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Maxillary molar distalization with a 2-week clear aligner protocol in patients with Class II malocclusion: A retrospective study

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Introduction: This study aimed to investigate the efficacy of molar distalization with or without anterior teeth retraction. **Methods:** Forty-three patients who received maxillary molar distalization with clear aligners were retrospectively enrolled and further divided into 2 groups: a retraction group (with maxillary incisor retraction ≥2 mm in ClinCheck) and a nonretraction group (without anteroposterior movement or with the labial movement of the maxillary incisor in ClinCheck). Pretreatment and posttreatment models were collected and laser-scanned to obtain the virtual models. Three-dimensional digital assessments of molar movement, anterior retraction and arch width were analyzed in the reverse engineering software Rapidform 2006. To calculate the efficacy of tooth movement, the achieved tooth movement assessed on the virtual model was compared with the predicted tooth movement in ClinCheck. **Results:** The achieved efficacy rates of molar distalization for the maxillary first and second molars were 36.48% and 41.94%, respectively. There was a significant difference in molar distalization efficacy between the retraction group (31.50% at the first molar and 35.63% at the second molar) and the non-retraction group (48.14% at the first molar and 52.51% at the second molar). In the retraction group, the efficacy of incisor retraction was 56.10%. The efficacy of dental arch expansion was more than 100% at the first molar levels in the retraction group and at the second premolar and first molar levels in the nonretraction group. **Conclusions:** There is a discrepancy between the outcome and the predicted maxillary molar distalization with clear aligners. The efficacy of molar distalization with clear aligners was significantly affected by anterior teeth retraction, and the arch width significantly increased at the premolar and molar levels. (Am J Orthod Dentofacial Orthop 2023;164:123-30)

In 1999, Invisalign was introduced by Align Technology (Santa Clara, Calif) as an alternative to fixed appliances for the treatment of mild to moderate malocclusion. Since then, clear aligners have become increasingly popular among adult patients and orthodontists because of their advantages, including better aesthetics, comfort, and convenience.

Maxillary molar distalization is frequently required for nonextraction treatment of patients with Class II malocclusion.[1-3] Clear aligners are considered effective in molar distalization,[4,5] probably because of their full coverage over the teeth crown and tendency to generate bodily movement during molar distalization. According to virtual model analysis, Simon et al[6] reported a high accuracy of maxillary molar distalization (up to 87%). In this study, tooth movement was analyzed after using a series of aligners, with molar anchorage loss during anterior teeth retraction ignored. Ravera et al[7] and

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Caruso et al[8] analyzed lateral cephalograms and reported that maxillary molars could be bodily distalized 2-3 mm with clear aligners without significant tipping or intrusion. However, they did not calculate the efficacy of molar distalization and compare the difference between patients with or without anterior teeth retraction.

Most studies concentrated on the efficacy of tooth movement during the molar distalization stage, whereas the anchorage loss during anterior teeth retraction was neglected. After molar distalization, the space obtained from molar distalization was used to retract anterior teeth. When the anterior teeth were retracted, an opposite and equal force was applied to the distalized molars, which resulted in a mesial movement of the distalized molars.[9,10] Therefore, compared with the efficacy of molar distalization without anterior teeth retraction, the efficacy when the anterior teeth were retracted would significantly decline. Consequently, the efficacy of tooth movement should be evaluated not only after molar distalization but also after the entire treatment with anterior teeth retraction.

The studies reporting the final efficacy of molar distalization with anterior teeth retraction are limited to date. Therefore, this retrospective study aimed to investigate the final efficacy of molar distalization with or without anterior teeth retraction with clear aligners.

MATERIAL AND METHODS

Forty-three patients (5 males, 38 females; aged 28.15 ± 6.94 years) who received maxillary molar distalization with clear aligners at Peking University School and Hospital of Stomatology were retrospectively enrolled in this study. The inclusion criteria were (1) aged >18 years, (2) nonextraction treatment (the maxillary third molars need to be extracted), (3) Class II molar relationship (with protruded maxillary incisors or with mild to moderate crowding), and (4) good compliance during the treatment. Patients with severe skeletal discrepancy, periodontal disease, temporomandibular disorder, absence of permanent maxillary teeth (except for third molars) or systematic disease were excluded. All the patients were divided into 2 groups: the retraction group (with maxillary incisor retraction ≥2 mm in ClinCheck) and the nonretraction group (without anteroposterior movement or with the labial movement of the maxillary incisor in ClinCheck). Considering the asymmetry of bilateral molar movement, the maxillary right and left quadrants were analyzed separately.[6]

All patients were treated with clear aligners (Align Technology) by 4 board-certified orthodontists with experience in orthodontics >15 years (L.Z., Y.H., Y.J., and W.L.). According to the protocol proposed by Align Technology,[11] a V-pattern was employed to achieve maxillary sequential distalization. No overcorrection was performed, and the aligners were changed every 2 weeks. To prevent maxillary incisor proclination, Class II elastics or miniscrews were used to reinforce the anchorage. The Class II elastics were worn daily from the button in the mandibular first molar to the precision cut in the maxillary canine. The buccally placed miniscrews were engaged with removable elastic attached to maxillary canine precision cut. The attachments were used according to the manufacturer's recommendation. The study protocol was approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (PKUSSIRB-202059159).

The plaster casts were collected and laser-scanned before (T0) and after treatment (T1) to obtain virtual models. The digital data were imported into the reverse engineering software Rapidform 2006 (Inus Technology, Seoul, South Korea) for further measurement. A coordinate system was established on the T0 virtual model (Fig 1). Cusps of maxillary premolars and first molars were selected to establish the functional occlusal plane.[12,13] The sagittal plane was perpendicular to the occlusal plane and through the midline palatal suture. The x-axis was defined along the anteroposterior direction. Then, the virtual models at T0 and T1 were regionally superimposed over the palatal stable region,[14,15] and the coordinate system at T0 was transferred to T1. To analyze the movement of maxillary molars, 5 reference points (Fig 2, *A*) and 2 reference planes were selected (Fig 2, *B*). As shown in Table I, 3 linear and angular measurements were taken to evaluate the 3-dimensional movement of maxillary molars.[12,13,16] In addition, incisor retraction and arch width were also measured.[17] To avoid the error of landmarking, reference points at T0 were transferred to T1 by superimposing the tooth crown surface bonded with reference points over the posttreatment virtual model.[12,13]

The data on predicted tooth movement were exported from the ClinCheck program (Align Technology). The efficacy of molar distalization was calculated by comparing the achieved tooth movement measured on the virtual model with the predicted tooth movement obtained from ClinCheck.

Statistical analysis

All values were measured by 1 examiner (L.L.), and 10 patients were randomly selected and remeasured by the same examiner within a 2-week interval to assess intraexaminer reliability. The intraclass correlation coefficient of all measurements was ≥ 0.889, indicating good reliability. The Shapiro-Wilk test was used to measure

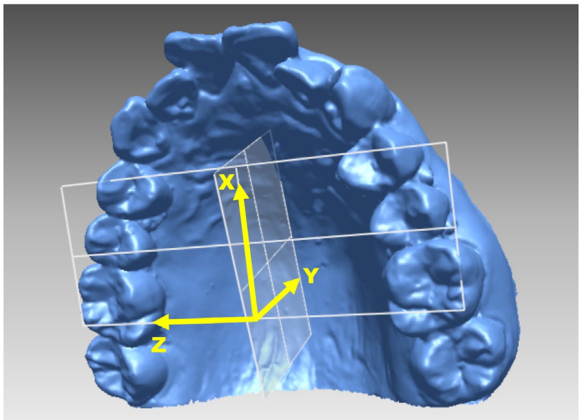

Fig 1. Reference coordinate system and directions of the virtual models. *X(+)*, mesial direction (molars) and labial direction (incisors); *X(−)*, distal direction (molars) and palatal direction (incisors); *Y(+)*, intrusion; *Y(−)*, extrusion; *Z(+)*, buccal direction (molars); *Z(−)*, palatal direction (molars).

normality. Paired *t* tests and independent *t* tests were used to analyze intragroup and intergroup significant differences, respectively. The significance level was set at $P < 0.05$. All statistical analyses were performed using SPSS software (version 26; SPSS, IBM, Armonk, NY). A post-hoc power analysis was performed using PASS software (version 11.0; NCSS, Kaysville, Utah). The sample size of 48 and 29 in the retraction and nonreatraction groups, respectively, were sufficient to provide 80% power (84% statistical power) at an α level of 0.05 to detect the significant difference of maxillary molar distalization efficacy between groups.

RESULTS

In this study, 77 maxillary quadrants of 43 including patients were included, and 9 maxillary quadrants without molar distalization were excluded. The molar distalization efficacy of all the patients for the maxillary first and second molars was 36.48% and 41.94%, respectively. Table II shows that the predicted molar distalization was 2.42 ± 1.19 mm for the first molar and 2.64 ± 1.23 mm for the second molar. The maxillary first molar was distalized 0.88 ± 0.83 mm, with significant intrusion (predicted intrusion, 0.13 mm; achieved intrusion, 0.63 mm) and buccal tipping (predicted movement, 1.87° lingual tipping; achieved movement, 2.84° buccal tipping). For the maxillary second molar, the achieved distalization was 1.11 ± 0.96 mm, also with significant intrusion (predicted movement, 0.22 mm extrusion; achieved movement, 0.50 mm intrusion) and buccal tipping (predicted movement, 5.68° lingual tipping; achieved movement, 0.32° lingual tipping).

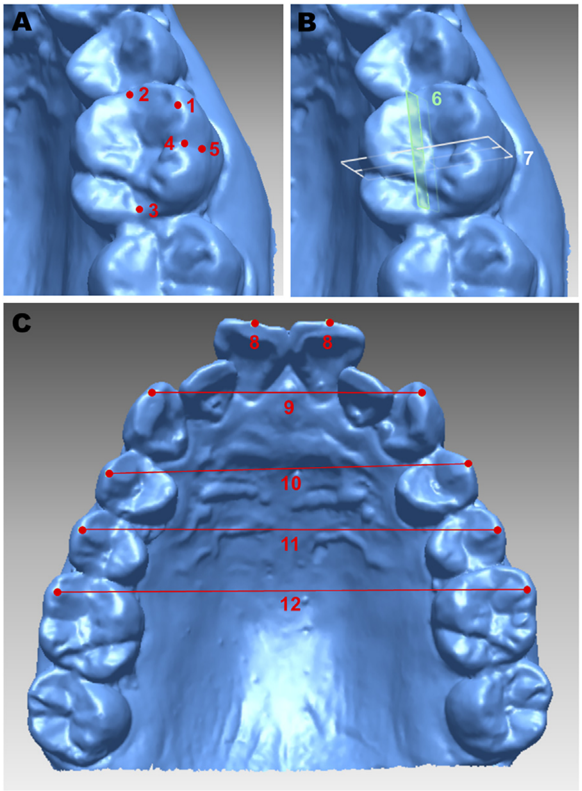

Fig 2. Reference points, lines and planes of the virtual models: **A,** Reference points and long axis of the molars (*1*, mesiobuccal cusp; *2*, mesio-occlusal point; *3,* disto-occlusal point; *4*, the most occlusal point of the buccal groove; *5*, the most gingival point of the buccal groove; the long axis was the line connecting point 4 and 5); **B,** Reference planes of the molars (*6*, mesiodistal plane, perpendicular to the occlusal plane and through the mesial and distal contact points; *7*, buccopalatal plane, simultaneously perpendicular to the occlusal plane and mesiodistal plane of the molars); **C,** Reference points of incisors and reference lines of the arch width (*8*, midpoints of the incisal edge of the central incisors; *9*, arch width at the canines; *10*, arch width at the first premolar; *11*, arch width at the second premolar; *12*, arch width at the first molar).

According to predicted maxillary incisor retraction in ClinCheck, all patients were further divided into a retraction group and a nonretraction group. There were 27 patients with 48 maxillary quadrants in the retraction group and 16 with 29 maxillary quadrants in the nonreatraction group. In the retraction group, there were 6 patients with asymmetrical overjet, which needed molar distalization and anterior retraction on 1 side. There was no significant difference in maxillary interproximal reduction between

Table I. Definition of linear and angular measurements

Parameter	*Definition*
Molar	
Anteroposterior (mm)	Anteroposterior translation in mesiobuccal cusp along the x-axis
Vertical (mm)	Occlusogingivar translation in mesiobuccal cusp along the y axis
Lateral (mm)	Buccopalatal translation in mesiobuccal cusp along the z-axis
Mesiodistal angulation (°)	The angle between the projected line (long axis projected onto the mesiodistal plane of molars) and the buccopalatal plane of molars
Buccolingual inclination (°)	The angle between the projected line (long axis projected onto the buccopalatal plane of molars) and the mesiodistal plane of molars
Rotation (°)	The angle between the mesiodistal plane of molars and the sagittal plane
Central incisor	
Incisor retraction (mm)	Anteroposterior translation in the midpoint of the incisal edge along the x-axis
Arch width	
Intercanine width (mm)	Distance between bilateral cusps of canines
Interpremolar width (mm)	Distance between bilateral buccal cusps of first or second premolars
Intermolar width (mm)	Distance between bilateral mesiobuccal cusps of molars

the 2 groups (retraction group, 1.15 ± 0.97 mm; nonretraction group, 0.84 ± 0.92 mm; $P = 0.322$).

In the retraction group, the achieved molar distalization was 0.78 mm for the maxillary first molar (predicted movement, 2.49 mm) and 0.99 mm for the maxillary second molar (predicted movement, 2.79 mm). In the nonretraction group, the achieved molar distalization was 1.10 mm for the maxillary first molar (predicted movement, 2.29 mm) and 1.30 mm for the maxillary second molar (predicted movement, 2.47 mm). There was a significant difference in molar distalization efficacy between the 2 groups. For maxillary first molars, the efficacy was 31.50% in the retraction group and 48.14% in the nonretraction group ($P = 0.038$). For maxillary second molars, the efficacy was 35.63% in the retraction group and 52.51% in the nonretraction group ($P = 0.010$).

For maxillary anterior teeth, the achieved anterior teeth retraction in the retraction group was 1.73 mm, significantly lower than the predicted value (3.08 mm), and the efficacy of anterior teeth retraction was 56.10%. As for overjet, the difference of overjet between the retraction and nonretraction group was significant at T0 (retraction group, 3.77 ± 1.40 mm; nonretraction group, 1.99 ± 1.16 mm; $P < 0.001$), and nonsignificant at T1 (retraction group, 1.60 ± 0.65 mm; nonretraction group, 1.28 ± 0.47 mm; $P = 0.022$). The overjet was significantly decreased in the retraction group ($P < 0.001$).

In the retraction group, the efficacy of dental arch expansion was more than 100% at the first molar level (predicted arch width expansion, 2.01 mm; achieved arch width expansion, 2.54 mm; $P = 0.028$). In the nonretraction group, there was also a significant expansion of dental arch at the second premolar (predicted arch width expansion, 3.65 mm; achieved arch width expansion, 4.14 mm; $P = 0.044$) and maxillary first molar level (predicted arch width expansion, 2.28 mm; achieved arch width expansion, 3.10 mm; $P = 0.017$). Other parameters are shown in Table III.

DISCUSSION

According to previous studies, maxillary molar distalization was considered a predictable tooth movement for clear aligners. A virtual model analysis from Simon et al. indicated that the efficacy for maxillary molar distalization was approximately 87%, with at least 1.5 mm of predicted translation.[6] Ravera et al[7] and Caruso et al[8] analyzed lateral cephalograms to evaluate molar distalization and reported that maxillary molars could be bodily distalized 2-3 mm without significant tipping or intrusion. However, in our study, the efficacy of maxillary molar distalization was only 36.48% at the first molar and 41.94% at the second molar, and the achieved molar distalization was 0.88 mm at the maxillary first molar and 1.11 mm at the maxillary second molar accompanied by significant intrusion and buccal tipping. The findings of previous studies and the results of our investigation cannot be directly compared. In the study of Simon et al,[6] the efficacy of molar distalization was calculated after a certain series of aligners, which was within the stage of molar distalization without anterior teeth retraction. The anchorage loss of distalized molars was neglected, and, therefore, the efficacy of maxillary molar distalization was much higher than that in our study, which was evaluated after the whole treatment in consideration of the anchorage loss of posterior teeth during anterior teeth retraction. For the studies of Ravera et al[7] and Caruso et al,[8] lateral cephalograms were used to evaluate molar movements, and inevitably, there was a difference in the measurements between cephalometric analysis and virtual model analysis. In this study, we concentrated on the final efficacy of molar distalization after the whole treatment, and it was revealed that the efficacy was not as high as previously reported because of the anchorage loss of distalized molars during anterior teeth retraction.

Table II. Predicted and achieved tooth movement of the maxillary first and second molar

Variables	*Predicted tooth movement*	*Achieved tooth movement*	P *value*
Maxillary first molar			
Anteroposterior (mm)	2.418 ± 1.1908	0.882 ± 0.8299	<0.001**
Vertical (mm)	−0.134 ± 0.5166	−0.625 ± 0.7618	<0.001**
Lateral (mm)	0.876 ± 0.9949	1.414 ± 0.9941	<0.001**
Mesiodistal (°)	−1.433 ± 2.9560	−2.006 ± 3.3637	0.160
Buccolingual (°)	−1.866 ± 4.1720	2.836 ± 3.2864	<0.001**
Rotation (°)	−0.920 ± 7.1566	−1.083 ± 6.0685	0.472
Maxillary second molar			
Anteroposterior (mm)	2.642 ± 1.2279	1.108 ± 0.9661	<0.001**
Vertical (mm)	0.217 ± 0.5547	−0.499 ± 0.8753	<0.001**
Lateral (mm)	0.140 ± 1.0547	0.559 ± 0.9579	<0.001**
Mesiodistal (°)	1.887 ± 5.5601	0.308 ± 5.1384	0.011*
Buccolingual (°)	−5.678 ± 10.0873	−0.321 ± 9.7310	<0.001**
Rotation (°)	0.362 ± 7.0890	0.298 ± 6.7663	0.726

Note. Values are shown as mean ± standard deviation. Positive values indicate posterior, extrusive, and buccal tooth movements, and mesial tipping, buccal tipping, and mesial-out rotation.
**P* <0.05; ***P* <0.001.

Table III. Predicted and achieved tooth movement of the nonretraction group and retraction group

	Nonretraction group (n = 29)			*Retraction group (n = 48)*		
Variables	*Predicted tooth movement*	*Achieved tooth movement*	P *value*	*Predicted tooth movement*	*Achieved tooth movement*	P *value*
Maxillary first molar						
Anteroposterior (mm)	2.291 ± 1.290	1.103 ± 1.027	<0.001***	2.486 ± 1.143	0.783 ± 0.703	<0.001***
Vertical (mm)	−0.111 ± 0.572	−0.664 ± 0.880	0.001**	−0.146 ± 0.491	−0.624 ± 0.710	<0.001***
Lateral (mm)	0.891 ± 0.845	1.582 ± 1.043	<0.001***	0.868 ± 1.075	1.303 ± 0.980	<0.001***
Mesiodistal (°)	−2.081 ± 2.802	−1.784 ± 3.717	0.681	−1.088 ± 3.007	−2.108 ± 3.258	0.034*
Buccolingual (°)	−1.013 ± 5.279	3.255 ± 4.114	<0.001***	−2.319 ± 3.424	2.606 ± 2.850	<0.001***
Rotation (°)	−4.408 ± 5.408	−4.115 ± 4.660	0.622	0.935 ± 7.326	0.400 ± 6.237	0.210
Maxillary second molar						
Anteroposterior (mm)	2.468 ± 1.264	1.296 ± 0.929	<0.001***	2.790 ± 1.209	0.994 ± 0.972	<0.001***
Vertical (mm)	0.284 ± 0.530	−0.377 ± 1.077	0.005**	0.167 ± 0.572	−0.597 ± 0.750	<0.001***
Lateral (mm)	0.195 ± 0.778	0.575 ± 0.984	0.050*	0.118 ± 1.207	0.529 ± 0.938	0.004**
Mesiodistal (°)	1.892 ± 6.726	1.581 ± 6.147	0.716	2.013 ± 4.955	−0.222 ± 4.5712	0.006**
Buccolingual (°)	−3.946 ± 6.386	−0.646 ± 5.294	<0.001***	−6.832 ± 11.717	−0.35 ± 11.760	<0.001***
Rotation (°)	−1.039 ± 7.088	−0.979 ± 6.976	0.926	1.499 ± 6.924	1.242 ± 6.652	0.629
Central incisor						
Incisor retraction (mm)	0.196 ± 1.5679	−0.341 ± 1.089	0.074	3.075 ± 1.442	1.725 ± 1.184	<0.001***
Dental arch width						
Canine (mm)	0.663 ± 2.361	0.526 ± 1.963	0.588	1.707 ± 1.541	1.093 ± 1.228	0.009**
First premolar (mm)	3.228 ± 2.239	3.018 ± 2.037	0.656	2.505 ± 1.900	2.245 ± 1.893	0.203
Second premolar (mm)	3.648 ± 1.710	4.143 ± 1.718	0.044*	2.642 ± 1.617	2.737 ± 1.806	0.629
First molar (mm)	2.284 ± 1.476	3.104 ± 1.738	0.017*	2.012 ± 1.543	2.542 ± 1.660	0.028*

Note. Values are shown as mean ± standard deviation. For incisor retraction, positive values indicate lingual tooth movements. For dental arch width, positive values indicate an increase in arch width.
**P* <0.05; ***P* <0.01; ****P* <0.001.

Distalization of the maxillary first and second molars was the first stage of sequential distalization. In this stage, the efficacy of molar distalization was relatively high, as had been reported previously.[6] After the maxillary first and second molars were distalized, the space obtained from molar distalization was used for crowding

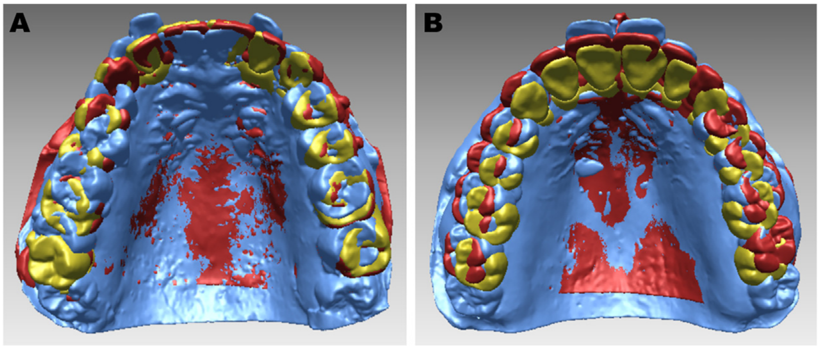

Fig 3. Superimposition of pretreatment and posttreatment models: **A,** Nonretraction group; **B,** Retraction group. *Blue*, pretreatment; *Red*, achieved outcome; *Yellow*, predicted outcome.

alleviation or anterior teeth retraction. Therefore, in our study, all the patients were divided into 2 subgroups (patients with or without anterior teeth retraction) to investigate the possible reason for the limited efficacy of molar distalization after the whole treatment. As shown in Figure 3, the efficacy of molar distalization in the nonretraction group (48.14% at the first molar and 52.51% at the second molar) was much higher than that in the retraction group (31.50% at the first molar and 35.63% at the second molar). This finding can be explained by the fact that in the retraction group after the maxillary first and second molars were distalized, the length of the aligners was decreased to retract the anterior teeth. Along with the decrease in aligner length, a mesial force was generated by aligners toward the maxillary molars,[18,19] which caused mesial movement of the maxillary molars. Hence, the final efficacy of molar distalization in the retraction group was relatively low. However, in the nonretraction group, after the maxillary first and second molars were distalized, the space obtained from molar distalization was used for crowding alleviation. The length of aligners was maintained, and mesial force toward the maxillary molars was barely generated, significantly reducing the anchorage loss of distalized molars. Consequently, because of the difference in whether there was an aligner length decrease after maxillary molar distalization, the anchorage loss of distalized molars was different in patients with or without anterior teeth retraction, and therefore, the efficacy of molar distalization after the whole treatment was significantly different.

During the distalization of premolars, canines and incisors, maxillary molars served as anchorage teeth against the rest of the arch for intramaxillary anchorage. Although the maxillary molar itself could not confront the mesial force generated by aligners, mesial movement of the maxillary molars always occurred. To prevent anchorage loss of the maxillary molars, Class II elastics and miniscrews were proposed by Align Technology to reinforce the anchorage.[11] However, the results in this study showed that Class II elastics and miniscrews were not strong enough either. Even if all the patients received Class II elastics or miniscrews, the molar distalization was still unpredictable with anterior teeth retraction. Therefore, we suggested that the forces from miniscrews could be directly applied to distalized maxillary molars, instead of aligners or maxillary canines, for stronger anchorage reinforcement.

Although the achieved molar distalization in the retraction group was 0.78 mm for the maxillary first molar and 0.99 mm for the maxillary second molar, the maxillary central incisors were retracted 1.73 mm with an efficacy of 56.10%. Increasing dental arch width may provide additional space to retract anterior teeth. Deregibus et al[20] reported that Invisalign Class II treatment with maxillary molar distalization significantly increased arch width at the molar and premolar levels. In our study, the achieved increase in dental arch width was approximately 2.5 mm at the first molar level, with efficacy >100%. Various studies have reported the high efficacy of dental arch expansion with clear aligners,[17,21-24] and given the limitation of aligner material properties,[25-27] there might be a transverse bend of aligners. Both of the abovementioned aspects might be the reason for the additional increase in dental arch width compared with that predicted.

In this study, the 2-week aligner protocol was used to achieve greater accuracy of tooth movement. Several studies have reported that the 2-week wear protocol was more accurate than the weekly wear protocol, especially for difficult tooth movement. In a prospective study conducted by Al-nadawi et al,[28] the 14-day wear protocol showed a significantly higher accuracy of posterior tooth movements compared with the 7-day and 10-day wear protocol. Another study by Linjawi et al[29] showed that the gap width between the aligner and the attachment was the least after an intraoral usage of 15 days, compared with 3-day, 7-day and 10-day groups. Recently, a 1-week wear protocol was proposed by Align Technology, which could shorten the duration of clear aligner treatment. The efficacy of maxillary molar distalization with a 1-week clear aligner protocol should be further investigated.

Some limitations existed in this retrospective study. First, the sample size in this study was relatively small and should be enlarged in future research. Second, although the protocol of maxillary molar distalization suggested by Align Technology was applied in all patients, the difference in clinical preference among orthodontists could not be neglected. Our study did not investigate the effect of clinical preference, such as attachment. Third, only crown movements were evaluated on virtual models. Three-dimensional imaging techniques such as cone-beam computed tomography should further evaluate root movements. Fourth, maxillary sequential distalization consists of 2 stages: molar distalization and incisor retraction. The efficacy of molar distalization at different stages should be separately investigated in future studies. In addition, the influence of refinement was not considered. Hence, this study aimed to concentrate on the final efficacy of molar distalization after the whole treatment instead of at a certain stage within the treatment. Even with refinement, molar distalization was not fully achieved as predicted. A prospective study with a large sample size was needed in the future to confirm the conclusion of this study.

CONCLUSIONS

1. There is a discrepancy between the outcome and the predicted maxillary molar distalization with clear aligners.
2. The efficacy of molar distalization with clear aligners is significantly affected by anterior teeth retraction.
3. The arch width increases at the molar level, which may provide additional space to retract anterior teeth.

AUTHOR CREDIT STATEMENT

Linwei Li contributed to investigation, formal analysis, and original draft preparation; Runzhi Guo contributed to conceptualization, methodology, and manuscript review and editing; Liwen Zhang contributed to resource and data curation; Yiping Huang contributed to resource and formal analysis; Yilin Jia contributed to manuscript review and editing and supervision; and Weiran Li contributed to manuscript review and editing and project administration.

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