ORIGINAL ARTICLE

Osseointegrated implants with pendulum springs for maxillary molar distalization: A cephalometric study

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Introduction: Maxillary molar distalization is a common treatment approach for patients with Class II malocclusions who do not require extractions. Despite the many advantages of pendulum appliances, the maxillary incisors and premolars tend to shift mesially as the maxillary molars move distally. The purpose of this study was to investigate anchorage loss in patients treated with palatal osseointegrated implants combined with pendulum springs. **Methods:** Pretreatment and posttreatment lateral cephalometric films of 30 consecutively treated patients were examined. One group (n = 15) had been treated with conventional pendulum appliances, and the other group (n = 15) was treated with palatal osseointegrated implants combined with pendulum springs. **Results:** In the pendulum group, significant distal tipping of the maxillary first molars and mesial tipping of the maxillary premolars were noted. Distalization of the maxillary first molars, mesialization of the maxillary first premolars, and proclination of the maxillary left central incisor were significant in the linear measurements. In the implant group, the distal tipping of the maxillary first molars and first premolars and the increases in SNGoGn, FMA, Na Me, and Na ANS were significant. Intergroup comparisons showed that changes in the maxillary first premolars, maxillary central incisors, and vertical measurements were significant. **Conclusions:** The use of palatal osseointegrated implants is reliable and provides absolute anchorage. (Am J Orthod Dentofacial Orthop 2007;131:16-26)

Maxillary molar distalization is the common approach for Class II nonextraction treatment of patients with maxillary skeletal or dentoalveolar protrusion.[1-9] Conventional molar distalization techniques, such as extraoral traction[10-14] and Schwarz plate-type appliances,[15] Wilson distalizing arches,[3,16] removable spring appliances,[4,17-20] distal jet appliances,[21] intermaxillary elastics with sliding jigs,[22,23] and magnets[5,6,18,24] are frequently used in this fashion.

Although absolute success can be achieved with these techniques, they require considerable patient cooperation.[3,16] Magnets are effective in molar distalization, but they are expensive, and the force exerted drops considerably with a small amount of movement, and patients must be seen every 1 to 2 weeks to activate the appliances.[6] Compressed stainless steel or nickel-titanium coils are also used in distalization, but they also need reactivation every month.[4,18-20,25]

Hilgers[26-28] and Hilgers and Bennet[29,30] introduced the pendulum appliance for Class II correction; it does not need patient cooperation and also expands the maxilla, distalizes the maxillary first molars, and uses the palate and the premolars as anchorage for distalization. The pendulum is a basic dentoalveolar appliance that corrects Class II relationships by tooth movement only. With a conventional pendulum appliance, the maxillary anterior teeth also shift mesially as the maxillary molars move distally. However, anchorage control is of great importance in orthodontic treatment, and researchers have made many modifications to minimize anchorage loss.[25,31-39]

In recent years, osseointegrated implants have been used in orthodontics in many ways. Studies in the 1970s and 1980s focused on loading the implants and their ability to resist stress vectors, and demonstrated that using implants as anchorage units is a valuable option in orthodontic treatment.[40-45] After success in animal studies,[46-49] Roberts et al,[50] Ödman et al,[51] and Drago[52] found similar results in humans. Wehrbein et al[53-55] presented an implant anchorage system placed in the anterior palatal region. Byloff et al[56] and Kärcher et al[57] used an implant-supported pendulum for molar

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distalization. Keleş et al[58] and Gelgör et al[59] used implants with other distalization techniques.

Our aim in this study was to determine whether anchorage loss occurs in patients treated with palatal oessointegrated implants combined with pendulum springs that were designed to move the maxillary molars distally. Cephalometric data were compared with those of a similar group of patients treated with conventional Hilgers pendulum appliances.

MATERIAL AND METHODS

The study group consisted of 30 patients who met the following criteria: (1) bilateral skeletal Class I or dental Class II molar relationship with normal or hypodivergent vertical growth pattern; (2) nonextraction treatment plan; (3) good oral hygiene; (4) no transverse discrepancy, with second molars erupted; and (5) no temporomandibular joint disorder.

The patients were divided into 2 groups of 15. In the pendulum group, the patients (9 girls, 6 boys) were treated with Hilgers pendulum appliances; those in the implant group (10 girls, 5 boys) were treated with the osseointegrated implant-supported molar distalization technique. Sex differences were not considered because of the short-term use of the appliances.

The pendulum appliance consisted of a Nance button, occlusal rests on the second premolars, bands on the first premolars, and pendulum springs. The right and left pendulum springs were formed from 0.032-in beta-titanium wire and consisted of a recurved molar insertion wire, a small horizontal adjustment loop, a closed helix, and a loop for retention on the acrylic button. The springs were extended as close to the center of the palatal button as possible to maximize their range of motion. The springs were inserted in the lingual sheaths on molar bands. The Nance button was held in place with occlusally bonded stainless steel rests on the second premolars and a soldered retaining wire to the bands on the first premolars. The Nance button and the rests on the maxillary premolars were used as the major anterior anchorage of the appliance. The molar bands were cemented, and, before the placement of the appliance, the springs were bent parallel to the midline of the palate for activation and then inserted in the lingual sheaths on the molar bands. The force applied was 300 g. The patients were seen once per month, and the pressure exerted by the springs was checked. If reactivation was needed, the springs were removed from the lingual sheaths and reactivated with bird-peek pliers.

In the osseointegrated implant molar distalization technique, placement was planned according to the radiological evaluation of the palatal bone morphology. There is enough bone to place an implant in a triangle formed by the nasal cavity, the incisor roots, and the palate, but this region has many risks, including penetration or damage when the implant is placed. To decrease the risk, circumstantial radiological evaluation was requested. In the transversal plane, the implant was not placed directly into the midpalatal suture that consisted of connective tissue. Instead, the lateral side of the palatal suture was chosen as the implant bed to increase retention by the bone. Each patient received an implant that was 3.8 mm in diameter and 9 mm long (Camlog screw cylinder; Camlog Biotechnologies, Basel, Switzerland); it was placed transmucosally in the anterior palatal region in 1-stage surgery under local anesthesia. A healing screw was placed at the same time, level with the palatal mucosa. To complete the osseointegration of the implant, 10 weeks were allowed without loading. The mechanical system of the appliances was the same as with the Hilgers pendulum appliance, except that the anchorage unit for molar distalization was an implant, not a Nance button and with rests on maxillary premolars. After osseointegration of the implant, the position of the implant was transferred to a model cast by silicone impression and impression post. A stainless steel casting crown was attached to abutment tubes that had a 0.036-in diameter and a 12.5-mm length (851-125, American Orthodontics, Sheboygan, Wis) and soldered to both lateral sides of the casting crown. The original pendulum helix was bent with 0.032-in beta-titanium wires on both sides, and they were inserted in the casting crown tubes (Fig 1).

Molar bands with palatal pendulum tubes for the maxillary first molars were cemented with glass ionomer cement (RelyX Luting, 3M Espe, St. Paul, Minn) to the maxillary first molars. Also, casting crowns with pendulum helixes were cemented to the implant with the same glass ionomer cement. Passive conditioned bands were placed on the palatal tubes with Weingarten pliers. Thus, the whole system was converted to the active form. Distalization forces of 300 g were applied to both sides.

Cephalometric films for patients' left and right sides were obtained by using reference wires for the maxillary central incisors, first premolars, and first molars before treatment and when a Class I molar relationship was obtained. Thus, the cephalometric positions of the right and left teeth were obtained by the guidance of these wires. For the other measurements, we used the mean values determined from both films. The average treatment times were 29 weeks for the pendulum

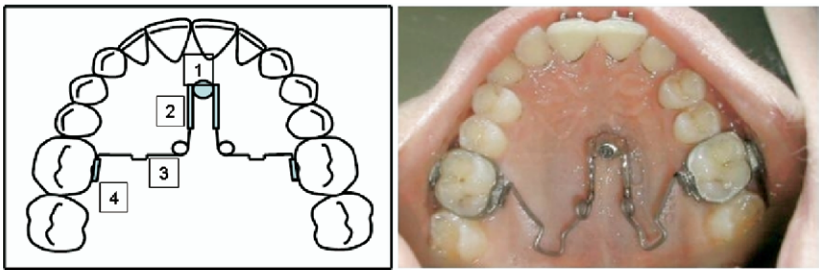

Fig 1. Appliance design of implants combined with pendulum springs.

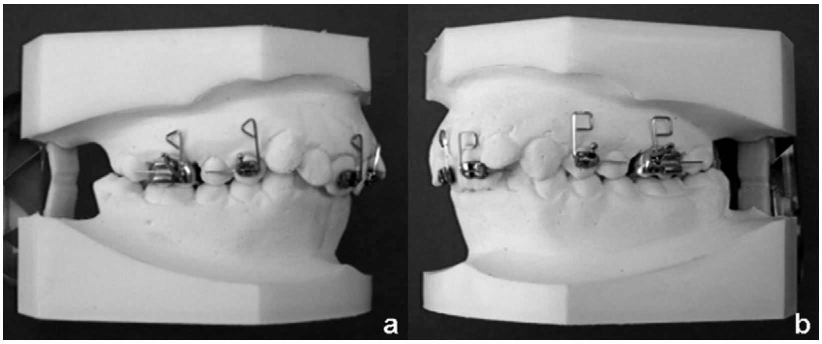

Fig 2. Reference wires used in sagittal cephalometric radiographs.

appliance group and 27 weeks for the implant appliance group.

To determine the inclination of the maxillary first molars, first premolars, and central incisors during the analysis of the sagittal cephalometric radiographs, 0.018 × 0.025-in stainless steel wires bent into different shapes for those teeth were placed in the molar tubes and the premolar and central incisor brackets when the radiographs were taken. These reference wires prepared for each patient were kept during the investigation period, and the same wires were used for each patient for the other radiographs (Fig 2). The linear and angular measurements used in the study are shown in Figures 3-5. A line drawn vertically from the sella-nasion plane through the distal Pterygomaxillary point is used as a reference line.

The cephalometric films were traced and measured by 1 examiner (G.Ö.).

Statistical analysis

For the statistical analysis, a software package (version 10.0, SPSS, Chicago, Ill) was used. Descriptive statistics (means, standard deviations) were calculated for each cephalometric measurement in Tables I and II.

The paired *t* test was used to analyze the differences between pretreatment and posttreatment cephalometric variables of the pendulum and implant groups (Tables I and II). The independent samples *t* test was used to determine the significant differences between the mean values of the cephalometric measurements for the pendulum and implant groups (Table III). The gage (ANOVA) test was used to determine the error of the method.

RESULTS

Pendulum appliance group

In the analysis of the angular measurements, ANB ($P < .05$), SNGoGn, SN OP ($P < .01$), and FMA increased at the end of pendulum treatment (Table I). SNB ($P < .05$) and SN PP ($P < .01$) decreased at the end of pendulum treatment. Protrusion was 2.3° ± 5.48° at the right and 1.76° ± 5.23° at the left central incisor. As the maxillary right and left first premolars tipped mesially ($P < .01$) (2.82° ± 3.84°, 3.13° ± 3.24°, respectively), the maxillary first molars tipped distally. The amounts of distal tipping were 7.06° ± 5.86° ($P < .001$) for the right first maxillary molar and 5.13° ± 2.84° ($P < .001$) for the maxillary left first molar.

The statistically meaningful increases in linear measurements Na ANS ($P < .05$), ANS Me ($P < .01$), and Na Me ($P < .001$) point out the increase in

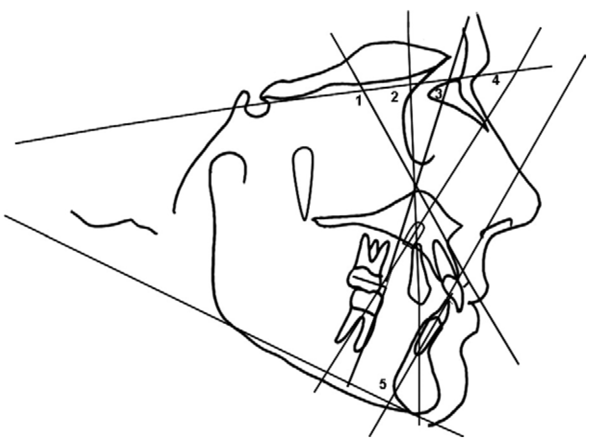

Fig 3. Dental angular measurements: *1,* maxillary central incisor and SN angle; *2,* maxillary first premolar and SN angle; *3,* maxillary first molar and SN angle; *4,* implant axis and SN angle; *5,* IMPA.

anterior face height. A smaller increase of Se Go ($P < .001$) was noted after pendulum treatment. The maxillary first molars moved distally, and the maxillary first premolars and maxillary central incisors moved mesially. The mesial movement of the left central incisor was statistically significant ($P < .001$) (2 ± 1.52 mm), but the mesial movement of the right central incisor was not significant. The mesial movements of the maxillary right and left first premolars were 1.56 ± 1.69 mm ($P < .01$) and 2.76 ± 1.03 mm ($P < .001$), respectively. Distal movement of the maxillary right first molar was 4.96 ± 1.44 mm ($P < .001$) and that of the left first molar was 5.10 ± 1.44 mm ($P < .001$). The linear dimension between Ptm vertical and Point A did not show statistically significant changes, but point B moved distally by 1.96 ± 2.61 mm ($P < .001$). LR1 Ptm distance decreased significantly ($P < .05$).

In the analysis of soft-tissue measurements, the distances of the upper and lower lips to Ptm decreased by 0.93 ± 2.77 mm and 0.70 ± 1.16 mm ($P < .05$), respectively. NLA angle decreased due to the upward movement of the upper lip ($P < .05$).

Implant supported appliance group

The sagittal skeletal changes of maxilla and mandible at the end of the treatment were not statistically significant (Table II). The increases in SNGoGn ($P < .001$), FMA ($P < .001$), and SN OP ($P < .001$) angles after distalization were statistically significant. After molar distalization, the maxillary right ($P < .01$) (1° ± 1.13°) and left central incisors

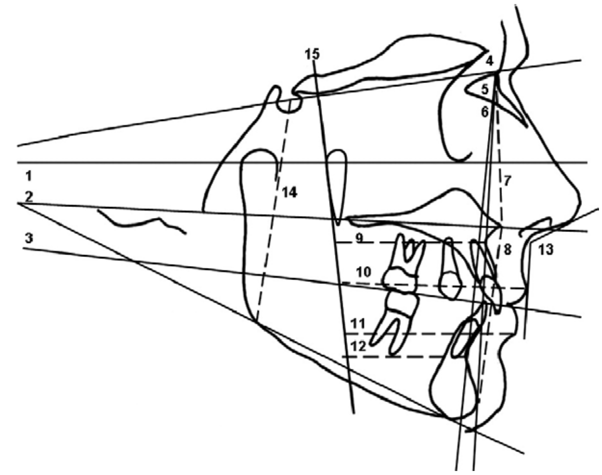

Fig 4. Skeletal and soft-tissue measurements: *1,* FMA; *2,* SN PP (sella-nasion plane and palatal plane angle); *3,* SN OP (sella-nasion plane and occlusal plane angle); *4,* SNA angle; *5,* SNB angle; *6,* ANB angle; *7,* Na ANS (nasion and spina nasalis anterior distance); *8,* ANS Me (spina nasalis anterior distance and menton distance); *9,* Ptm A (Ptm vertical line and A-point distance); *10,* UL Ptm (upper lip and Ptm vertical line distance); *11,* LL Ptm (lower lip and Ptm vertical line distance); *12,* Ptm B (Ptm vertical line and B-point distance); *13,* NLA (nasolabial angle); *14,* Se-Go (sella and gonion distance); *15,* Ptm vertical line.

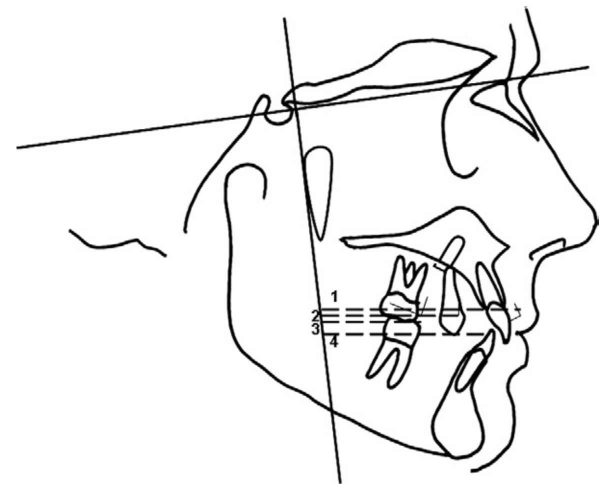

Fig 5. Dental linear measurements: *1,* UR1 Ptm/UL1 Ptm (maxillary right and left central incisor and Ptm vertical line distance); *2,* UR4 Ptm/UL4 Ptm (maxillary right and left first premolars and Ptm vertical line distance); *3,* UR6 Ptm/UL6 Ptm (maxillary right and left first molars and Ptm vertical line distance); *4,* LL1 Ptm (most protruded mandibular incisor and Ptm vertical line distance).

Table I. Pretreatment and posttreatment measurements in pendulum group

		Pretreatment				*Posttreatment*				*Differences*				
Variable	*n*	*Min*	*Max*	$\bar{X}$	*SD*	*Min*	*Max*	$\bar{X}$	*SD*	*Min*	*Max*	$\bar{D}$	*SD*	P
Angular (°)														
SNA	15	79.00	86.00	82.4	1.58	78.00	87.00	82.1	1.97	−2.50	1.00	−036	0.95	NS
SNB	15	75.50	82.00	77.9	1.96	74.00	82.00	77.2	2.35	−4.00	0.00	−0.73	1.03	*
ANB	15	7.50	5.50	4.5	1.35	2.00	7.50	5	1.42	−1.00	1.50	0.46	0.81	*
SNGoGn	15	27.00	39.00	33.9	2.55	25.50	42.00	34.2	3.69	−2.50	3.00	0.33	1.49	NS
FMA	15	22.00	31.00	27.4	2.38	21.00	37.00	29.2	3.7	−9.00	8.00	1.83	4.04	NS
IMPA	15	83.00	97.00	90.5	3.41	86.50	97.00	92.1	3.18	−3.00	11.00	1.53	3.24	NS
SN PP	15	0.00	13.00	7.5	3.02	0.00	10.00	6.8	2.77	−3.00	1.00	−0.73	0.92	†
SN OP	15	9.00	24.00	16.4	3.94	10.00	24.00	18.2	4.09	−3.50	6.00	1.76	2	†
UR1 SN	15	86.00	114.00	100	7.09	92.50	116.00	102.3	6.3	−7.00	15.00	2.3	5.48	NS
UR4 SN	15	69.00	108.00	82.7	8.43	73.00	108.00	85.6	8.5	−1.50	14.50	2.83	3.84	†
UR6 SN	15	61.00	109.00	72.9	11.05	52.50	84.00	65.9	7.18	−25.00	−1.00	−7.06	5.86	‡
UL1 SN	15	96.00	113.00	103.1	4.69	96.00	117.00	104.9	5.43	−14.00	10.50	1.76	5.23	NS
UL4 SN	15	70.00	87.00	79.3	3.64	77.00	88.00	82.5	2.91	−2.00	10.00	3.13	3.24	†
UL6 SN	15	61.00	80.00	69.1	4.32	53.50	74.00	64	4.79	−11.50	−1.00	−5.13	2.84	‡
NLA	15	107.00	140.00	118	7.95	91.00	139.00	115.3	9.91	−17.00	2.00	−2.7	4.39	
Linear (mm)														
UR1 Ptm	15	52.00	64.00	58.5	3.11	53.00	64.00	59.2	3.37	−3.00	6.00	0.73	2.61	NS
UR4 Ptm	15	40.00	46.00	43	2.07	41.00	48.00	44.5	2.42	−3.00	4.00	1.56	1.69	†
UR6 Ptm	15	22.00	31.00	27.1	2.66	17.00	27.00	22.1	2.53	−9.00	−3.00	−4.96	1.44	‡
LR1 Ptm	15	45.00	54.00	50.3	2.91	44.00	53.00	49.3	2.34	−4.00	2.00	−1.03	1.34	*
UL1 Ptm	15	53.00	62.50	58	2.52	55.00	63.00	60	2.25	−1.00	6.00	2	1.52	‡
UL4 Ptm	15	40.00	45.50	42.3	1.49	43.00	47.00	45.1	1.16	0.50	4.00	2.76	1.03	‡
UL6 Ptm	15	25.00	31.50	27.4	1.86	16.00	27.00	22.3	2.89	−9.00	−3.00	−5.1	1.44	‡
LL1 Ptm	15	48.00	66.00	51.5	4.29	47.00	65.00	50.7	4.43	−4.00	3.00	−0.8	1.82	NS
Ptm A	15	49.00	58.00	53.3	2.69	49.00	57.00	53.3	2.28	1.50	10.00	6.73	2.32	NS
Ptm B	15	39.00	48.50	43.1	2.66	38.00	47.50	41.8	2.74	−2.50	6.00	1.96	2.61	‡
Na ANS	15	50.00	59.00	54.3	2.38	51.00	59.00	55	1.93	−1.50	3.50	0.73	1.25	*
ANS Me	15	59.00	71.00	66.4	2.98	60.00	73.00	68.6	3.05	−4.00	5.50	2.2	2.13	†
Na Me	15	117.00	127.50	122	2.75	118.00	132.00	126.1	3.88	−3.00	9.00	4.13	2.61	‡
Se Go	15	72.00	87.00	78.7	3.43	79.00	92.00	81.8	3.08	−2.50	8.00	3.13	2.35	‡
UL Ptm	15	64.00	75.00	70.3	3.17	65.00	73.00	69.3	2.27	−6.50	4.50	−0.93	2.77	NS
LL Ptm	15	60.00	71.00	66	3.02	62.00	70.00	65.3	2.46	−3.00	2.00	−0.7	1.16	*

Min, Minimum; *Max,* maximum; *NS,* not significant.
**P* <.05; †*P* <.01; ‡*P* <.001.

retracted (0.6° ±1.29°). The maxillary right and left first premolars tipped distally by 7.26° ± 4.54° (*P* <.001) and 6.33° ± 3.81° (*P* <.001), respectively. The maxillary first molars also tipped during distalization. Amounts of distal tipping of the maxillary right and left first molars were 10° ± 3.29° (*P* <.001) and 14° ± 5.08° (*P* <.001), respectively. An 0.8° ± 0.94° change in the angle between the longitudinal axis of the implant and the SN plane was statistically significant (*P* <.01).

As the distance between the Ptm vertical and maxillary right central incisors remained unchanged, the distance to the maxillary left central incisor decreased (0.2 ± 0.77 mm), but this was not statistically significant. Distalization of the maxillary right first premolar was 2.8 ± 0.94 mm (*P* <.001), and the maxillary left first premolar was 3.4 ± 1.45 mm (*P* <.001). The amounts of distalization of the maxillary right and left first molars were 3.4 ± 1.18 mm (*P* <.001) and 4.5 ± 1.12 mm (*P* <.001), respectively. The distances between Point A, Point B, and implant and Ptm vertical did not show significant changes.

In the analysis of soft-tissue measurements, 1 mm of retraction was seen between Ptm vertical and the upper lip, but this was not statistically significant. The changes in lower lip-Ptm vertical distance and nasolabial angle were also not statistically significant. The statistically significant increases in the Na ANS (*P* <.01), ANS Me (*P* <.05), and Na Me (*P* <.001) measurements indicated the increase in anterior face height. A smaller increase in the Se Go measurement (*P* <.05) was observed after pendulum and implant treatment.

Table II. Pretreatment and posttreatment measurements in implant group

		Pretreatment				*Posttreatment*				*Differences*				
Variable	*n*	*Min*	*Max*	$\bar{X}$	*SD*	*Min*	*Max*	$\bar{X}$	*SD*	*Min*	*Max*	$\bar{D}$	*SD*	P
Angular (°)														
SNA	15	83.00	90.00	86.3	2.19	83.00	90.00	86.1	2	−1.00	0.50	−0.16	0.48	NS
SNB	15	80.00	86.00	82.7	1.7	80.00	86.00	82.7	1.66	−1.00	1.00	0.03	0.51	NS
ANB	15	1.00	7.00	3.6	1.79	1.50	6.00	3.4	1.37	−1.50	1.00	−0.2	0.79	NS
SNGoGn	15	28.00	36.00	31	2.69	28.00	39.00	33	3.03	0.00	3.00	2.06	0.88	‡
FMA	15	20.00	36.00	27.4	4.13	22.00	37.00	29.2	3.87	0.00	3.00	1.73	0.79	‡
IMPA	15	95.00	110.00	102.1	3.39	95.00	110.00	102.1	3.51	−1.00	1.00	−0.03	0.71	NS
SN PP	15	6.00	16.00	10	2.21	7.00	17.00	10.3	2.3	−1.00	2.00	0.33	0.77	NS
SN OP	15	16.00	22.00	19.9	1.88	19.00	24.00	21.3	1.43	−0.50	4.00	1.4	1.07	‡
UR1 SN	15	66.00	119.00	94.3	13.8	65.00	121.00	93.3	14.1	−3.00	2.00	−1	1.13	†
UR4 SN	15	90.00	112.00	100.6	6.66	86.00	109.00	93.4	6.2	−19.00	−2.00	−7.26	4.54	‡
UR6 SN	15	57.00	80.00	69.9	6.05	41.00	69.00	59.9	6.79	−16.00	−1.00	−10	3.29	‡
UL1 SN	15	60.00	120.00	92.1	15.2	60.00	120.00	91.5	14.8	−3.00	2.00	−0.6	1.29	NS
UL4 SN	15	88.00	114.00	98.3	7.8	85.00	111.00	92	7.16	−19.00	−3.00	−6.33	3.81	‡
UL6 SN	15	58.00	88.00	72.7	7.85	44.00	78.00	58.2	8.98	−28.00	−6.00	−14.4	5.08	‡
IMP-SN	15	40.00	50.00	45.8	2.14	41.00	51.00	46.6	2.41	−1.00	3.00	0.8	0.94	†
NLA	15	111.00	133.00	120.7	6.52	112.00	135.00	122.6	6.94	−10.00	14.00	1.9	5.95	NS
Linear (mm)														
UR1 Ptm	15	48.00	58.00	53.4	2.89	48.00	57.00	53.4	2.77	−2.00	3.00	0.06	1.09	NS
UR4 Ptm	15	34.00	42.00	38	2.42	31.00	39.00	35.2	2.7	−4.00	−1.00	−2.8	0.94	‡
UR6 Ptm	15	23.00	33.00	28	2.93	19.00	31.00	24.5	3.58	−5.00	−1.00	−3.4	1.18	‡
LR1 Ptm	15	43.00	53.00	48.2	3.19	43.00	54.00	48.4	3.5	−1.00	1.00	−0.2	0.77	NS
UL1 Ptm	15	51.00	73.00	59.1	6.03	49.00	72.00	57.1	6.27	−5.00	1.00	−2	1.81	†
UL4 Ptm	15	36.00	44.00	40.2	2.78	33.00	42.00	36.8	2.51	−7.00	−1.00	−3.4	1.45	‡
UL6 Ptm	15	23.00	32.00	28	2.93	19.00	28.00	23.5	2.87	−7.00	−3.00	−4.5	1.12	‡
LL1 Ptm	15	44.00	53.00	48.8	2.69	44.00	53.00	48.7	2.63	−2.00	2.00	−1.3	1.12	NS
Ptm A	15	48.00	56.00	51.6	2.25	48.00	55.00	52	2	0.00	19.00	5.4	5.3	NS
Ptm B	15	30.00	46.00	39.8	4.42	31.00	48.00	40.7	4.45	−9.00	9.00	−3	5.39	NS
Na ANS	15	56.00	59.00	57.6	0.99	57.00	59.00	58.2	0.67	0.00	2.00	0.53	0.66	†
ANS Me	15	65.00	75.00	68.3	2.52	64.00	75.00	68.9	2.64	−3.00	3.00	0.66	1.26	*
Na Me	15	122.00	133.00	127.5	2.79	124.00	135.00	128.8	2.88	0.00	3.00	1.36	0.85	‡
Se Go	15	84.00	93.00	88.3	2.57	86.00	92.00	89.1	1.37	−2.00	2.00	0.76	1.09	*
UL Ptm	15	64.00	72.00	68.8	2.35	62.00	73.00	67.8	3.29	−8.00	6.00	−1	3.56	NS
LL Ptm	15	55.00	69.00	61	3.39	55.00	69.00	61.1	3.29	−4.00	2.00	0.06	1.33	NS
IMP Ptm	15	30.00	40.00	34.2	2.75	30.00	40.00	34.8	3.18	−2.00	4.00	0.6	1.45	NS

Min, Minimum; *Max,* maximum; *NS,* not significant.
**P* <.05; †*P* <.01; ‡*P* <.001.

Intergroup comparison

Intergroup comparisons were significant for SNB angle (*P* <.05) because the pendulum group showed a decrease in the mean value of the angle, whereas the implant group had no change (Table III). The increase in the mean value of the SNGoGn angle was statistically significant (*P* <.01) for the implant group. However, the increase in anterior facial height was greater than that of the implant group, and this difference was statistically significant (*P* <.01). Both central incisors tipped labially in the pendulum group and palatally in the implant group. The differences were statistically significant (*P* <.05) for the maxillary right central incisor. The maxillary right and left first premolars tipped mesially in the pendulum group and distally in the implant group; this change was statistically significant (*P* <.001). Also, the maxillary left first molars had much more distal tipping in the implant group than in the pendulum group; this was determined to be statistically significant (*P* <.001).

The distance from Ptm to the maxillary left and right central incisors increased in the pendulum group and decreased in the implant group; the difference was statistically significant (*P* <.001) for the maxillary left central incisor between these 2 groups. The distalization of the maxillary first molars was similar in both groups, but the change for the maxillary right first molar was significant (*P* <.01). Moreover, the PtmB distance decreased in the pen-

Table III. Intergroup comparison

Variables	n	Pendulum appliance Min	Max	$\bar{D}$	SD	Implant appliance Min	Max	$\bar{D}$	SD	Differences $\bar{D}$	P
Angular (°)											
SNA	30	−2.50	1.00	−0.36	0.95	−1.00	0.50	−0.16	0.48	0.2	NS
SNB	30	−4.00	0.00	−0.73	1.03	−1.00	1.00	0.03	0.51	−0.76	*
ANB	30	−1.00	1.50	0.46	0.81	−1.50	1.00	−0.2	0.79	0.66	*
SNGo Gn	30	−2.50	3.00	0.33	1.49	0.00	3.00	2.06	0.88	−1.73	†
FMA	30	−9.00	8.00	1.83	4.04	0.00	3.00	1.73	0.79	0.01	NS
IMPA	30	−3.00	11.00	1.53	3.24	−1.00	1.00	−0.03	0.71	1.56	NS
SN PP	30	−3.00	1.00	−0.73	0.92	−1.00	2.00	0.33	0.77	−1.06	†
SN OP	30	−3.50	6.00	1.76	2	−0.50	4.00	1.4	1.07	0.36	NS
UR1 SN	30	−7.00	15.00	2.3	5.48	−3.00	2.00	−1	1.13	3.3	*
UR4 SN	30	−1.50	14.50	2.83	3.84	−19.00	−2.00	−7.26	4.54	10	‡
UR6 SN	30	−25.00	−1.00	−7.06	5.86	−16.00	−1.00	−10	3.29	2.93	NS
UL1 SN	30	−14.00	10.50	1.76	5.23	−3.00	2.00	−0.6	1.29	2.36	NS
UL4 SN	30	−2.00	10.00	3.13	3.24	−19.00	−3.00	−6.33	3.81	9.46	‡
UL6 SN	30	−11.50	−1.00	−5.13	2.84	−28.00	−6.00	−14.4	5.08	9.27	‡
NLA	30	−17.00	2.00	−2.7	4.39	−10.00	14.00	1.9	5.95	−4.63	*
Linear (mm)											
UR1 Ptm	30	−3.00	6.00	0.73	2.61	−2.00	3.00	0.06	1.09	0.66	NS
UR4 Ptm	30	−3.00	4.00	1.56	1.69	−4.00	−1.00	−2.8	0.94	4.36	‡
UR6 Ptm	30	−9.00	−3.00	−4.96	1.44	−5.00	−1.00	−3.4	1.18	−1.56	†
LR1 Ptm	30	−4.00	2.00	−1.03	1.34	−1.00	1.00	−0.2	0.77	−0.83	†
UL1 Ptm	30	−1.00	6.00	2	1.52	−5.00	1.00	−2	1.81	4	‡
UL4 Ptm	30	0.50	4.00	2.76	1.03	−7.00	−1.00	−3.4	1.45	6.16	‡
UL6 Ptm	30	−9.00	−3.00	−5.1	1.44	−7.00	−3.00	−4.5	1.12	−0.56	NS
LL1 Ptm	30	−4.00	3.00	−0.8	1.82	−2.00	2.00	−1.3	1.12	−0.5	NS
Ptm A	30	1.50	10.00	6.73	2.32	0.00	19.00	5.4	5.3	1.33	NS
Ptm B	30	−2.50	6.00	1.96	2.61	−9.00	9.00	−3	5.39	4.96	†
Na ANS	30	−1.50	3.50	0.73	1.25	0.00	2.00	0.53	0.66	2	NS
ANS Me	30	−4.00	5.50	2.2	2.13	−3.00	3.00	0.66	1.26	1.53	*
Na Me	30	−3.00	9.00	4.13	2.61	0.00	3.00	1.36	0.85	2.76	†
Se Go	30	−2.50	8.00	3.13	2.35	−2.00	2.00	0.76	1.09	2.36	†
UL Ptm	30	−6.50	4.50	−0.93	2.77	−8.00	6.00	−1	3.56	0.06	NS
LL Ptm	30	−3.00	2.00	−0.7	1.16	−4.00	2.00	0.06	1.33	−0.76	NS

Min, Minimum; *Max,* maximum; *NS,* not significant.
*$P < .05$; †$P < .01$; ‡$P < .001$.

dulum group and increased in the implant group, and the difference between the groups was statistically significant ($P < .01$).

Statistically significant differences were found in the ANS Me ($P < .05$), Na Me ($P < .01$), and Se Go ($P < .01$) measurements.

Because of the protrusion of the incisors, the nasolabial angle decreased in the pendulum group and increased in the implant group. The changes in the distances from upper and lower lips to Ptm were statistically significant between the 2 groups ($P < .05$).

DISCUSSION

Many extraoral and intraoral appliances are used for molar distalization.[1,6,7,12,13,18,19,23,24,60] The Hilgers pendulum appliance is an intraoral molar appliance, and it uses the maxillary premolars, the incisors, and the anterior palatal region as anchorage for molar distalization. Like the other intraoral appliances, it is effective in molar distalization, but the acrylic button in palatal depth is insufficient to resist the reciprocal mesial force of the appliance. Therefore, anchorage loss is seen, especially with the proclination of the maxillary incisors.[2,8,25,27,29,61]

To minimize this side effect, palatal implants became an alternative mode of treatment in orthodontics. This treatment option is debatable because of the surgery, but its benefits are significant.[42,44,51,53,54,62-64]

In our study, we compared the cephalometric results of the Hilgers pendulum appliance and our implant-supported molar distalization technique. Sagittal cephalometric films were taken from patients' left and right sides. Therefore, we eliminated superimposition errors.

The amounts of molar distalization were 4.96 mm on the right and 5.10 mm on the left with the pendulum appliance (P <.001) after 6 months. Moreover, distalization tipping of the maxillary first molars was noted in every patient (right molar, 7.06 °; left molar, 5.13°; P <.001). These changes pointed out increases similar to those of Byloff and Darendeliler[31] (3.39 mm, 14.5°), Bussick and McNamara[37] (5.7 mm, 10.6°), Ghosh and Nanda[25] (3.37 mm, 8.36°), Hilgers[26] (5 mm), Burkhardt et al[65] (0.8 mm, 3.7°), Taner et al[61] (3.81 mm, 11.77°), and Kinzinger et al[8] (3.14 mm) with the modified pendulum appliance. The distalization amount was greater than in other intraoral techniques.[5,6]

Kinzinger et al[8] reported that, with pendulum treatment, distal tipping of the first molars was less in patients with erupted second molars than in those whose second molars were not yet erupted. If a second molar has not erupted, it acts as a fulcrum and causes first molar tipping.[20] Byloff et al,[32] Bussick and McNamara,[37] Ghosh and Nanda,[25] and Joseph and Butchart[66] concluded that second molars do not affect linear and angular changes in molar distalization. In our study, the second molars were fully erupted at the beginning of the treatment, and tipping was noted in every subject.

Loss of anchorage was measured at the maxillary first premolars and the incisors. The maxillary first premolars were mesialized 1.54 mm at the right side (P <.01) and 2.76 mm at the left side (P <.001), and tipped mesially 2.83° at the right side (P <.01) and 2.13° (P <.01) at the left side. These findings are supported by those of Taner et al[61] (0.73 mm, 4.07°), Ghosh and Nanda[25] (2.55 mm, 1.29°), and Bussick and McNamara[37] (1.8 mm, 1.5°). Ghosh and Nanda[25] stated that for every millimeter of distal molar movement, the maxillary first premolars moved 0.75 mm mesially. Byloff and Darendeliler[31] measured the maxillary second premolars for anchorage loss and found 1.63 mm mesial movement.

The maxillary central incisors were proclined by 2.3° and 1.76° (not significant) and mesialized by 0.73 mm (not significant at the right side) and 2 mm at the left side (P <.001) in our study. Even though the studies of Kinzinger et al,[8] Byloff and Darendeliler,[31] Byloff et al,[32] Burkhardt et al,[65] Wong et al,[2] Bussick and McNamara[37] (0.9 mm, 3.6°), and Taner et al[61] (2 mm., 6.08°) support these findings, they did not measure the values from the left and right sides separately as we did.

The pendulum appliance also had an effect on SNB (P <.05) and ANB (P <.05) angles, upper (P <.05) and lower (P <.01) anterior facial height, and posterior facial height (P <.001). SNOP (P <.01) and also Na Me angle increased (P <.001). B-point (P <.001) and the lower lip also moved distally (P <.05). As the maxillary first molars move distally with tooth-borne appliances, there is a wedging, bite-opening tendency,[25] and this might account for the reductions in SNB and ANB angles.[65]

Implants are used for anchorage control with fixed and removable appliances. Experimental and clinical studies about orthodontically loaded osseointegrated titanium implants showed that these implants are effective for stationary anchorage.[53-55,67-70]

Triaca et al[40] and Wehrbein et al[55] described the median-sagittal region of the hard palate as a suitable location for implant placement. This region is surgically a well-accepted area. Besides the median-sagittal suture, the paramedian region is also a suitable place for implants.[67] We also prefer the paramedian region. Block and Hoffman[64] used a subperiosteal disc 10 mm in diameter, Triaco et al[40] used a screw implant 7.5 mm in diameter and 3 mm in length, and Wehrbein et al[53] used implants 3.3 mm in diameter and 4 and 6 mm in length. We used implants 3.8 mm in diameter and 9 mm in length (Camlog screw cylinder). Byloff et al[56] and Kärcher et al[57] used titanium plates with two 9-mm pins attached to the palate by four 5-mm miniscrews for anchorage.

After implant-supported appliance treatment, the maxillary right first molar moved 3.4 mm, and the maxillary left first molar moved 4.5 mm distally (P <.001) and tipped 10° and 14.4°, respectively. These findings were supported by those of Gelgör et al,[59] Keleş et al,[58] Kärcher et al,[57] and Karaman et al.[34]

The first premolars and the incisors moved and tipped distally. The amounts of distalization in the premolars were 2.8 and 3.4 mm (P <.001), and tipping was 7.27° and 6.33° (P <.001). Because we did not use the maxillary premolars as anchorage units, they distalized by interceptal fibers between the maxillary molars and premolars. The studies of Kärcher et al,[57] Byloff et al,[56] and Keleş et al[58] support these findings.

There was no proclination of the maxillary central incisors, although the maxillary left incisors moved distally by 2 mm (P <.05). This result might have occurred because of the placement of the implants on the left side. Distalization of the mandibular incisors was not significant. SNGoGn angle (P <.001), FMA (P <.001), upper anterior facial height (P <.01), lower anterior facial height (P <.05), posterior facial height archer (P <.05), and Na Me angle (P <.001) all increased. Despite our findings, Gelgör et al[59] did not report changes in vertical measurements. This might be because of the stainless steel transpalatal arch placed between the premolars.

When the 2 groups were compared, first molar distalization was greater in the pendulum group, but maxillary right first molar distalization was significant ($P < .01$). The tipping of the left first molar was found to be significant ($P < .001$).

The changes in the maxillary first premolars were also significant ($P < .001$) because, in the pendulum group, the premolars were used as anchorage but not in the implant-supported group. Thus mesial movement of pendulum did not affect the maxillary premolars in the implant group. The difference between the maxillary right central incisors was not important, but the left central incisors showed significant changes ($P < .001$). As in the maxillary first molar changes, the tipping of the maxillary left central incisor was not important but the right central incisor tipping was important ($P < .05$).

The increase in SNGoGn angle was greater in the implant group ($P < .01$); the other vertical measurements (ANS Me [$P < .05$] and Se Go [$P < .01$]) were greater in pendulum group. Distalization techniques tend to increase the extrusion of the molars.[36] Our results showed that extrusion was greater in pendulum group.

In the analysis of soft-tissue changes, lower lip retraction and NLA changes were significant in pendulum group ($P < .05$). NLA changes were due to the proclination of the maxillary incisors, and lower lip retraction was due to the posterior rotation of the mandible that was supported by the significant change in the PtmB measurement. Soft-tissue changes follow incisor changes, as reported by Üçem et al.[17] The soft-tissue changes were not important in the implant group. In the intergroup comparisons, only NLA was important due to the change in the maxillary incisors in the pendulum group.

In both groups, the patients tolerated the appliances easily. There was no breakage in either group. Only the cephalometric analysis showed a slight forward inclination movement in the implants (0.8 mm) ($P < .01$), but forward movement was not important. Akın-Nergis et al[68] found a 0.03-mm sagittal displacement of the implant with 204 g of load in an animal study.

CONCLUSIONS

1. Distalization of the maxillary first molars was successfully achieved in both groups.
2. Anchorage loss was significant in the pendulum group; however, anchorage was not lost in the implant group.
3. The amount of distal tipping of the maxillary first molars was significant in the implant group.
4. The distal movement of the maxillary first premolars after the distalization of the maxillary first molars would positively affect the prognosis.
5. The increase in the vertical dimensions was significant in the implant group.
6. In patients with protruding maxillary central incisors and certain posterior anchorage needs, it would be more appropriate to distalize the maxillary first molars by implant-supported mechanics.

We evaluated the dentofacial changes after distalizations of the maxillary first molars. The evaluation of the changes after orthodontic treatment with full fixed appliances will be discussed in a subsequent article.

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