A voxel-based CBCT superimposition of upper molar distalisation using clear aligners in conjunction with Class II elastics

Mingxin Zhang,* Xulin Liu,† Ruijie Zhang,‡ Axian Wang,† Yubohan Zhang,† Yanning Ma§ and Zuolin Jin*

Shenzhen Clinical College of Stomatology of Southern Medical University, Shenzhen Stomatology Hospital (Pingshan) of Southern Medical University, Shenzhen, China*

State Key Laboratory of Oral & Maxillofacial Reconstruction and Regeneration, National Clinical Research Center for Oral Diseases, Shaanxi Clinical Research Center for Oral Diseases, Department of Orthodontics, School of Stomatology, The Fourth Military Medical University, Xi'an, Shaanxi, China†

Department of Oral Sciences, Faculty of Dentistry, University of Otago, Dunedin, New Zealand‡

School and Hospital of Stomatology, Shanxi Medical University, Taiyuan, China§

Objective: The discrepancy between an anticipated digital configuration and the realised results poses a continual challenge during clear aligner therapy. The present study aims to examine the generated tooth movement achieved when upper molars are moved distally using clear aligners and Class II elastics.

Materials and methods: Thirty adult patients (13 males and 17 females) aged between 18 and 35 years-old were analysed. CBCT scans taken before and at the end of a distalisation phase were superimposed using a voxel-based registration. Molar distalisation efficiency, tipping and rotation angles, and changes in arch width were quantified to assess the achieved tooth movement. Pearson's correlation coefficients and multiple linear regression models were applied to examine the tooth changes, and how gender, attachments, and initial crowding affected the results.

Results: The study determined that the effectiveness of moving upper molars distally using clear aligners along with Class II elastics was 60% ± 7% of the designed movement. Due to a counterforce, the upper incisors experienced labial tipping of 3.84° ± 1.1°, the lower molar was mesialised by 0.64 mm ± 0.27 mm, and the lower incisors underwent labial tipping of 2.61° ± 1.13°. The upper archwidth displayed a non-significant increase, whereas the width of the lower arch exhibited a non-significant reduction. Furthermore, molars with attachments exhibited reduced distal tipping and rotation. The initial crowding was inversely related to the amount of upper molar distalisation and positively related to tipping.

Conclusion: This is the first CBCT superimposition study to reveal the achieved tooth movements during upper molar distalisation. The results suggest that multiple factors impact tooth movement.

(Aust Orthod J 2025; 41: 369 - 379. DOI: 10.2478/aoj-2025-0033)

Received for publication: October, 2024
Accepted: August, 2025.

Mingxin Zhang: mingxinee@foxmail.com; Xulin Liu: 17713744250@163.com; Ruijie Zhang: 2358768008@qq.com; Axian Wang: a165311219@163.com; Yubohan Zhang: zhangyubohan@163.com; Yanning Ma: blueskyabc1007@163.com; Zuolin Jin: zuolinj@163.com

Introduction

Clear aligner therapy (CAT) has significantly revolutionised contemporary orthodontics by offering aesthetic and comfort advantages over fixed multibracket therapy (FMB).[1] With advancements in materials and the introduction of auxiliaries, clinicians have increasingly utilised CAT to address complex malocclusions. Maxillary molar distalisation is now considered a viable approach for the treatment of Class II malocclusions.[2] The findings of retrospective studies inferred that upper molar distalisation using CAT offers effective vertical control.[2,3] Notwithstanding, the discrepancy between an anticipated digital configuration and the actual tooth movement remains a clinical challenge. The existing literature on molar distalisation using

CAT lacks a clear consensus, with the predictability of tooth movement varying from 55% to 87%.[4,5] The variability can be attributed to differences in research methodologies and in the reference points utilised, as well as discrepancies in the application of Class II elastics.[6,7]

Clinically, Class II elastics are commonly applied to improve anchorage.[8] Ravera et al. combined Class II elastics with clear aligners which led to a 2.25 mm distalisation of the upper first molar, with minimal crown tipping and vertical movements reported in the superimposed lateral cephalograms.[2] The study focused on Class II elastics that were applied after the molar distalisation phase, and the evaluation conducted at the completion of the entire treatment rather than specifically at the end of molar distalisation. Additionally, Amm et al. suggested that the early incorporation of Class II elastics alongside the clear aligners before arch levelling as a method to accelerate the sagittal correction of a Class II malocclusion.[9] The use of Class II elastics in FMB chiefly produces dentoalveolar effects, while facilitating maxillary incisor extrusion and mandibular molar mesialisation.[10] Nevertheless, the use of clear aligners as an overlay appliance was found to partially mitigate the vertical side effects elicited by the Class II elastics.[11] Later studies utilised a biomechanical assessment through a finite element technique (FEM) to investigate the effects of integrating clear aligners with Class II elastics during upper- molar distalisation. This process entailed immediate shifts in the initial phases, while force directions consistently varied in practice.[12,13]

Cone-beam computer tomography (CBCT) has attracted extensive attention owing to its precise capabilities, lower radiation exposure, and minimal image distortion.[14,15] The utilisation of stable anatomical structures as references for three-dimensional reconstruction and superimposition enables an evaluation of orthodontic treatment outcomes and an analysis of skeletal and dental changes.[16] There has been an increase in the use of voxel-based superimposition in CBCT volumes, as it has been found to be valid, reliable, and repeatable.[17]

The present study therefore aimed to assess the displacement of the upper and lower teeth using clear aligners and Class II elastics for molar distalisation by using a voxel-based CBCT superimposition to enhance treatment strategies for clinicians.

Materials and methods

The retrospective analysis followed the guidelines of the Helsinki Declaration and received approval from the Ethics Committee of The Air Force Medical University (IRB-REV-2022079). Written permission was provided by all study participants. A sample size of 30 was calculated based on a standard error of 5% and a confidence interval of 95%. A total of 30 individuals, consisting of 13 males and 17 females, were therefore selected for the study. The average age was 25.4 years, with ages ranging from 18 to 35 years. The inclusion criteria identified adults with a Class II malocclusion and without prior orthodontic treatment. The participants were treated by non-extraction methods, using clear aligners along with Class II elastics for maxillary molar distalisation. Patients with syndromes, alveolar bone defects, and those receiving pharmaceutical medications that potentially alter tooth movement were excluded from the investigation.

Each patient was treated using Angelalign® clear aligners to move the maxillary molars by a 0.25 mm step distance, and Class II elastics were placed between the upper canines and lower first molars. The total designed distal molar change was between 1 mm to 5 millimeters. Twenty-four patients had horizontal rectangular attachments bonded on the upper first molars, eighteen patients had vertical rectangular attachments and eighteen patients had no molar attachments. Patients were reminded to follow the treatment guidelines by wearing the aligners for at least 22 hours daily. Therapy involved a sequential distalisation approach, involving a staging of 50% applied in all cases. The patients were also directed to consistently bilaterally wear 3.5 oz Class II elastics. Additionally, each patient underwent two CBCT scans for treatment evaluation, with scans conducted at the beginning of treatment (T0) and at the end of the distalisation phase (T1). The CBCT scans were performed using equipment from GE Healthcare, USA, with a full field of view and a centered rotation. The DICOM data collected at both T0 and T1 were later transferred to Dolphin Imaging software (Dolfin, Chatsworth, CA, USA).

There were ten landmarks selected as reference points for the maxillary and mandibular voxel-based superimposition (Figure 1, Table I).[18,19] The second volume's head orientation was adjusted based on the skull's 3D position when overlaid on the base volume.

Figure 1. Voxel-based superimposition using Dolphin software. A. Landmarks for maxillary superimposition; B. Landmarks for mandibular superimposition.

T2U was the label assigned to the second volume adjusted using maxillary superimposition, while T2L was the volume adjusted using mandibular superimposition and exported. The DICOM data at time points T0, T2U, and T2L were imported into Mimics 20.0 Software (Materialise, Leuven, Belgium) for three-dimensional reconstruction using a threshold set above 600HU. In each 3D model, the maxillary and mandibular regions were separately segmented and saved in STL format.

The maxillary teeth and surrounding structures in T0 and T2U were both inputted into Geomagic Studio 2014 software (Raindrop GEOMAGIC, NC, USA) for measuring the upper jaw. Similarly, the mandibular bone and dentition at T0 and T2L were simultaneously imported for mandibular measurements. A horizontal plane parallel to the line connecting OrL and OrR passed through ANS and PNS, while a sagittal plane was defined as the plane passing through N, ANS, and PNS, and a coronal plane was defined as the plane passing through ANS and perpendicular to both the horizontal and sagittal planes.[18,19] The sagittal plane was used to measure the disto-mesial tipping angles of the molars and the labio-lingual tipping angles of the incisors between each vector at T0 and its corresponding vector at

Table I. Maxillary and mandibular landmarks

Maxillary landmarks		
1	OrR	The inferiormost aspect of the right orbital cavity
2	OrL	The inferiormost aspect of the left orbital cavity.
3	N	The anteriormost point along the nasofrontal suture.
4	ANS	The apex of the anterior nasal spine
5	PNS	The apex of the posterior nasal spine
Mandibular landmarks		
1	MfR	The anteriormost point of the right mental foramen
2	MfL	The anteriormost point of the left mental foramen
3	GoR	The midpoint along the bony border of the right mandibular angle
4	GoL	The midpoint along the bony border of the left mandibular angle
5	Gn	The point where the mid-sagittal plane intersects the lowest point of the mandibular symphysis

T2, as shown in Figure 2. In addition, the rotation angle of the molars was assessed on the horizontal plane using the line between the mesio-buccal cusp and the disto-lingual cusp as landmarks. The bucco-lingual tipping angles of the molars were measured in the coronal plane. Five points on the upper and lower first molars were identified on the T0 and T2 models to determine the achieved amount of tooth displacement. The arch width was measured by the facial axis (FA) points of the first molars.

Statistical analysis

Data analysis was performed using IBM SPSS Statistics for Windows, version 26.0 (IBM, Armonk, NY, USA). Continuous variables in the study were normally distributed and were expressed as means and standard deviations (SD). The connection between anticipated and actual movements was illustrated through scatter plots, Pearson's correlation values, and basic linear regression examinations. Multiple linear regression models were applied to investigate the impact of various factors. A *p*-value less than 0.05 was deemed to be statistically significant and 20% of the models underwent a re-analysis by both the original examiner and a second examiner after an interval of 2 weeks following the initial measurements.

Results

A total of 60 upper molars and 60 upper incisors were examined to evaluate the accuracy of molar distalisation and the level of anchorage loss involving the upper incisors. In addition, 60 lower molars and 60 lower incisors were evaluated to determine the actual movement of the mandibular dentition. Reproducibility was evaluated using the intraclass correlation coefficient (ICC), which showed strong agreement with a value of 0.96 for examiner reliability and 0.94 for reliability between examiners. Table II presents the descriptive statistics of the actual tooth movements. The upper molar aligner distalisation efficiency in conjunction with the Class II elastics was 60% ± 7% of the designed movement. The distalised molars displayed distal and buccal tipping and accompanying disto-buccal rotation. The upper incisors showed labial tipping of 3.84° ± 1.1° due to anchorage loss. The lower first molars exhibited mesial and lingual tipping, as well as a mesial shift of 0.64 mm ± 0.27 mm, due to the force exerted by the Class II elastics. There was a slight increase of 1.68 mm in upper arch width at the first molar level, which was not statistically significant ($p > 0.05$), while the lower arch width at the first molar level had a minor decrease of 0.63 mm, also not statistically significant ($p > 0.05$).

It was noted that Pearson's correlation coefficients revealed a moderate-to-high correlation between the predicted upper molar distalisation and achieved distalisation ($r = 0.9917$, $p < 0.0001$), actual upper molar distal tipping ($r = 0.5676$, $p < 0.0001$), actual upper molar rotation ($r = 0.7113$, $p < 0.0001$), actual upper incisor tipping ($r = 0.7903$, $p < 0.0001$), actual lower molar medialisation ($r = 0.9073$, $p < 0.0001$), and actual lower incisor tipping ($r = 0.8394$, $p < 0.0001$), as presented using scatter diagrams and simple linear regression equations (Figure 3).

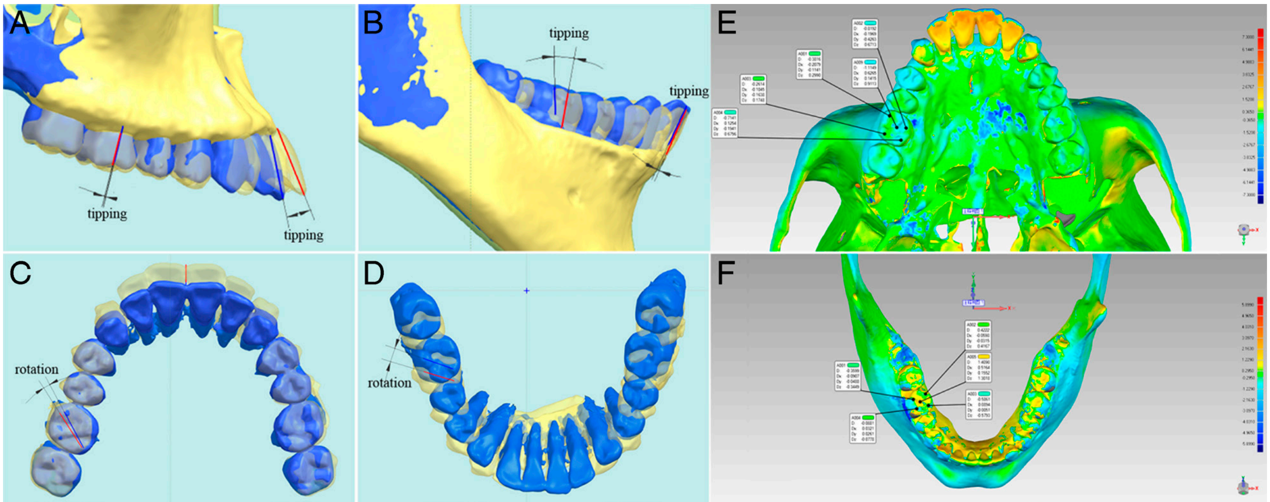

Figure 2. Measurement of tooth movements. A. Disto-mesial tipping angles of the upper molars and labio-lingual tipping angles of the upper incisors; B. Disto-mesial tipping angles of the lower molars and labio-lingual tipping angles of the lower incisors; C. Rotation angle of the upper molars; D. Rotation angle of the lower molars; E. Displacement of the upper molars; F. Displacement of the lower molars.

The results of the simple linear regression analysis indicated that a 1 mm prediction in molar distal movement corresponded to an average achievement of 0.64 mm in molar distalisation, 2.42° in molar distal tipping, 2.24° in molar rotation, 2.39° in upper incisor labial tipping, 0.30 mm in lower molar mesialisation, and 1.02° in lower incisor tipping.

Table III outlines the influence of predicted upper molar distalisation, gender, attachment, and initial crowding on the achieved tooth movement using multiple linear regression models. Male and female patients showed comparable values in all measurements. Patients with a horizontal or vertical rectangular attachment on the upper molars exhibited an inverse correlation with molar distal tipping (horizontal and vertical attachments: $p < 0.05$) and molar rotation (vertical attachments: $p < 0.0001$) compared with those with no attachment. The initial crowding had a negative correlation with upper molar distalisation success and a positive correlation with upper molar distal tipping, upper incisor tipping, and lower incisor tipping. Mild crowding showed significance at $p < 0.05$ for upper molar distal tipping, while moderate crowding had significance at $p < 0.05$ for upper incisor tipping.

Discussion

The use of clear aligner therapy cannot fully achieve designed tooth movement goals due to material limitations and the biomechanical response of the teeth.[20] Herein, discrepancies between predicted tooth movements and actual treatment outcomes of upper molar distalisation were measured to help clinical practitioners to understand clear aligner therapy outcomes. Previous studies have evaluated the effectiveness of clear aligners for molar distalisation by superimposing cephalometric radiographs[2] and superimposing digital models of teeth[5,6] or palatal rugae.[7,21] D'Antò et al. reported that molar distalisation efficacy varied between 68.0% and 79.9% based on the superimposition of digital models using untreated teeth as reference points, wherein anchorage teeth mesialisation is typically overlooked.[6] Moreover, Simon et al. documented a molar distalisation accuracy of 87% in the superimposition of plaster cast models, using untreated teeth as reference points. However, this approach was relatively unreliable due to anchorage loss.[5] An accuracy of 73.8% was reported in a comparison between predicted and achieved upper molar distalisation using the palatal rugae for the superimposition of digital models, despite the absence of Class II elastics during the distalisation process. However, there was no stable landmark for mandibular superimposition using oral scan digital models.

CBCT is widely used in orthodontics owing to its accurate 3D outcomes. A voxel-based comparison allows superimposition on stable skeletal anatomic

Table II. Descriptive statistics

	Mean	SD	n
Upper molar distalization efficiency (%)	0.60	0.07	60
Upper incisors labial tipping (°)	3.84	1.10	60
Upper molar distal tipping (°)	3.67	1.31	60
Upper molar disto-buccal rotation (°)	3.70	1.23	60
Upper molar buccal tipping (°)	0.99	0.33	60
Lower molar mesialization (mm)	0.64	0.27	60
Lower molar lingual tipping (°)	0.75	0.43	60
Lower molar mesial tipping (°)	1.93	0.99	60
Lower incisors labial tipping (°)	2.61	1.13	60

SD, Standard Deviation; n, number

landmarks and accurately matches structures using high grayscale levels, which renders greater accuracy and reliability for assessing treatment effects.[17,21] In the present study, a skeletal superimposition technique revealed a 60% ± 7% decrease in upper molar distalisation efficiency when using clear aligners and Class II elastics, which suggested a need for greater over-correction in clinical applications. By proposing a linear regression coefficient, the achieved tooth movement can be inferred from the designed amount of molar distalisation. Due to anchorage loss, the average labial tipping of 2.39° in the upper incisor and 1.02° in lower incisor tip were achieved when 1 mm molar distalisation was predicted. This implies that a suitable torque design needs to be incorporated in order to improve anchorage control. Furthermore, the mesialisation of the lower molars by 0.30 mm, despite a predicted 1 mm molar distalisation, was attributed to a counterforce associated with the Class II elastics. Therefore, the correction of a Class II malocclusion is not solely dependent on the distalisation of maxillary molars, but also on a small amount of mesialisation of the mandibular molars. If the mandibular molar mesialisation is not expected, a corresponding anchorage consideration should be designed.

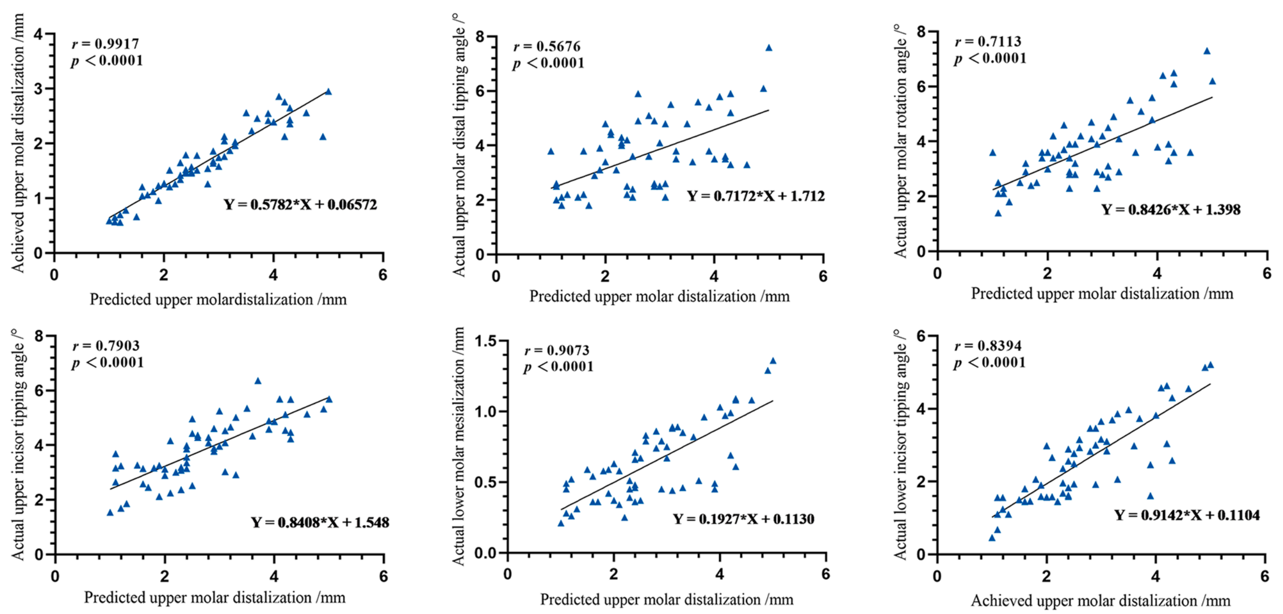

Figure 3. Scatter diagram, Pearson's correlation coefficients, and simple linear regression analyses of the predicted upper molar distalisation and achieved tooth movement.

Table III. Multiple linear regression models for predicted and achieved tooth movements

Variables	Unstandard coefficients		95.0% CI		Standard coefficients		
	B	SE	Lower	Upper	*β*	*t* value	*P* value
Achieved upper molar distalization							
Intercept	0.120	0.097	–0.075	0.316		1.236	0.222
Predicted molar distalization	0.573	0.028	0.518	0.629	0.940	20.580	0.000*
Sex	–0.089	0.059	–0.207	0.030	–0.070	–1.506	0.138
Attachment							
No attachment	Reference						
Horizontal	0.035	0.064	–0.093	0.163	0.027	0.551	0.584
Vertical	0.010	0.072	–0.135	0.155	0.007	0.139	0.890
Crowding							
No crowding	Reference						
Mild crowding	–0.042	0.070	–0.184	0.099	–0.034	–0.603	0.549
Moderate crowding	–0.056	0.077	–0.211	0.098	–0.040	–0.734	0.466
Upper molar distal tipping							
Intercept	1.698	0.369	0.958	2.438		4.606	0.000
Predicted molar distalization	0.955	0.108	0.739	1.171	0.756	8.861	0.000*
Sex	–0.223	0.233	–0.690	0.245	–0.085	–0.956	0.343
Attachment							
No attachment	Reference						
Horizontal	–0.659	0.251	–1.163	–0.156	–0.248	–2.629	0.011*
Vertical	–1.981	0.280	–2.542	–1.419	–0.686	–7.078	0.000*
Crowding							
No crowding	Reference						
Mild crowding	0.560	0.272	0.014	1.105	0.215	2.060	0.044*
Moderate crowding	0.093	0.294	–0.497	0.683	0.032	0.316	0.753
Upper molar rotation							
Intercept	1.325	0.341	0.642	2.008		3.890	0.000
Predicted molar distalization	1.004	0.100	0.804	1.203	0.847	10.083	0.000*

Table III. Continued

Variables	Unstandard coefficients B	SE	95.0% CI Lower	Upper	Standard coefficients β	*t* value	*P* value
Sex	–0.189	0.215	–0.620	0.243	–0.077	–0.876	0.385
Attachment							
No attachment	Reference						
Horizontal	–0.016	0.232	–0.481	0.449	–0.006	–0.068	0.946
Vertical	–1.100	0.258	–1.619	–0.582	–0.406	–4.257	0.000*
Crowding							
No crowding	Reference						
Mild crowding	0.265	0.251	–0.239	0.768	0.109	1.055	0.296
Moderate crowding	–0.269	0.272	–0.814	0.276	–0.098	–0.991	0.326
Lower molar mesialization							
Intercept	0.125	0.080	–0.036	0.285		1.559	0.125
Predicted molar distalization	0.183	0.028	0.127	0.238	0.714	6.568	0.000*
Sex	–0.012	0.056	–0.124	0.100	–0.023	–0.216	0.830
Attachment							
No attachment	Reference						
Horizontal	–0.053	0.057	–0.167	0.060	–0.099	–0.944	0.350
Vertical	–0.026	0.066	–0.158	0.106	–0.044	–0.393	0.696
Crowding							
No crowding	Reference						
Mild crowding	0.077	0.069	–0.061	0.215	0.146	1.121	0.267
Moderate crowding	0.083	0.089	–0.095	0.261	0.133	0.936	0.354
Upper incisors tipping							
Intercept	1.481	0.289	0.901	2.062		5.125	0.000
Predicted molar distalization	0.855	0.084	0.686	1.025	0.804	10.126	0.000*
Sex	–0.273	0.183	–0.639	0.094	–0.123	–1.493	0.142
Attachment							
No attachment	Reference						
Horizontal	–0.230	0.197	–0.624	0.165	–0.103	–1.168	0.248
Vertical	–0.007	0.219	–0.447	0.434	–0.003	–0.030	0.976

Table III. Continued

Variables	Unstandard coefficients B	Unstandard coefficients SE	95.0% CI Lower	95.0% CI Upper	Standard coefficients β	*t* value	*P* value
Crowding							
No crowding	Reference						
Mild crowding	0.279	0.213	–0.148	0.706	0.127	1.310	0.196
Moderate crowding	0.766	0.231	0.303	1.229	0.309	3.322	0.002*
Lower incisors tipping							
Intercept	0.196	0.264	–0.334	0.727		0.743	0.461
Predicted molar distalization	0.811	0.092	0.627	0.996	0.745	8.840	0.000*
Sex	–0.183	0.185	–0.554	0.187	–0.081	–0.994	0.325
Attachment							
No attachment	Reference						
Horizontal	–0.124	0.187	–0.499	0.250	–0.054	–0.666	0.509
Vertical	–0.030	0.218	–0.467	0.406	–0.012	–0.139	0.890
Crowding							
No crowding	Reference						
Mild crowding	0.499	0.227	0.044	0.955	0.223	2.201	0.032*
Moderate crowding	0.752	0.293	0.164	1.340	0.284	2.568	0.013*

*Signifcant P < 0.05.

Variable coding: sex (0 = male; 1 = female); attachment (0 = no attachment; 1 = horizontal attachment; 2 = vertical attachment); Crowding (0 = no crowding; 1 = mild crowding; 2 = moderate crowding); Traction method (0 = button; 1 = precision cutting).

A slight increase in the width of the upper dental arch was observed at the first molar level, possibly due to the buccal tipping of the distalised molars. Recent research has indicated that using clear aligners for moving the maxillary molars can effectively widen the arch, potentially creating more room to move the anterior teeth back.[22,23] However, the objects in the studies were designed for dental arch expansion, and the achieved arch width increase was more than the original design. Therefore, the upper arch width increase induced by molar distalisation was present in small quantities. Additionally, a slight reduction in the width of the lower dental arch was observed at the first molar position, possibly due to the pressure from the Class II elastics and the lingual tilt of the mandibular first molars.

The tooth movement trend is consistent with that of previous finite element (FEM) studies; nonetheless, direct numerical comparisons are challenging, given that FEM exclusively involves instantaneous movement in the initial stages without a consideration of complicating factors.[12,13]

In the present study, multiple factors influencing the achieved tooth movement were explored using multiple linear regression models. The study subjects were all adult patients; consequently, growth and development considerations were not applicable. Of note, gender effects on tooth movement were not significant. Patients who had attachments either horizontally or vertically bonded on their upper molars exhibited reduced tipping and rotation of distalised molars in comparison to those without attachments. This aligns with findings from earlier research, in which the group lacking attachments displayed uncontrolled tipping, whereas the attachment groups showed better control over bodily movement.[24,25] Gao et al. found no significant difference in the effects of horizontal and vertical rectangular attachments on molar distalisation.[26] Furthermore, Garino et al. discovered that attachments play a crucial role in improving posterior anchorage during the distalisation and anterior retraction stages of orthodontic treatment.[27]

Initial crowding was demonstrated to substantially impact anchorage loss during premolar extraction space closure during fixed orthodontic treatment.[28] Dai and colleagues reported that clear aligner therapy of initial crowding was correlated with anchorage loss in extraction patients, whereby greater crowding resulted in mesial tipping and translation of the first molars.[29] However, as highlighted in the present study, in non-extraction patients, increased initial crowding corresponded to reduced upper molar distalisation. In addition, initial crowding was positively correlated with upper molar distal tipping, plus upper and lower incisor tipping. The findings collectively indicate a higher demand for over-correction and anchorage preparation in patients requiring molar distalisation within a mild or moderately crowded dentition.

Nevertheless, the present study had limitations that require consideration. The investigation did not include an assessment of patient compliance. Additionally, factors related to age, periodontal health, and tooth root length, which can influence tooth movement, were not considered. Future studies should aim to increase the sample size and further explore other anchorage control methods used in conjunction with clear aligners.

Conclusions

The present study explored the achieved tooth movement using clear aligners and Class II elastics used for upper molar distalisation via a voxel-based CBCT superimposition. The results quantitatively revealed distal and buccal tipping along with a disto-buccal rotation of the upper molars, labial tipping of the upper and lower incisors, and mesialisation of the lower molars. The upper arch width displayed a non-significant increase while the lower arch width showed a non-significant decrease. Molars with attachments exhibited less distal tipping and rotation. Initial crowding was inversely correlated with the achieved upper molar distalisation but positively correlated with tipping.

Conflict of interest

The authors declare that there are no competing interests.

Corresponding author

Zuolin Jin, Email: zuolinj@163.com and Yanning Ma, E-mail: blueskyabc1007@163.com

Ethical statement

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and complies with Chinese legislation and guidelines. Ethical approval was obtained from the Medical Research and Ethics Committee (MREC) of Air Force Medical University (Ethical approval number: IRB-REV-2022079). Written informed consent was obtained from all subjects and/or their legal guardian(s) prior to their participation in the study.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

References

1. Fujiyama K, Honjo T, Suzuki M, Matsuoka S, Deguchi T. Analysis of pain level in cases treated with Invisalign aligner: comparison with fixed edgewise appliance therapy. Prog Orthod 2014; 15:64.
2. Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, Deregibus A. Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study. Prog Orthod. 2016; 17:12.
3. Caruso S, Nota A, Ehsani S, Maddalone E, Ojima K, Tecco S. Impact of molar teeth distalization with clear aligners on occlusal vertical dimension: a retrospective study. BMC Oral Health 2019; 19:182.
4. Galan-Lopez L, Barcia-Gonzalez J, Plasencia E. A systematic review of the accuracy and efficiency of dental movements with Invisalign(R). Korean J Orthod 2019; 49:140–9.
5. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique--regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health. 2014; 14:68.
6. Antò VD, Valletta R, Ferretti R, Bucci R, Kirlis R, Rongo R. Predictability of Maxillary Molar Distalization and Derotation with Clear Aligners: A Prospective Study. Int J Environment Res Public Health 2023; 20:2941.
7. Saif BS, Pan F, Mou Q, Han M, Bu W, Zhao J, et al. Efficiency evaluation of maxillary molar distalization using Invisalign based on palatal rugae registration. Am J Orthod Dentofac 2022; 161:e372–e379.

8. Rongo R, Dianiskova S, Spiezia A, Bucci R, Michelotti A, D'Anto V. Class II Malocclusion in Adult Patients: What Are the Effects of the Intermaxillary Elastics with Clear Aligners? A Retrospective Single Center One-Group Longitudinal Study. J Clin Med 2022; 11:7333.
9. Amm E, El AC, Vaden J. Effect of Class II elastics on different mandibular arch preparation stabilized with aligners and stainless-steel wires: A FEM study. Orthod Craniofac Res 2022; 25:520–9.
10. Janson G, Sathler R, Fernandes TM, Branco NC, Freitas MR. Correction of Class II malocclusion with Class II elastics: a systematic review. Am J Orthod Dentofac 2013; 143:383–92.
11. Staderini E, Ventura V, Meuli S, Maltagliati L, Gallenzi P. Analysis of the Changes in Occlusal Plane Inclination in a Class II Deep Bite "Teen" Patient Treated with Clear Aligners: A Case Report. Int J Environment Res Public Health 2022; 19:651.
12. Liu X, Cheng Y, Qin W, Fang S, Wang W, Ma Y, et al. Effects of upper-molar distalization using clear aligners in combination with Class II elastics: a three-dimensional finite element analysis. BMC Oral Health 2022 22:546.
13. Liu X, Wang W, Gao J, Qin W, Wen Y, Luo H, et al. Actual contribution ratio of maxillary and mandibular molars for total molar relationship correction during maxillary molar sequential distalization using clear aligners with Class II elastics: A finite element analysis. Am J Orthod Dentofac 2023 164:e106–e120. doi: 10.15690/vramn.v69i7-8.1117
14. Dunaev MV, Kitaev VA, Matavkina MV, Druzhinin AE, Bubnov AS. Comparative analysis and clinical experience with osteoplastic materials materials based on non-demineralized bone collagen and artificial hydroxylapatite at the close of bone defects in ambulatory surgical dentistry. Vestn Ross Akad Med Nauk. 2014:112–20.
15. Takei Y, Monzen H, Matsumoto K, Hanaoka K, Tamura M, Nishimura Y. Registration accuracy with the low dose kilovoltage cone-beam CT: A phantom study. BJR Open 2019; 1:20190028.
16. Dot G, Rafflenbeul F, Salmon B. Voxel-based superimposition of Cone Beam CT scans for orthodontic and craniofacial follow-up: Overview and clinical implementation. Int Orthod 2020; 18:739–48.
17. Bazina M, Cevidanes L, Ruellas A, Valiathan M, Quereshy F, Syed A, et al. Precision and reliability of Dolphin 3-dimensional voxel-based superimposition. Am J Orthod Dentofac 2018; 153:599–606.
18. Zhang C, Ji L, Li Y, Pan F, Liao W, Zhao Z. A Novel Method to Combine Maxilla-Based Coordinate System and Mandibular Voxel-Based Superimposition with Cone-Bean Computed Tomography. J Clin Med 2022; 11:5229.
19. Cattaneo PM, Yung AKC, Holm A, Mashaly OM, Cornelis MA. 3D landmarks of Craniofacial Imaging and subsequent considerations on superimpositions in orthodontics—The Aarhus perspective. Orthod Craniofac Res 2019 22:21–9.
20. Grunheid T, Loh C, Larson BE., How accurate is Invisalign in nonextraction cases? Are predicted tooth positions achieved? Angle Orthod 2017;87:809–15.
21. Mavropoulos A, Karamouzos A, Kiliaridis S, Papadopoulos MA. Efficiency of noncompliance simultaneous first and second upper molar distalization: a three-dimensional tooth movement analysis. Angle Orthod 2005; 75:532–9.
22. Li L, Guo R, Zhang L, Huang Y, Jia Y, Li W.. Maxillary molar distalization with a 2-week clear aligner protocol in patients with Class II malocclusion: A retrospective study. Am J Orthod Dentofac 2023; 164:123–30.
23. Deregibus A, Tallone L, Rossini G, Parrini S, Piancino M, Castroflorio T. Morphometric analysis of dental arch form changes in class II patients treated with clear aligners. J Orofac Orthop 2020; 81:229–38.
24. Ayidağa C, Kamiloğlu B. Effects of Variable Composite Attachment Shapes in Controlling Upper Molar Distalization with Aligners: A Nonlinear Finite Element Study. J Healthc Eng 2021; 2021:1–8.
25. Haouili N, Kravitz ND, Vaid NR, Ferguson DJ, Makki L. Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign. Am J Orthod Dentofac 2020; 158:420–5.
26. Gao J, Guo D, Zhang X, Cheng Y, Zhang H, Xu Y, et al. Biomechanical effects of different staging and attachment designs in maxillary molar distalization with clear aligner: a finite element study. Prog Orthod 2023; 24:43.
27. Garino F, Castroflorio T, Daher S, Ravera S, Rossini G, Cugliari G, et al. Effectiveness of Composite Attachments in Controlling Upper-Molar Movement with Aligners. J Clin Orthod 2016; 50:341–7.
28. Geron S, Shpack N, Kandos S, Davidovitch M, Vardimon AD. Anchorage loss--a multifactorial response. Angle Orthod 2003; 73:730–7.
29. Dai FF, Xu TM, Shu G. Comparison of achieved and predicted tooth movement of maxillary first molars and central incisors: First premolar extraction treatment with Invisalign. Angle Orthod 2019; 89:679–87.