This is for the following reasons: treatment-induced changes of molar positions were determined by cast analyses only in a small number of studies (Bondemark and Kurol 1992; Bondemark *et al.*, 1994; Ghosh and Nanda, 1996; Gulati *et al.*, 1998; Kinzinger *et al.*, 2000, 2004a, 2005b; Bolla *et al.*, 2002; Mavropoulos *et al.*, 2005). Insights into other side effects, such as adversely affected mucosa, can be found only rarely (Bondemark and Kurol, 1992; Hilgers, 1992; Kinzinger *et al.*, 2000; Escobar *et al.*, 2007), while data on difficulties and problems of manufacture in the dental laboratory are lacking completely.

Nonetheless, trends can be observed in the efficiency of the various appliances. The Jones Jig appliances cause, besides small total distalization values, an increased trend for molar and premolar tipping in particular, which can be explained as being built into the design and by biomechanics. For the magnet appliances, a high anchorage loss in the area of the incisors reduces the percentage share in total movement as compared with other appliances. The substantial loss of force during distalization due to the increasing distance between the magnets has to be considered as a further disadvantage of these appliances. Total distalization values that are in part higher and exhibit lower anchorage loss have to be taken into account for appliances with coiled spring set-ups fitted vestibularly (first class appliance and distal jet). A modified pendulum appliance (Pendulum K) showed convincing treatment effects for both distalization and low levels of side effects and allowed almost bodily distalization of the molars.

Conclusions

Non-compliance molar distalization can be achieved with a large number of appliances. Active components used include intramaxillary magnetic modules, loaded coiled springs, or pendulum springs. The efficiency of these appliance types with intramaxillary anchorage in clinical application, however, also depends on a stabilizing anchorage unit. Side effects occur simultaneously with molar distalization. These, in general undesirable, effects are distributed in the force system to the distalization and the anchorage units. In the relevant teeth, they maybe expressed by tipping and movements in the vertical dimension (intrusion or extrusion). Side effects have to be assessed in order to obtain objective evaluations of the efficiency of the appliances.

While in terms of molar distalization the Hilgers pendulum resulted in the longest dental-linear distalization measurements, substantial therapeutically undesirable distal tipping also occurred. However, by appliance modifications almost bodily molar distalization can be achieved. The efficiency of coil spring designs for molar-distalizing movement differs among the studies but it would seem that the first class appliance and the palatal distal jet are more efficient than the vestibular Jones Jig.

Reported anchorage loss is more marked in the area of the incisors compared with that of the first premolars. There is a trend for reciprocal side-effects to occur to a greater extent when only two teeth are part of the anchorage design.

Vertical aspects in relation to the molars, premolars, and incisors, such as intrusion and extrusion, play only a minor part and may be ignored in terms of side-effects.

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