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Efficient Contributions Proportion of the Molar Under Sequential Distalization with Clear Aligners and Micro-Implant Anchorage-Finite Element Research

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KEYWORDS

Distalization, Micro-Implants, Aligners, Molars

Abstract

Introduction The purpose of this work is to examine the biomechanical impacts of molar distalization anchorage reinforcement utilising clear aligners (CAs) with microimplants. further looks at possible therapeutic approaches to improve anchoring throughout the progressive distalization phase. **Methodology:** In order to simulate the CAs, microimplants, alveolar bone, periodontal ligament (PDL), and upper teeth, finite element models were created. In group I, the second molars moved 0.25 mm in a distal direction, whereas in group II, the first molars moved 0.25 mm in a distal direction after the second molars were positioned in a target location. Three models made up each group set: Model A was the control model, Model B represented the use of microimplants that were affixed to the aligner using precise incisions, and Model C represented the usage of microimplants attached by buttons. **Results** In the absence of anchoring reinforcement, the distalization of the second molars accounted for only 52.86% of the 0.25-mm step distance. The mesial movement of the anchoring teeth and other undesirable movements were responsible for the remaining %. Models B and C demonstrated a reduced loss of anchoring and an enhanced effective contribution ratio of molar distaliation. On the other hand, there was a minor rise in the undesirable movement of molar rotation and tilting. Because of the reciprocal tension created by the distalization of the first molar, group II's second molar experienced a process known as mesial relapse. Moreover, the efficacy of molar distalization in terms of contribution ratio was found to be positively correlated with the magnitude of force applied. In cases where stronger anchorage reinforcement is required, precision cuts is the superior method. **Conclusions**- The utilization of microimplants in conjunction with CAs can facilitate the effective contribution ratio of molar distalization. However, it is important to note that complete elimination of anchorage loss is not achievable. To mitigate undesired movement, careful planning of anchorage preparation and overcorrection is recommended.

Introduction

A growing percentage of adult patients have indicated their need for more comfortable and aesthetically pleasing options to traditional fixed equipment and have sought orthodontic treatment over the past few years[1,2] When Kesling[3] came up with the idea of gradually realigning mismatched teeth to better positions using a succession of thermoplastic tooth positioners in 1946, the option of employing clear overlay orthodontic equipment was presented. Kesling's idea became a viable orthodontic therapy option in 1997 when Align Technology© (Santa Clara, Calif.) adopted and integrated contemporary technologies to establish the clear aligner treatment (CAT) as we know it. Few studies[4,5] have examined the predictability of orthodontic tooth movement (OTM), despite the fact that CAT has been hailed as a secure, aesthetic, and comfortable orthodontic technique for adults as well. Only two research about the effectiveness of Invisalign therapy matched the inclusion requirements set out by Lagravère

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and Flores-Mir[6] in their 2005 review. Regarding the treatment outcomes of this type of orthodontic treatment, the authors concluded that solid conclusions could not be drawn. Because of this, medical professionals who intend to employ CAT on their patients must rely on their own clinical judgement, the advice of specialists, and the scant published data.[6]

Functional orthopaedic treatment is the initial line of treatment for correcting a dentoskeletal Class II relationship, although it is only applicable to the skeletal component during the growing period. Maxillary molar distalization is a legitimate substitute that can be utilised to get space, retract the upper anterior teeth, and establish a Class I canine connection. In traditional orthodontic therapy, upper molars can be distalized using both fixed intraoral appliances and extraoral equipment. Headgear is a useful tool that uses extraoral anchorage without negatively affecting neighbouring teeth, however patient compliance is frequently low and it needs to be worn for 12 to 14 hours every day. Pendulum and distal jet are two examples of intraoral fixed gadgets that were presented as more cosmetically pleasing options.since they minimize or eliminate the need for compliance; by using the palate, teeth, or both as sources of anchorage, the main side effect is anterior anchorage loss. Additionally, children and adolescents with a molar Class II relationship may benefit from the use of intermaxillary Class II elastics and other intraoral fixed appliances (Herbst, Forsus); nonetheless, the primary goal is to advance the mandibular arch dentally.When it comes to distalizing upper molars, [7] CAT is seen as a viable substitute for conventional orthodontic systems. The sequential distalization protocol begins with the second molar moving distally, and the first molar doesn't begin to move until it reaches 50% of the intended movement, and so on up to the canine. The final step in the treatment plan is en masse anterior retraction, which maximises posterior anchoring by using attachments from the canine to the second molar. Furthermore, inter-arch Class II elastics are commonly utilised to reduce the risk of anterior anchorage loss. Nevertheless, by applying forces at the clinical crown level, and not at the centre of resistance, bodily mesio-distal movement is difficult to realize, and tipping is often the unwanted result. Although some tipping may occur, attachments are used to generate a moment that counteracts dental tipping in order to increase predictability.[7] Consequently, the goal of this research is to determine the molar's effective contribution ratio during the sequential distalization process using micro-implant anchoring and clear aligners.

Methodology

A 24-year-old female patient classified as Class II had a complete dentition with the extraction of her third molars and a healthy craniofacial structure. Cone-beam computed tomography (CBCT) data were acquired from the patient (GE Healthcare, USA). The results of CBCT had already been acquired for medical use. Before beginning the study, the participant gave her informed agreement to be included. The Modern Dental College and Research Centre, Indore's Ethics Committee gave its approval and the study was carried out in accordance with the principles of the Declaration of Helsinki. 668 horizontal CBCT slices were rebuilt overall, with a 0.15 mm thickness for each slice. The software Mimics 20.0 was used to import the CBCT data. The Compile 3D control was used to reconstruct the original 3D model. With the aid of the software Geomagic Studio 2014 (Raindrop GEOMAGIC, North Carolina, USA), the original 3D models were optimised, and a surface structure for the model was produced. Utilizing the 3D mechanical drawing program NX 1911 (Siemens, Germany), the periodontal ligament (PDL), alveolar bone, microimplants, and attachments were constructed in the preliminary model, as previously mentioned. The exterior surface of the tooth roots was expanded by 0.25 mm in order to restore the PDL as a homogeneous layer. Following being offset by 1.3 mm, the maxilla bone migrated inward to create a model of the cancellous bone. The cortical bone was then created by removing the cancellous bone from the maxilla bone. For retention, all premolars had vertical rectangular attachments (2 × 3 × 1 mm) built on their buccal surfaces, while the upper second molars had a horizontal rectangular attachment (3 × 2 × 1 mm) designed on them. In order to mimic a CA appliance, the tooth crowns and attachments were stretched outward by 0.5 mm. A set of two 8 mm long by 1.5 mm wide microimplants was created and positioned at a height of 5 mm from the alveolar crest and at an angle of 60° with the occlusal plane between the second premolar and first molar.

To create a 3D FE-based model, the original model and appliances were imported into ANSYS Workbench 2019. The 3D 10-node tetrahedral structural solid

SOLID187 was employed. The material characteristics agreed with those found in earlier research (Table 1). It was supposed that all constructions were composed of homogenous, linear, elastic, and isotropic materials. Using design inspiration from previous work, two group sets with three submodels (Fig. 1) were built to simulate the simplified sequential molar distalization process. Group II was used to represent the 0.25 mm distal movement of the first molar following the 2 mm distal migration of the second molar. Group I was used to replicate the 0.25 mm distal movement of the second molars. To simulate not having any anchoring reinforcement, control models A1 and A2 were employed. Precision cuts were a hallmark of Models B1 and B2. A hook was positioned on the transparent aligner at the dog's surface for precision cutting. The buttons on the maxillary canines of Models C1 and C2 (diameter of bottom surface: 3 mm, height: 1 mm) had matching CA portions removed. Clinical research and real-world scenarios were taken into consideration when designing the buttons and precision cutting.

Table 1 Material properties

Material	**Young's modulus (MPa)**	**Poisson's ratio**
Tooth	1.96×10^4	0.3
PDL	6.9×10^{-1}	0.45
Cortical bone	1.37×10^4	0.26
Cancellous bone	1.37×10^3	0.3
Clear Aligner	5.28×10^2	0.36
Attachments	1.25×10^4	0.36
Buttons	1.14×10^5	0.35
micro-implants	1.14×10^5	0.35

Boundary and contact conditions

The motion of the temporal and maxilla bones was constrained to all degrees of node freedom in its superior area due to boundaries limitations. Interfaces between gingious and cortical bone, cortical bone and PDL, bone microimplants, PDL tooth, tooth buttons, and tooth attachment were all found to have bonding interactions. There is no movement between the contact surfaces thanks to this bonding. Moreover, it was considered that there was no division among the points of contact of the relationships of the neighbouring teeth. Between the CA and the tooth crown surface, a friction-based state was established in the contact surfaces with a friction coefficient of 0.2.

Loading method

This FEM simulation was performed with static loading. A 0.25 mm step distance was established for the molar distal movement. To produce a loaded condition CA in group set I, a distal movement of 0.25 mm was applied to the second molar. The discrepancy between the initial dentition and the CA then applied the loading force. The second molar in group II was then moved distally by 2 mm to attain a goal location, and the first molar was moved distally by 0.25 mm to create a loading condition CA. Finally, a spring connected to the microimplants and the buttocks in models B and C applied a series force of 100, 150, and 200 g. NiTi springs are employed for the purpose of simulating the implementation of elastic traction. This FEM simulation was performed with static loading. A 0.25 mm step distance was established for the molar distal movement. To produce a loaded condition CA in group set I, a distal movement of 0.25 mm was applied to the second molar. The discrepancy between the initial dentition and the CA then applied the loading force. The second molar in group II was then moved distally by 2 mm to attain a goal location, and the first molar was moved distally by 0.25 mm to create a loading condition CA. Finally, a spring connected to the microimplants and the buttocks in models B and C applied a series force of 100, 150, and 200 g. NiTi springs are employed for the purpose of simulating the implementation of elastic traction.

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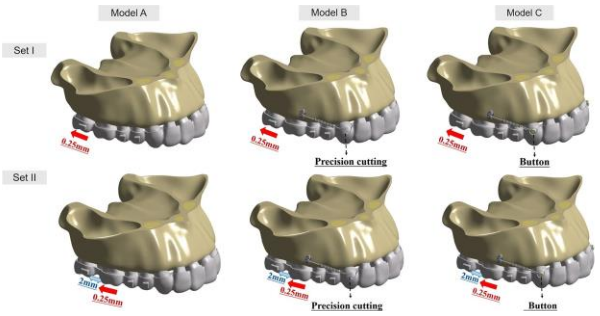

Fig. 1 Model figures. Two group sets including six submodels were constructed. Group set I was created to simulate the initial distalization of the 2nd molar, whereas Group set II was built to model the initial distalization of the 1st molar after the 2nd molar had been distalized by 2 mm. Models A1 and A2 were control models simulating upper-molar distalization with clear aligners, and no anchorage reinforcement was used. Models B1 and B2 represent the upper-molar distalization combining transparent aligners with microimplants via buttons. Models C1 and C2 were designed to simulate upper-molar distalization using clear aligners in combination with microimplants attached by precision cuts

Table 2 Nodes and elements

	A1	A2	B1	B2	C1	C2
Nodes	694,964	704,124	709,482	719,254	711,376	720,443
Elements	391,609	397,830	399,748	406,462	400,825	407,009

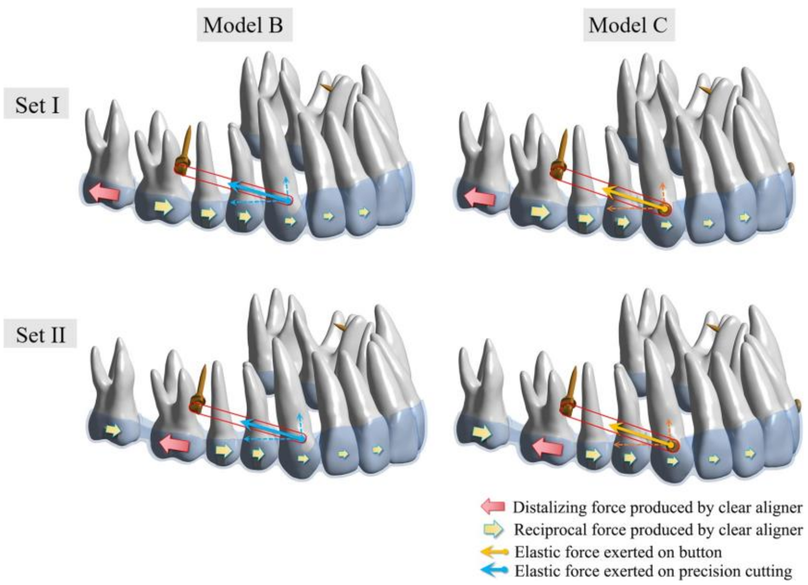

Fig. 2 The force loading system. The pushing force produced by the CA varied from group set I to set II. When the upper 2nd molar was distalized, the CA produced a mesial reciprocal force on the anchorage teeth. When moving the 1st molar distally, the pushing force exerted a reciprocal force on the 2nd molars and other anchorage teeth. In model B, the elastic force was exerted on the CA, whereas in model C, it was applied directly on the upper canines by button

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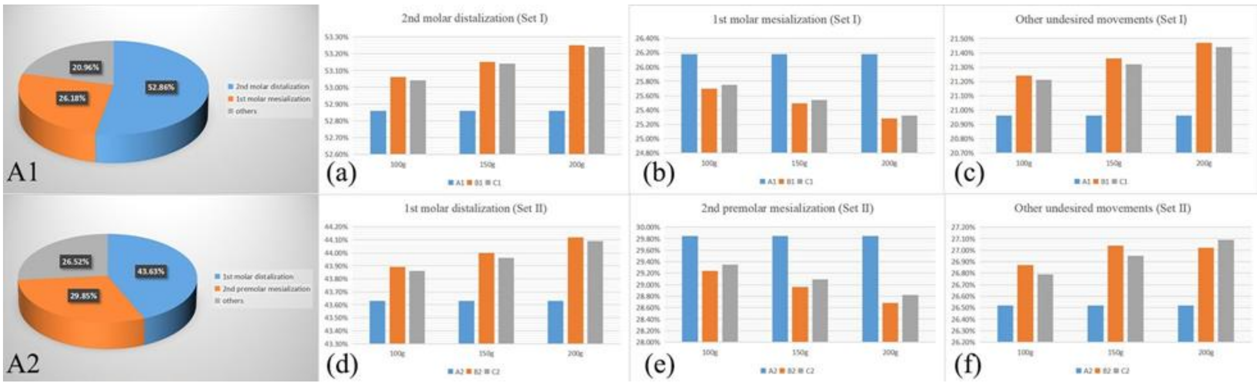

Fig. 3 The effective contribution ratio of molar distal movement at a 0.25 mm step distance. The pie charts show the contribution ratio of molar distalization, anchorage teeth mesialization to the 0.25 mm step distance, and the other percentage were occupied by buccal tipping and rotation. A1, model A1; A2, model A2. Subimage **a** represents the contribution ratio of 2nd molar distalization in group set I with various traction forces. Subimage **b** represents the contribution ratio of 1st molar mesialization during the 2nd molar distalization. Subimage **c** represents the contributionratio of the other undesired movements. Subimage **d** represents the contribution ratio of 1st molar distalization in group set Ⅱ. Subimage **e** represents the contribution ratio of 2nd premolar mesialization during the 1st molar distalization. Subimage **f** represents the percentage of other undesired movements

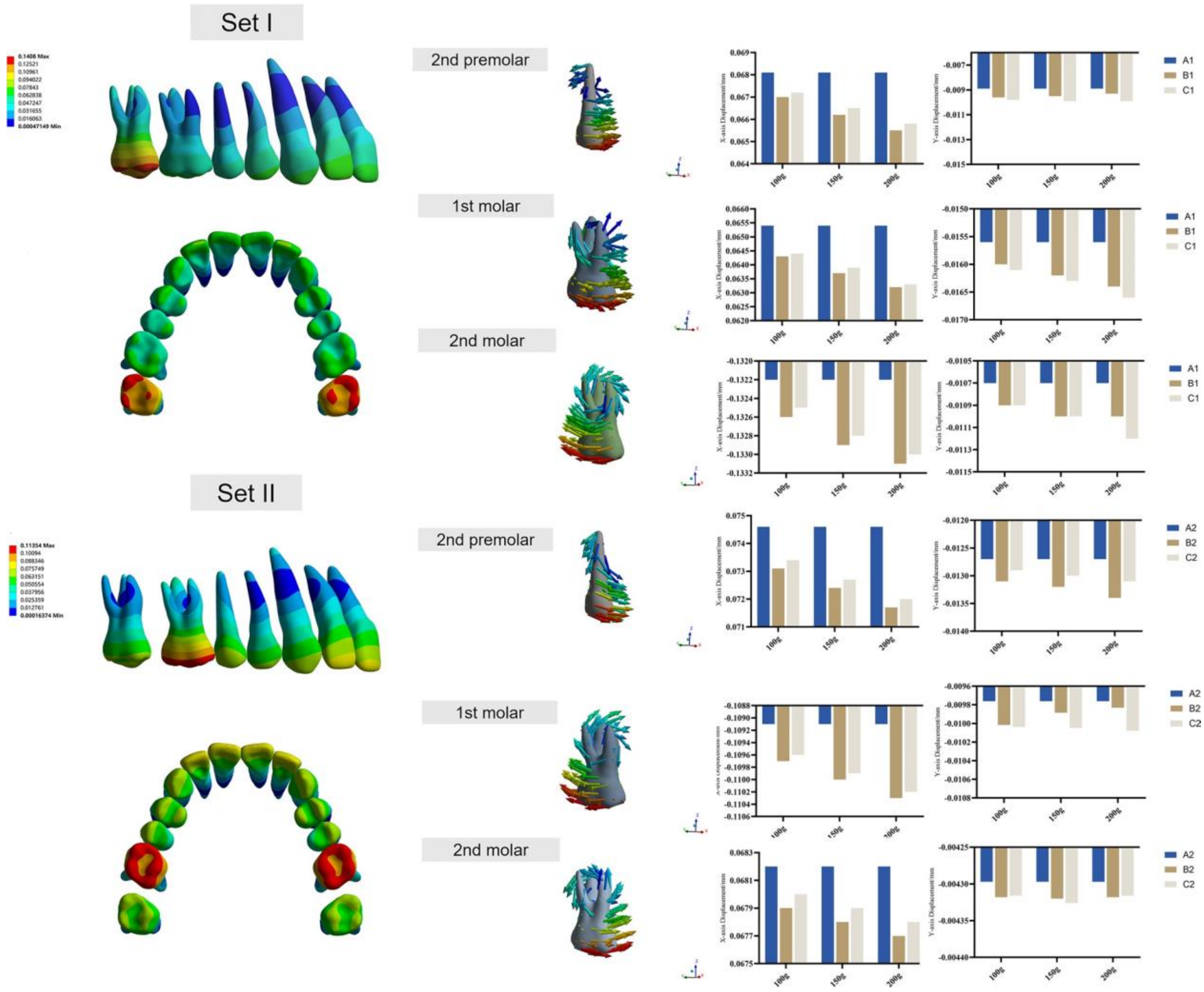

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Fig. 4 Three-dimensional displacement of the posterior teeth. In color maps, the red color shows the maximum displacement areas, and the blue color shows the minimum displacement areas. Vector diagrams show initial displacement patterns of 2nd premolars, 1st molars, and 2nd molars. Histograms present the x-axis and y-axis displacement values (mm). The coordinate system was centered on each tooth (local coordinate system); the positive value for the x-axis represents the mesial surface of the teeth, and the positive value for the y-axis represents the palatal surface of the teeth

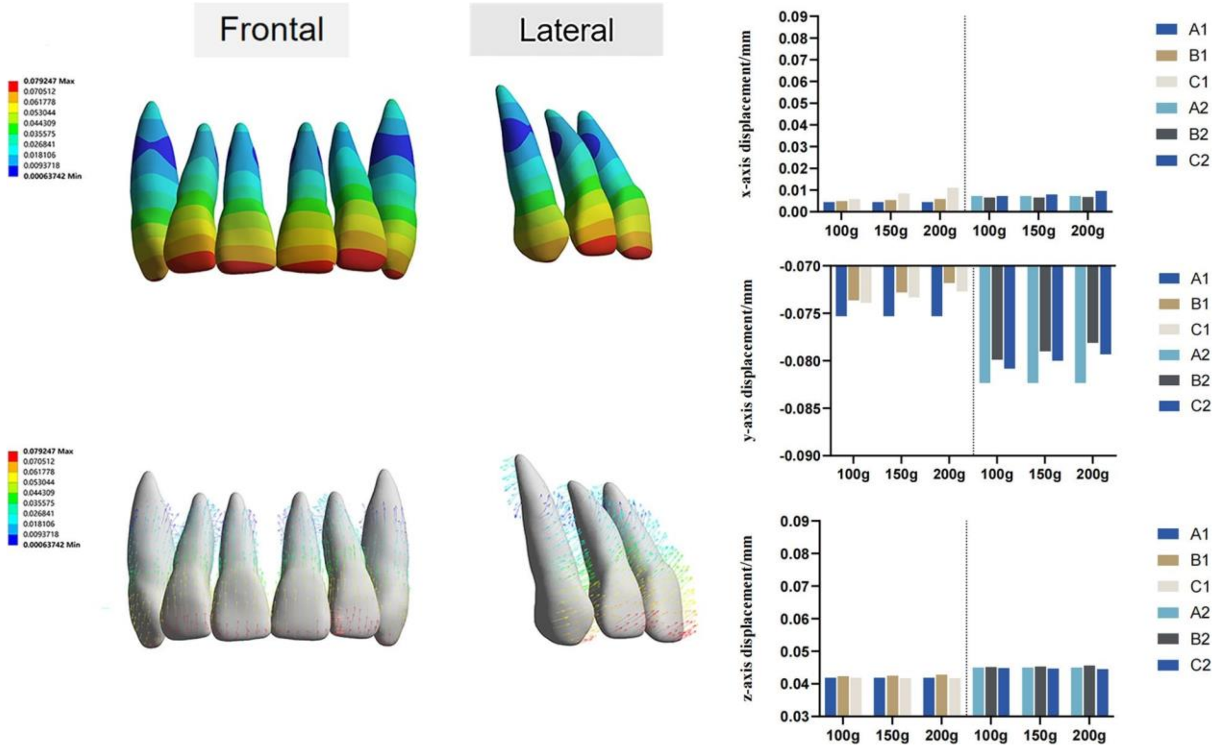

Fig.5 Three-dimensional displacement of the anterior teeth. Color maps and vector diagrams show the initial displacement patterns of central incisors, lateral incisors, and canines. Histograms present three-dimensional displacement values of different models in two group sets with various traction forces (mm). The coordinate system was centered on each tooth (local coordinate system)

Discussion

The present investigation was planned to concentrate on the initial stage of therapy, and measurements were made following the conclusion of the distalization movements, with the aim of assessing the correctness of the distalization and derotation of upper molars. The outcomes demonstrate the effectiveness of distalizing the buccal cusps of maxillary molars, with precision ranging from 68.0% of the first molar's mesio-buccal cusp to 79.9% of the second molar's mesio-buccal cusp. Research using the Invisalign® aligner system yields findings that are similar. In 2014, Simon et al.8 reported an 87% accuracy rate for upper molar distalization; their sample consisted of 15 patients, 8 of whom had attachments and 7 of whom had none. There was no discernible statistical difference between the groups that underwent the Achieved Movement and the Prescription group, nor between the groups that had attachments and those that did not. The study's result said that aligners can be used to achieve distalization and other bodily tooth motions, even though the examination of molar tipping movement was absent. Rossini et al.[10] considered this study of methodologically limited quality; therefore, those results should be regarded with caution.

A subsequent study by Saif et al.9, using a bigger sample consisting of 142 maxillary molars, revealed an accuracy of 73.8%. When molar distalization reached 2 to 3 mm, aligners were deemed effective. Just 56.3% of the molars in this study had an attachment, and no uniform technique for attachments was used. Additionally, there was no statistically significant difference between the group with attachments and the group without them in this investigation. The primary explanation for the discrepancies in the findings among our investigation and the research conducted by Simon et al. and Saif et al. was the variation in the distalization measurement. In fact, our research was especially designed to examine the distal displacement of the buccal cusps, whereas theirs measured the total distal movement of the molars on the sagittal axis. Moreover, there could be a reason for the discrepancy in findings between research if Class II elastics are used. Patients in our study were instructed to wear elastics on both sides for the entire day. Class II elastics are frequently employed in clinical settings to reinforce anchorages and enhance the distalization that aligners accomplish. However, it can be challenging to determine how much of the distalization is attributable to the elastics and how much to the aligners.

Professional 3D quality control software, Geomagic Control X, can do linear and angular measurements in addition to surface-based digital model superimpositions.Eleven Although stable anatomic landmarks that are not altered by bone remodelling or development after orthodontic treatment are excellent for digital model superimposition, there is disagreement in the literature on the most effective method for producing trustworthy superimpositions.[12] Regarding the maxillary arch, a number of investigations suggest that the palate, and specifically the region 5 mm dorsal to the third rugae and the medial two-thirds of the rugae, could be a reliable area for superimposition. However, these studies are highly variable and have a high risk of bias.[13,14] A further possibility is to superimpose digital models on stable teeth, although they may be subjected to periodontal traction as well as anchorage stress, which makes this method highly unreliable when complex treatment mechanics are used to move teeth with a great root surface area, such as molars.

The prior to treatment digital model and the optimum post-treatment STL files that were exported from the planning programme must be compared in order to assess dental movement predictability. The palatal area may be included in digital models created before and after treatment, but it is not included in the virtual plan STL file. In order to achieve a global best-fit, a closer-point algorithm was run 50 times to refine the initial registration, which was based on the mesial-incisal point of the right central incisor and the mesial-buccal cusps of the first molars. This was an adaptation of another superimposition method from Grünheid et al. [19]. Other writers have utilised this method subsequently[15,16], and it exhibits great consistency and accuracy for linear measurements.[11] Differently, in our study soft tissue areas were included when the final global best-fit was performed.

Two approaches were taken to mitigate the inherent risk associated with manually locating landmarks at the cusp points. First, by ensuring that every point selected was the same on both digital models through a methodology that included molar segmentation and a surface-based best fit of the occlusal surface of the particular molar, the variability of landmark identification between two digital models was significantly reduced. The measurements' reproducibility was then evaluated using the ICC, which demonstrated good agreement for both intra-examiner (0.995) and inter-examiner (0.986) reliability.

Similar conclusions were observed in studies conducted using the Invisalign® aligner system. In fact, the accuracy of upper-molar derotation in a prospective study17 was only about 43%, and rotating canines, premolars, and molars was usually thought to be a difficult movement to accomplish with clear aligners. In growing children with edge-to-edge Class II, Lione et al.17 recently reported a predictability of 60% for the rotation of the upper first molars prior to the eruption of the second molars; with a mean derotation of 6°, approximately 1 mm of arch space was obtained. When a mean derotation of 11.6° is anticipated, our study's derotation accuracy for the first molars was 77.5%, and for the second molars, it was 62.7%. These results suggest a moderate to high predictability. These numbers seem greater than the ones that were previously published. One explanation could be that the distalization treatment enhances the system's biomechanics, which would increase upper-molar derotation predictability. With its short tooth crown and position near the back of the arch, the second molar is less likely to undergo derotation.

A finite element research by Rossini et al.10 revealed that attachments are necessary to regulate the upper second molar's body movement; additionally, they found that a layout with a rectangle vertical from canine to second molar was the most probable.

This is in line with earlier research using cephalometric radiographs, which found that attachments from the canine to the second molar increased the amount of distalization and were useful in limiting body movement without causing appreciable distal tilting.[19]

Conclusion

The purpose of this work was to use a transparent aligner with microimplant to sequentially distalize teeth, and to biomechanically analyze the effective contribution ratio of molar distal movement at a 0.25-mm step distance. The results showed that the anchorage teeth underwent mesiobuccal tipping as a result of the reciprocal force, but the distalized molars displayed disto- buccal tipping. As a result, during the course of successive distaliza-tion, anchoring consumption rose and the effective contribution ratio of molar distal movement dropped. These findings imply that improved anchoring protection is required in these kinds of operations. Because of the reinforcement that microimplants provided, the effective contribution ratio of molar distalization rose along with a decrease in anchoring consumption. However, there was a minor rise in the rotation and tilting of the unintended molar teeth. Furthermore, when compared to buttons, precision cuts showed a better effective contribution ratio and anchoring reinforcement for incisors.

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