Original Article

Evaluation of the effects of the hybrid Pendulum in comparison with the conventional Pendulum appliance

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ABSTRACT

Objective: To evaluate the anchorage control and distalization of maxillary molars with the hybrid Pendulum appliance and to compare the results with a conventional Pendulum appliance.

Materials and Methods: This study was carried out on the pre-(T0) and post-(T1) treatment lateral cephalograms and dental casts of 43 patients with Angle Class II molar relationships who were treated with conventional or hybrid Pendulum appliances. The hybrid Pendulum (HP) group consisted of 22 patients (14 females; eight males; mean age 14.3 $\pm$ 2.43 years) and treatment results were compared with a conventional Pendulum appliance (CP) group, which consisted of 21 patients (15 females; six males; mean age 14.6 $\pm$ 3.39 years). Intragroup comparisons were made with Wilcoxon test and intergroup comparisons were made with Mann-Whitney *U*-test ($P < .05$).

Results: The mean distalization duration was 0.70 $\pm$ 0.25 years in the HP group and 0.83 $\pm$ 0.4 years in the CP group. Maxillary first molars showed significant distal movement and tipping of 4.25 mm and 9.09° in the HP group, and 3.21 mm and 9.86° in the CP group. Loss of anchorage at the first premolars was significantly smaller in the HP appliance group compared to CP group. The second premolars distalized spontaneously in the HP group while they mesialized significantly in the CP group. Proclination and protrusion of maxillary incisors were greater with the CP appliance compared to the HP appliance.

Conclusions: Maxillary molar distalization was achieved with both appliances. Mesialization of the anchorage unit was controlled successfully with the hybrid Pendulum; however, the conventional Pendulum appliance caused anchorage loss. (*Angle Orthod.* 2020;90:194–201.)

KEY WORDS: Molar distalization; Pendulum appliance; Skeletal anchorage

INTRODUCTION

Maxillary molar distalization is an important treatment modality that requires absolute anchorage. For this purpose, miniscrew-assisted maxillary molar distalization techniques have been integrated into orthodontic practice.[1–3]

Based on distalization mechanics and miniscrew insertion sites, various maxillary molar distalization techniques have been proposed.[4,5] The conventional Pendulum appliance of Hilgers[6] has been modified several times with miniscrews to overcome the side effects caused by occlusal rests on the premolars.[1–3,7–10] In most of these previous studies, the Pendulum appliance was supported with two miniscrews inserted to anterior paramedian region.[1,3,7–10] There were a few studies using one miniscrew and without occlusal rests on the premolars.[2,3]

Despite several studies evaluating bone supported Pendulum appliances in the literature,[1–3,7–10] there was no study with a tooth- and bone-supported (hybrid) Pendulum appliance. Therefore, the aim of the present study was to evaluate the anchorage control and distalization of maxillary molars with a hybrid Pendulum appliance and to compare the results with a conventional Pendulum appliance.

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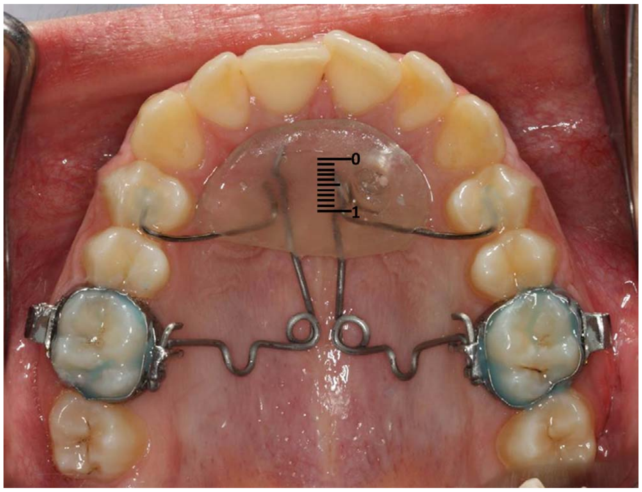

Figure 1. Intraoral view of a hybrid Pendulum (HP) appliance.

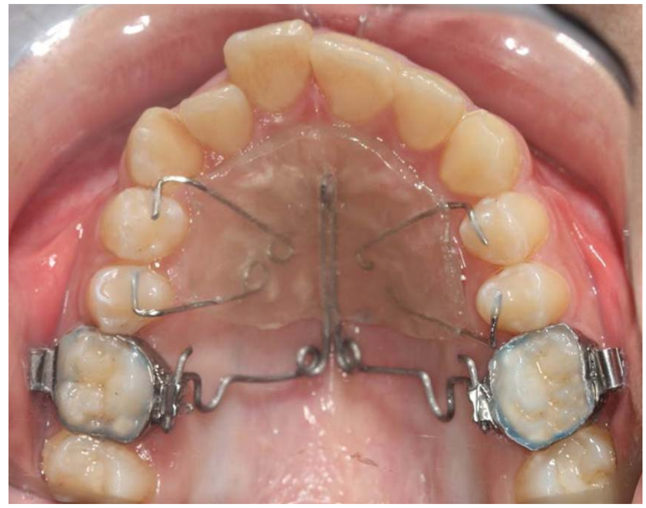

Figure 2. Intraoral view of a conventional Pendulum (CP) appliance.

MATERIALS AND METHODS

This retrospective study was carried out on the pre-(T0) and post-(T1) distalization lateral cephalograms and dental casts of patients who were treated with conventional or hybrid Pendulum appliances at Gazi University Dental Faculty. The study was approved by the Ethics Committee of Gazi University (2018-106).

The sample size was estimated by the G*Power Software (v3.1.3; Franz Faul, Universität Kiel, Germany). Based on an alpha significance level of 0.05 and a beta of 0.2 to achieve 80% power, to detect a minimum difference of 4.8 mm molar distalization with a 1.8 mm of estimated standard deviation,[3] 21 subjects per group were required.

The patients were selected according to the following inclusion criteria: (1) no craniofacial anomalies and no previous orthodontic treatment, (2) Class II molar relationship, (3) minimal crowding in the mandibular arch ($\leq$2 mm) and moderate crowding in the maxillary arch ($\leq$5 mm), (4) fully erupted maxillary second molars, and (5) SN/GoGn $\leq$38°. A signed informed consent form regarding the treatment protocol was obtained from all the patients and their parents.

Based on the inclusion criteria and power analysis results, the hybrid Pendulum appliance group (HP) was composed of 22 patients (14 females; eight males; mean chronological age 14.3 $\pm$ 2.43 years) and the conventional Pendulum appliance group (CP) consisted of 21 patients (15 females; six males; mean chronological age 14.6 $\pm$ 3.39 years).

In both groups, the Pendulum appliance was constructed according to the method of Hilgers,[6] excluding the auxiliary occlusal rests from second premolars in the HP group. Additionally, in the HP group, a self-drilling miniscrew (Spider screw, HDC Company, Thiene, Italy) of 1.9 mm diameter and 9 mm length was placed in the paramedian area of the anterior palate, approximately 4–5 mm posterior to the incisive papilla and 4–5 mm lateral to the median palatal suture to provide monocortical anchorage. The appliance was connected to the miniscrew with cold-curing, methyl methacrylate-free acrylic resin (Ufi Gel Hard; Voco GmbH, Cuxhaven, Germany) (Figures 1 and 2). Distalization was continued until an Angle Class I molar relationship was achieved.

All cephalometric radiographs were traced and superimposed by the same researcher (E.B.). Local maxillary superimposition was performed on the anatomical structures of the hard palate and anterior maxillary trabecular structures[11] to evaluate the dento-alveolar changes. The "maxillary horizontal reference plane (PP Line)" was drawn along ANS-PNS plane, and the "maxillary vertical reference plane (PPvert Line)" was constructed perpendicular to this plane at PNS point. Nine angular and 14 linear measurements were evaluated on lateral cephalometric radiographs (Figures 3 and 4). The dental casts were scanned using a 3D scanner (3Shape, Copenhagen, Denmark) and three linear measurements were made using OrthoAnalyzer (3Shape) (Figure 5).

Statistical Analysis

The data were evaluated with SPSS version 21.0 (IBM SPSS Statistics for Windows, Armonk, New York: IBM Corp.). Normality of the distribution of the variables was examined with Shapiro-Wilk test. Intra-group comparisons were analyzed with the Wilcoxon test and Mann-Whitney *U*-test was used for intergroup comparisons.

Two weeks after the first measurements, records of 15 randomly selected subjects were remeasured by the same examiner (E.B.). A high intra-observer

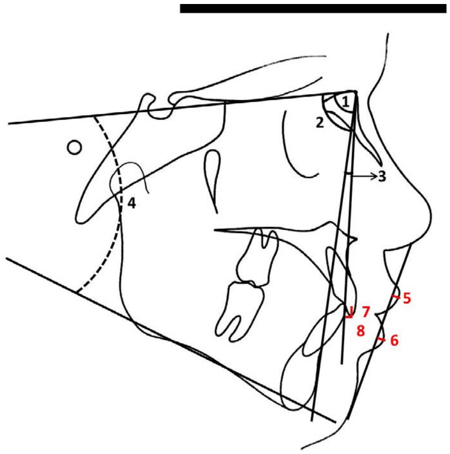

Figure 3. Cephalometric measurements evaluated in the present study: 1-SNA; 2-SNB; 3-ANB; 4-SN/GoGn; 5-UL-S Line; 6-LL-S Line; 7-Overbite; 8-Overjet.

reproducibility was found by intraclass correlation coefficient (0.9–1.0).

RESULTS

Descriptive statistics are shown in Table 1. U7/PP° was significantly different between the two groups at T0 ($P < .05$) (Table 1).

Table 2 presents the intra- and intergroup differences related to HP and CP treatments. The mean distalization duration was 0.70 $\pm$ 0.25 years in the HP group and 0.83 $\pm$ 0.4 years in the CP group ($P >$ .05) (Table 2).

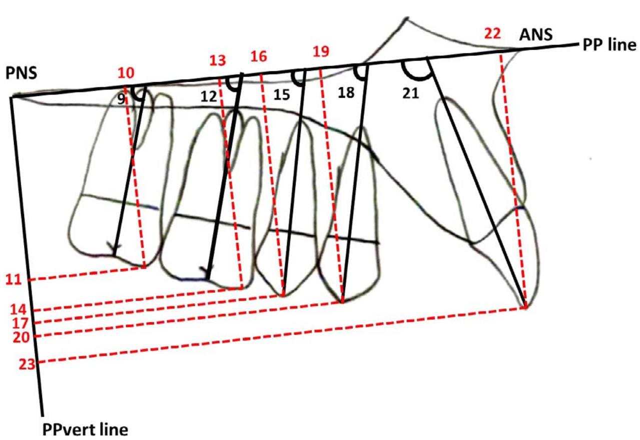

Figure 4. Maxillary dentoalveolar cephalometric measurements evaluated in the present study: 9-U7/PP; 10-U7-PP; 11-U7-PPvert.; 12-U6/PP; 13-U6-PP; 14-U6-PPvert.; 15-U5/PP; 16-U5-PP; 17-U5-PPvert.; 18-U4/PP; 19-U4-PP; 20-U4-PPvert.; 21-U1/PP; 22-U1-PP; 23-U1-PPvert.

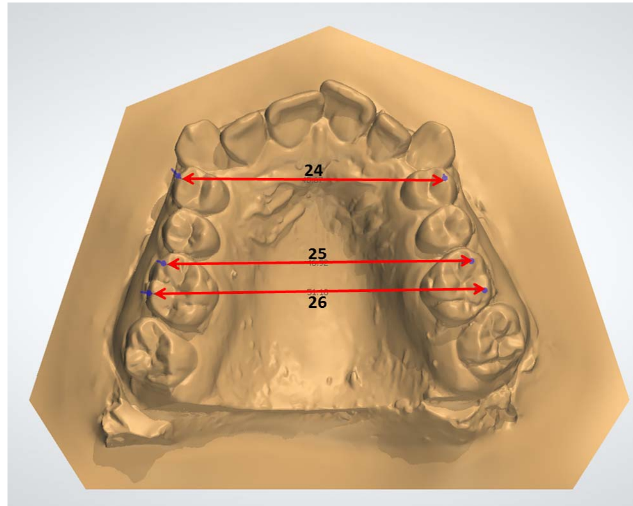

Figure 5. Maxillary dental cast measurements evaluated in the present study: 24-UL4-UR4; 25- UL6m-UR6m; 26- UL6d-UL6d; (m-Mesiobuccal cusp; d-Distobuccal cusp).

HP Group

The increase in SNA° and SNB°, and the decrease in SN/GoGn°, were statistically significant from T0 to T1 ($P < .01$).

Significant distal movement (U6-PPvert and U7-PPvert, $P < .001$), tipping (U6/PP and U7/PP, $P <$ .001), and intrusion (U6-PP, $P < .05$; U7-PP, $P < .01$) of maxillary molars were observed.

Maxillary second premolars showed significant distal movement (U5-PPvert, $P < .001$) and tipping (U5/PP, $P < .001$) while maxillary first premolars showed only distal tipping (U4/PP, $P < .05$) and some intrusion (U4-PP, $P < .05$).

Maxillary incisors (U1-PPvert) showed significant protrusion ($P < .01$).

According to dental cast analysis, there were significant increases in interpremolar (U4R-U4L) and intermolar (UL6m-UR6m, UL6d-UR6d) distances ($P <$ .001) (Table 2).

CP Group

There was a significant increase in SN/GoGn° ($P <$ .05).

Distal movement (U6-PPvert and U7-PPvert) and tipping (U6/PP and U7/PP) of maxillary molars were significant ($P < .001$).

Significant mesial movement (U4-PPvert, $P < .001$; U5-PPvert, $P < .01$), mesial tipping (U4/PP, $P < .001$; U5/PP, $P < .05$) and extrusion (U4-PP, $P < .01$; U5-PP, $P < .001$) were observed for the maxillary first and second premolars. Maxillary incisors showed significant proclination (U1/PP) and protrusion (U1-PPvert) ($P < .001$).

Table 1. Descriptive Statistics of Initial Measurements and Comparison Between Groups

Parameter		Hybrid Pendulum (HP) Group (n = 22)				Conventional Pendulum (CP) Group (n = 21)				
		Mean	Median	SD[b]	IQR[b]	Mean	Median	SD	IQR	*P*[a]
Age	**Age (years)**	14.30	14.17	2.43	4.13	14.60	13.83	3.39	4.17	.865
Skeletal	**SNA (°)**	78.73	79.00	3.50	5.63	78.38	79.00	3.28	5.00	.770
	SNB (°)	75.84	76.25	3.36	5.00	75.36	76.00	3.26	3.25	.688
	ANB (°)	2.89	3.00	1.36	1.75	3.07	3.50	1.65	2.75	.378
	SN/GoGn (°)	33.02	33.50	3.66	4.88	32.67	33.00	5.06	9.5	.855
Dental sagittal	**U1-PPvert (mm)**	54.45	55.00	3.34	5.13	52.19	52.00	3.84	5.25	.051
	U4-PPvert (mm)	36.75	36.50	3.88	4.25	35.14	34.50	3.46	4.50	.095
	U5-PPvert (mm)	28.25	29.00	3.69	5.13	27.67	27.00	3.37	3.25	.421
	U6-PPvert (mm)	22.34	21.75	3.02	4.63	21.71	21.00	3.21	3.75	.566
	U7-PPvert (mm)	9.66	10.00	3.76	4.88	11.07	11.50	3.02	4.50	.238
	Overjet (mm)	3.66	3.25	2.37	2.75	3.62	3.50	1.55	1.75	.549
	Overbite (mm)	2.98	3.00	1.38	2.00	3.55	3.50	1.51	1.00	.108
Dental vertical	**U1-PP (mm)**	29.98	29.25	2.71	4.25	29.52	29.50	2.69	3.75	.617
	U4-PP (mm)	27.36	27.38	2.65	4.00	25.52	26.00	2.51	4.00	.050
	U5-PP (mm)	25.75	26.00	2.81	4.63	24.69	25.00	2.57	3.75	.232
	U6-PP (mm)	24.77	24.50	2.69	4.00	23.02	23.00	2.67	3.50	.059
	U7-PP (mm)	18.70	19.75	4.09	5.25	19.12	19.00	3.32	4.75	.884
Dental angular	**U1/PP (°)**	110.48	111.25	5.62	7.88	109.74	111.00	7.10	11.00	.798
	U4/PP (°)	92.11	91.25	5.44	5.69	92.10	91.00	4.91	7.00	.913
	U5/PP (°)	83.82	83.25	4.40	6.63	86.50	86.00	4.66	6.50	.056
	U6/PP (°)	81.80	80.88	5.66	6.13	80.76	80.00	5.30	9.50	.770
	U7/PP (°)	67.11	68.00	4.85	7.25	71.83	72.00	7.13	11.75	**.034***
Soft tissue	**UL-S Line (mm)**	−0.80	−0.75	2.05	2.75	−1.10	−1.00	2.05	2.75	.826
	LL-S Line (mm)	−0.25	−0.50	2.62	4.00	−0.36	−0.50	3.07	4.75	.913
Dental transverse	**U4R-U4L (mm)**	39.33	39.59	1.98	3.08	39.14	38.59	2.20	2.26	.489
	UL6m-UR6m (mm)	50.24	50.52	3.34	4.07	50.11	50.06	2.75	3.97	.618
	UL6d-UR6d (mm)	53.68	53.56	3.19	3.83	52.34	52.10	2.73	2.66	.089

[a] Intergroup comparisons performed by Mann-Whitney *U*-test.
[b] SD indicates standard deviation; IQR, interquartile range.
* $P < .05$; ** $P < .01$; *** $P < .001$.

Overjet increased and overbite decreased significantly ($P < .001$).

Upper and lower lips protruded significantly (UL-S, $P < .01$; LL-S, $P < .05$).

According to dental cast analysis, significant increases were observed in interpremolar (U4R-U4L) and intermolar (UL6m-UR6m, UL6d-UR6d) distances ($P < .01$) (Table 2).

Comparison of the Groups

The change in SNA° ($P < .05$), SNB° ($P < .01$), and SN/GoGn° ($P < .01$) during treatment were significantly different between the groups.

Distal movement of the maxillary molars was significantly greater in the HP group compared to the CP group (U6-PPvert, $P < .01$; U7-PPvert, $P < .05$). The intrusion of maxillary second molars was significantly greater in the HP group compared to the CP group (U7-PP, $P < .05$).

The significant mesial movement (U4-PPvert, $P < .001$; U5-PPvert, $P < .01$), mesial tipping (U4/PP, $P < .001$; U5/PP, $P < .05$) and extrusion (U4-PP, $P < .01$; U5-PP, $P < .001$) of the maxillary first and second premolars in the CP group showed significant differences compared to the significant distal movement (U5-PPvert, $P < .001$), tipping (U5/PP, $P < .001$) and insignificant extrusion (U5-PP, $P > 0.05$) of the maxillary second premolars with insignificant mesial movement (U4-PPvert, $P > 0.05$), significant distal tipping (U4/PP, $P < .05$) and intrusion (U4-PP, $P < .05$) of maxillary first premolars in the HP group ($P < .001$).

Proclination (U1/PP°) and protrusion (U1-PPvert) of maxillary incisors were significantly greater in the CP group than in the HP group ($P < .001$).

Increase in overjet was more pronounced in the CP group than in the HP group ($P < .001$). Overbite decreased in the CP group ($P < .001$) while it increased in HP group ($P > .05$). These changes were significantly different between the groups ($P < .001$).

The significant protrusion of the upper and lower lips in the CP group (UL-S, $P < .01$; LL-S, $P < .05$) were significantly different than the insignificant retrusion of the upper and lower lips in the HP group (UL-S, $P < .01$; LL-S, $P < .05$) (Table 2).

Table 2. Descriptive Statistics of Treatment Changes and Comparison Between Groups

Parameter		Hybrid Pendulum (HP) Group (n = 22)					Conventional Pendulum (CP) Group (n = 21)					
		Mean	Median	SD[a]	IQR	P[b]	Mean	Median	SD	IQR	P[b]	P[c]
Treatment duration	**Treatment duration (years)**	0.70	0.63	0.25	0.28	**<.001*****	0.83	0.91	0.40	0.54	**<.001*****	.138
Skeletal	**SNA (°)**	0.61	0.5	0.82	1.00	**.002****	0.02	0	1.05	1.75	.773	**.037***
	SNB (°)	0.66	0.75	0.81	1.00	**.002****	−0.29	−0.5	1.07	1.25	.081	**.001****
	ANB (°)	−0.05	0	0.58	1.00	.691	0.26	0	0.7	1.00	.098	.235
	SN/GoGn (°)	−0.39	−0.25	0.63	1.00	**.009****	0.64	1	1.31	2.50	**.041***	**.006****
Dental sagital	**U1-PPvert (mm)**	0.5	0.5	0.67	1.00	**.004****	2.38	2	1.59	3.00	**<.001*****	**<.001*****
	U4-PPvert (mm)	0.28	0.5	0.91	1.50	.136	3.12	2.5	2.36	3.00	**<.001*****	**<.001*****
	U5-PPvert (mm)	−2.09	−2	0.65	0.50	**<.001*****	2.55	2.5	2.99	3.75	**.002****	**<.001*****
	U6-PPvert (mm)	−4.25	−4	0.95	1.50	**<.001*****	−3.21	−3	1.79	2.00	**<.001*****	**.003****
	U7-PPvert (mm)	−3.55	−3.5	0.87	1.13	**<.001*****	−2.86	−2.5	1.42	1.75	**<.001*****	**.030***
	Overjet (mm)	0.07	0	0.6	1.00	.471	1.5	1	1.24	2.25	**<.001*****	**<.001*****
	Overbite (mm)	0.3	0.5	0.84	1.50	.115	−1.5	−1.5	1.46	2.50	**<.001*****	**<.001*****
Dental vertical	**U1-PP (mm)**	0.27	0	0.75	1.13	.097	0.02	0	0.99	1.00	.874	.455
	U4-PP (mm)	−0.42	−0.5	0.77	1.00	**.024***	1.19	1	1.1	2.00	**.001****	**<.001*****
	U5-PP (mm)	0.18	0	0.52	0.50	.123	1.5	1.5	1.16	2.00	**<.001*****	**<.001*****
	U6-PP (mm)	−0.58	−0.75	0.99	1.38	**.014***	0.1	0	1.2	2.00	.808	.071
	U7-PP (mm)	−0.48	−0.5	0.68	1.00	**.004****	−0.1	0	1.58	1.75	.899	**.033***
Dental angular	**U1/PP (°)**	0.03	0	1.79	3.13	.913	4.76	4	4.62	6.00	**<.001*****	**<.001*****
	U4/PP (°)	−1.38	−1.75	2.94	3.56	**.010***	7.48	5	8.52	12.00	**<.001*****	**<.001*****
	U5/PP (°)	−3.98	−4	2.91	2.25	**<.001*****	3.81	3.5	7.67	8.50	**.038***	**<.001*****
	U6/PP (°)	−9.09	−9.13	3.33	4.44	**<.001*****	−9.86	−8	6.97	9.00	**<.001*****	.846
	U7/PP (°)	−8.45	−9	2.46	3.25	**<.001*****	−9.86	−8.5	7.41	5.50	**<.001*****	.951
Soft tissue	**UL-S Line (mm)**	−0.25	−0.25	1.21	1.50	.351	0.86	1	1.29	2.00	**.009****	**.008****
	LL-S Line (mm)	0.16	0	1.43	1.13	.947	0.81	0.5	1.21	2.00	**.012***	**.045***
Dental transverse	**U4R-U4L (mm)**	0.29	0.29	0.3	0.20	**<.001*****	1.34	1.15	1.76	2.62	**.003****	.126
	U6mR-U6mL (mm)	2.4	2.47	1.15	1.50	**<.001*****	2.37	2.36	2.4	3.31	**.001****	.808
	U6dR-U6dL (mm)	2.28	2.56	0.95	1.27	**<.001*****	1.59	1.25	2.54	3.72	**.006****	.120

[a] SD indicates standard deviation; IQR, interquartile range.
[b] Intragroup comparisons performed by Wilcoxon test.
[c] Intergroup comparisons performed by Mann-Whitney *U*-test.
* $P < .05$; ** $P < .01$; *** $P < .001$.

DISCUSSION

Since Hilgers[6] introduced the Pendulum appliance to orthodontics, it has been widely used for maxillary molar distalization.[7,12–15] However, loss of anchorage is an important disadvantage of a conventional Pendulum appliance.[6,7,12–14] Subsequently, many studies demonstrated that miniscrews might provide rigid anchorage and overcome this disadvantage.[1–3,8,9,16,17] Despite the successful results of purely bone supported Pendulum appliances, usually two miniscrews were preferred and that increased the cost and invasiveness of these systems. No previous studies investigated the effects of a hybrid Pendulum appliance supported by one miniscrew and occlusal rests on the first premolars that may be advantageous for clinicians in some cases. Additionally, only one study compared the effects of conventional and miniscrew-supported Pendulum appliances in the literature[3]. The present study aimed to evaluate maxillary molar distalization and anchorage control with a hybrid Pendulum appliance and to compare it with the conventional Pendulum appliance.

In the present study, miniscrews were inserted to the anterior paramedian region of palatal bone. This region was preferred since the greatest bone thickness was reported in the anterior paramedian part of the palatal bone and would therefore be relatively safe for miniscrew insertion.[18–20] Since bone thickness in this area varies depending on sex and age, cone-beam computed tomography (CBCT) scans have been recommended before insertion of orthodontic miniscrew.[18–20] However, CBCT evaluations were not performed in this study because of its retrospective design.

In previous studies, usually two miniscrews were used to increase anchorage of the Pendulum appliance[1,3,8,9,16,17] (Table 3). Kırcelli et al.,[2] however, used only one miniscrew in all subjects. Also, Polat-Özsoy et al.[3] used only one screw in nine out of 20 subjects. As Kırcelli et al.[2] observed rotation of the Pendulum appliance in two patients and Polat-Özsoy et al.[3] reported miniscrew failure in one patient, the authors suggested using two miniscrews to prevent possible miniscrew failure. In the present study, the Pendulum

Table 3. Summary of Dental Changes in Studies Utilizing Mini-Screw Anchored Pendulum Appliance According to Mini-Screw Number

		Current Study	**Kırcelli et al.[2]**	**Polat-Özsoy et. al.[3]**	**Escobar et. al.[1]**	**Kaya et. al.[9]**	**Cambiano et. al.[17]**	**Şar et al.[16]**
	Anchorage type	1 mini-screw and first premolars	1 mini-screw	1 or 2 mini-screws	2 mini-screws	2 mini-screws	2 mini-screws	2 mini-screws
	Treatment duration (months)	8.4 ± 3	7 ± 1.8	6.8 ± 1.7	7.8 ± 1.7	8.1 ± 4.2	4.8	8.2 ± 4.8
Upper central incisor	**Sagital (mm)**	0.5 ± 0.67 **	−0.2 ± 0.7 NS	−0.1 ± 1.7 NS	−.054 ± 1.33 NS	1.10 ± 2.44 NS	−0.53 NS	1.07 ± 2.53 NS
	Vertical (mm)	0.27 ± 0.75 NS	0 ± 0.6 NS	–	1.15 ± 1.69 *	0.17 ± 1.13 NS	0.44 NS	–
	Tipping (°)	0.03 ± 1.79 NS	−0.6 ± 1.8 NS	−1.7 ± 2.9 *	2.50 ± 2.98 *	2.00 ± 5.9 NS	−0.65 NS	1.96 ± 5.49 NS
Upper first premolars	**Sagital (mm)**	0.28 ± 0.91 NS	−3.8 ± 1.1 **	−2.7 ± 1.6 ***	–	−0.90 ± 1.26 ***	−1.65 *	−0.93 ± 1.30 *
	Vertical (mm)	−0.42 ± 0.77 *	0.4 ± 0.7 NS	–	-	0.57 ± 1.13 NS	0.61 NS	–
	Tipping (°)	−1.38 ± 2,94 *	−3.8 ± 1.1 **	−7.7 ± 5.1 ***	-	−4.53 ± 3.25 ***	0.46 NS	−4.93 ± 2.97 ***
Upper second premolars	**Sagital (mm)**	−2.09 ± 0.65 ***	−5.4 ± 1.3 **	−4.1 ± 2.8 ***	−4.85 ± 1.96 ***	−1.83 ± 1.14 ***	–	−1.75 ± 1.14 ***
	Vertical (mm)	0.18 ± 0.52 NS	0.1 ± 0.6 NS	–	0.46 ± 1.61 NS	0.50 ± 0.89 NS	–	–
	Tipping (°)	−3.98 ± 2.91 ***	−16.3 ± 6.5 **	−9.9 ± 5.2 ***	−8.62 ± 5.08 **	−6.10 ± 5.80 ***	–	−6.04 ± 6.01 **
Upper first molars	**Sagital (mm)**	−4.25 ± 0.95 ***	−6.4 ± 1.3 **	−4.8 ± 1.8 ***	−6.00 ± 2.27 ***	−3.00 ± 1.70 ***	−3.45 **	−2.93 ± 1.74 ***
	Vertical (mm)	−0.58 ± 0.99 *	0.1 ± 0.5 NS	–	0.50 ± 1.73 NS	−0.07 ± 1.02 NS	−0.74 *	–
	Tipping (°)	−9.09 ± 3.33 ***	−10.9 ± 2.8 **	−9.1 ± 4.6 ***	−11.31 ± 6.22 ***	−8.80 ± 6.54 ***	−11.24 **	−9.00 ± 6.74 ***
Upper second molars	**Sagital (mm)**	−3.55 ± 0.87 ***	–	−3.3 ± 1.3	–	−2.43 ± 1.24 ***	−3.00 **	−2.39 ± 1.27 ***
	Vertical (mm)	−0.48 ± 0.48 **	–	–	–	−1.57 ± 1.90 ***	−1.55 *	–
	Tipping (°)	−8.45 ± 2.46 ***	–	−9.5 ± 5.2 ***	–	−12.30 ± 6.60 ***	−12.62 **	−12.46 ± 6.88 ***
Inter dental	**Overjet (mm)**	0.07 ± 0.6 NS	0.3 ± 0.6 NS	0 ± 0.8 NS	–	0.73 ± 1.57 NS	0.09 NS	0.71 ± 1.63 NS
	Overbite (mm)	0.3 ± 0.84 NS	−0.5 ± 0.5 *	−0.3 ± 0.9 NS	–	−1.30 ± 1.51 **	−1.03 **	−1.39 ± 1.52 NS

[a] NS indicates nonsignificant.
* $P < .05$; ** $P < .01$; *** $P < .001$.

appliance was supported with one miniscrew to avoid anchorage loss and the appliance was fixed to the maxillary first premolars with two occlusal rests to reduce the chance of miniscrew failure and rotational movements of the Pendulum appliance; therefore, mobility or loss of miniscrews was not observed.

In the present study, maxillary first molars showed significant distal movement of 4.25 mm and distal tipping of 9.09° in the HP group, and 3.21 mm and 9.86° in the CP group, respectively. In previous Pendulum appliance studies, 2.9 mm–6.4 mm distal movement and 8.8°–11.3° of distal tipping of the maxillary first molars were reported with skeletal anchorage[2–4,13,16,17] (Table 3) and 2 mm–6.1 mm distal movement and 5.3°–18.5° distal tipping were reported with dental anchorage.[3,21–24] The current results showed that the hybrid design was as successful as two miniscrew-supported systems in the control of distal tipping during distal movement of maxillary molars. Similar to the first molars, the maxillary second molars moved significantly more and tipped less in the HP group (3.55 mm and 8.45°, respectively) compared to the CP group (2.86 mm and 9.86°, respectively), and the amount of distalization was significantly different between the groups. This also supports the ability of the hybrid appliance to move teeth distally more with less tipping.

The previous conventional Pendulum appliance studies that used the maxillary first and second premolars as anchorage units reported 1.4–2.55 mm mesial movement with 1.29°–4.84° mesial tipping.[12,13,21] The present study CP appliance results were in agreement with the previous literature regarding mesial movement and mesial tipping of the first and second premolars but the mesial tipping of the first premolars was found to be higher than previous studies (3.12 mm mesial movement with 7.48° mesial tipping of maxillary first premolars and 2.55 mm mesial movement with

3.81° mesial tipping of maxillary second premolars). Mesial tipping and movement of maxillary premolars are known to be side effects of CP and occlusal rests inhibit the spontaneous distal drifting of premolars due to the tensile strength of the transseptal fibers during distalization. To overcome this problem, clinicians excluded all premolars from the anchorage unit and used skeletally anchored Pendulum appliances[1,2,8,9,17] (Table 3). In the present study, only the first premolars were included in the anchorage unit in the HP group with one miniscrew, resulting in a nonsignificant 0.28 mm of mesial movement and a significant 1.38° of distal tipping of maxillary first premolars that were observed. With this design, the loss of anchorage in the first premolars was significantly reduced in comparison to the CP group. Additionally, the second premolars showed spontaneous drift of 2.09 mm distal movement and 3.98° distal tipping.

In the HP group, maxillary first molars, second molars, and first premolars were intruded significantly resulting in significant anterior rotation of the mandible. Contrary to the current findings, Escobar et al.[1] reported posterior rotation of the mandibular plane with a bone-supported Pendulum appliance because of the inclination and rotation of the molars that created premature contacts with a tendency to open the bite. In the CP group, while the vertical changes of maxillary molars were insignificant, the premolars extruded significantly which caused posterior rotation of mandible. Byloff and Darendeliler[12] reported significant intrusion of maxillary molars with the CP appliance because of significant distal tipping of these teeth. Kale Varlik et al.[25] reported that comparison of treatment changes using different molar landmarks showed significant differences during molar distalization, so the difference between the current study and that of Byloff and Darendeliler[12] might have been due to the use of different locations of the landmarks. In addition, it should be considered that the vertical changes in the present study might have been affected by growth. In longitudinal studies evaluating growth changes of Class II subjects, insignificant decreases in mandibular plane angle and increases in vertical position of the maxillary molars were reported with growth.[26,27] In the present study, vertical dentoalveolar growth of the teeth attached to the Pendulum appliance might have been inhibited because the appliance was stabilized with a miniscrew.

Proclination of the maxillary incisors is one of the most common side effects in CP appliance studies[12,21,22,28]. Similarly, in the present study, significant proclination and protrusion of the maxillary incisors were observed in the CP group. In the HP group, significant protrusion of maxillary incisors was also observed; however, the change in proclination was insignificant. Escobar et al.[1] and Polat-Özsoy et al.[3] reported maxillary incisor retroclination with a skeletally anchored Pendulum appliance. The difference might be attributed to the occlusal rests in the HP group. However, the hybrid design was still more effective for anchorage control than the CP appliance in controlling incisor inclination.

In the present study, the interpremolar and intermolar distances were increased significantly with the mesiobuccal cusps of the first molars showing a greater increase than the distobuccal cusps in both groups. These results demonstrated that Pendulum springs have an expansive and a rotational force on the first molars during distalization. A significant increase in intermolar width was reported with the bone-anchored Pendulum appliance by Kırcelli et al.[2] and with the conventional Pendulum appliance by Ghosh and Nanda.[28]

The results of the present study showed that anchorage has a crucial effect on maxillary molar distalization systems. Stable anchorage units result in less side effects, greater distalization, and spontaneous distal drift of second premolars during distalization that might facilitate subsequent fixed orthodontic treatment procedures and decrease overall treatment time. The hybrid Pendulum can be an effective option for maxillary molar distalization requiring less invasive procedures. It is also more economical than a bone anchored system with two miniscrews. Still, it must be noted that incisor position is the critical factor in determining the choice of the anchorage method to use with a Pendulum appliance.

CONCLUSIONS

In this study:

- Molar distalization was achieved with both CP and HP appliances.
- Distal tipping was successfully controlled with the HP appliance during distal movement of the maxillary molars.
- Anchorage loss was controlled successfully with the HP appliance.
- Protrusion and proclination of the maxillary incisors were greater with the CP appliance.

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