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Upper First Molar and Second Premolar Distalization with Clear Aligner and Interradicular Skeletal Anchorage: A Finite Element Study

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Abstract: Background—Upper molar distalization with a clear aligner is a debated topic in the scientific literature. One of the main issues is the loss of anchorage, so Class II elastics or the application of miniscrews are recommended. The aim of this study is to evaluate, through Finite Element Method (FEM) analysis, the effects of the application of the interradicular miniscrew as an anchorage device. Methods—A maxillary arch model from the second molar to second molar, which was obtained from a Cone Beam Computed Tomography (CBCT) and 0.2 mm distalization of the upper second premolar and upper first molar, was simulated. Therefore, nine different anchorage configurations were analyzed, with a miniscrew simulated between the upper first and second molars. Results—Considering the anchorage of a Class I elastic on the first premolar, the resulting side effect was a buccal movement of the canine. When the Class I elastic was anchored on the canine, distal displacement of the canine was observed. The distalization movements of second premolars and first molars were more efficient when the elastics were parallel to the occlusal plane. A greater anterior anchorage loss was observed when the elastic was anchored on the canine, with a proclination of the upper central incisor 30% higher than in the simulation, in which the elastic was on the first premolar. Conclusion—The use of interradicular buccal skeletal anchorage could reduce issues of patient compliance, provide a consistent intraoral anchorage unit and allow the desired tooth movements, reducing unwanted movement of the anterior teeth.

Keywords: clear aligners; upper distalization; miniscrews; orthodontics

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1. Introduction

Despite the increasing use of clear aligner treatment (CAT) among patients and specialists, its predictability in the expression of orthodontic tooth movement (OTM) is still debated [1]. In their 2015 systematic review, Rossini et al. [2] specified a threshold for the predictability of CAT and limits in controlling OTM, and Haouili et al. [3] stated that the mean accuracy of the Invisalign© (Santa Clara, CA, USA) technique is about 50%, depending on the type of movement considered. Nonetheless, when the results of this study were evaluated to determine their clinical significance, 74% of randomly chosen patients had passed the American Board of Orthodontics cast evaluation system, demonstrating the possibility of obtaining clinically excellent results.

Class II malocclusion involves the 25% of adults in the European populations, according to De Ridder et al. [4]. The correction of the molar class II relationship with CAT could be obtained with extractions of the first upper premolars, with mandibular advancement or with distalization of the upper molars. Considering Class II non-extraction cases, the upper molars' distalization could be considered as one of the possible choices [5,6]. According to

Align Technology's "best practice protocols", distalization is effective when it is planned with sequentialization and attachments placed on teeth [7–10]. Available evidence supports antero-posterior correction of 2.5 mm to 3 mm and suggests the use of attachments on all teeth from the canine to the second molar [6,9].

In upper distalization with CAT, one of the main problems is the loss of anterior anchorage, resulting in uncontrolled proclination movement of the anterior teeth, producing an overjet increase [11]. To prevent these side effects, Class II elastics are recommended. From the patients' point of view, the use of inter-arch elastics could be considered annoying because of possible smile esthetics interference during the orthodontic treatment, and one of the main risks in aligner orthodontics is the loss of patient compliance.

Alternatively, it is possible to use temporary anchoring devices (TADs) positioned in the buccal interradicular space between the first and the second molars to use the Class I elastics configuration, to stretch an elastic from the precision-cut aligner to the TAD.

TADs can also be used as an indirect anchorage, creating a pseudo-ankylosis by connecting the miniscrew to an adjacent tooth by means of a rectangular steel wire (miniscrew-supported pseudo-ankylosis) [12]. To analyze the biomechanical characteristics of these approaches and to provide the best indication for their clinical applications, the Finite Element Method (FEM) represents a valid tool.

It Is a numerical technique, approved and accepted in medicine, used to perform finite element analysis (FEA) of physical phenomena, and evaluate characteristics of biomaterials, devices and human tissues [13–18]. Quantitative data are provided by simulating the physiological response of the dento-alveolar complex to increase the understanding of the reaction occurring after the application of orthodontic forces. Moreover, it is possible to separately analyze the response of individual tissues such as the periodontal ligament and the alveolar bone, and to make a comparison between different simulations [19].

The aim of this study was to evaluate, through FEM analysis, the effects on the periodontal ligament, teeth and aligner, of the application of a distalization force on the upper first molar and second premolar using a skeletal interradicular miniscrew as a posterior anchorage preservation device. The study is required in order to better understand clear aligner biomechanics and to improve the daily clinical experience of orthodontists and patients.

2. Materials and Methods

CAD Design

A maxillary arch model considering teeth from the second molar to the second molar, the periodontal ligament (PDL) of each tooth, rectangular attachments from the second molar to the canine on both sides and dedicated orthodontic aligners, was obtained using SpaceClaim Computer-aided Design (CAD) software (SpaceClaim Corporation; Canonsburg, PA, USA) [Figure 1].

The teeth were created by one of the authors (GR), starting from a full arch STL file derived from a real patient CBCT. The PDL was designed using the SpaceClaim offset and Boolean intersection functions, on the basis of root shapes. The PDL average thickness was 0.25 mm, according to the existing literature [20].

Attachments were built, based on ClinCheck® software (Align Technology, Inc., San Jose, CA, USA) auxiliaries, with a vertical rectangular shape, 3 mm height, 2 mm width and 1 mm thickness [7].

The shape, size and position of composite attachments were determined by simulating rectangular attachments designed for distalization on a real case with ClinCheck® software. Aligners were obtained by applying the SpaceClaim software offset function on all tooth crowns and attachments and then manually refined to remove redundant surfaces and increase the accuracy of the aligners' contours. In this way, the shape of the obtained virtual model corresponded to that of a real aligner. After repeated measurements with a Micro-CT Scan (SkyScan 1172: Bruker-microCT; Kontich, Belgium) of brand new Invisalign® aligners (Align Technology, Inc., San Jose, CA, USA), the virtual aligner thickness was set at 0.5 mm.

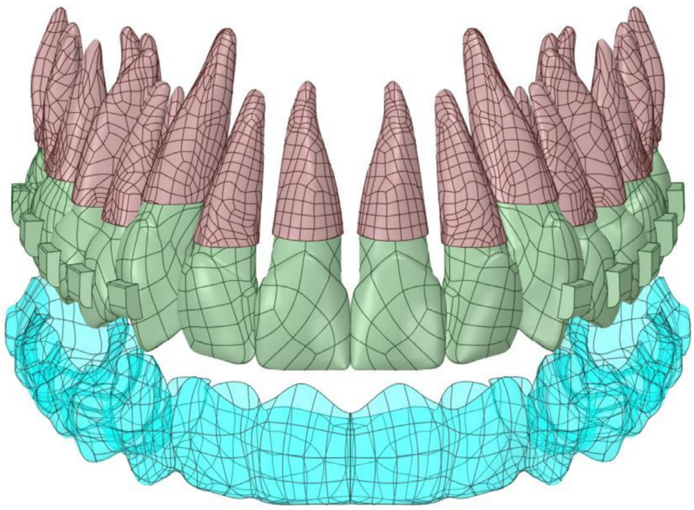

Figure 1. CAD Design.

The adopted FE software was ANSYS, (ANSYS 18.2, Inc.; Canonsburg, PA, USA), in which the model was imported after the CAD process.

After an initial phase of alignment and leveling of the teeth, the model was modified in order to reproduce a clinical condition in which the second molar was already distalized by 2.5 mm [9] and the first molar was already distalized by 1.2 mm, in a 50% sequential distalization protocol configuration. This is a sequentialization pattern where the upper second molar started to distalize; when it reached 50% of its movement, the upper first molar started to distalize. When the second molar completed distalization and the first molar completed 50% of distalization, the upper second premolar started to distalize; when the first molar completed distalization and the second premolar reached 50% of its movement, the upper first premolar started to distalize; and so on until the upper distalization of the arch was completed. From canine to canine, the arch will distalize en masse, according to the protocol.

Therefore, the simulated movement was represented by 0.2 mm distalization of the upper second premolar and upper first molar, reproducing a real clinical setting [21].

According to the existing literature, every CAD element, with the exception of the PDL, was considered isotropic and homogeneous [22].

The teeth and their attachments were considered as a single body with a Young's Modulus of 19,600 MPa and Poisson's Ratio of 0.3 [15]. The aligner was considered as an isotropic and homogeneous material with a Young's Modulus of 528 MPa and Poisson's Ratio of 0.36 [Table 1].

Table 1. Material properties.

Material	Young's Modulus, E (MPa)	Poisson Ration, v
Teeth	1.96×104	0.30
Attachment	1.25×104	0.36
Periodontal ligament	0.69	0.45
Aligners	528	0.36

The skeletal anchorage requested for the distalization movement was provided through the simulation of a buccal interradicular TAD located in the space between the first and second upper molar. Furthermore, in order to avoid proclination of the upper incisors, the effect of a Class I elastic was analyzed in two possible configurations: (1) stretched from the TAD to the upper canine and (2) from the TAD to the first upper premolar.

The following parameters were considered for the mesh [6]:

- Mesh size: 0.09 mm;

- Type of element: linear;
- Average nodes: 1,240,850;
- Average elements: 1,435,655.

The effects of 3/16 4.5 Oz elastics (Ormco Inc., Glendora, CA, USA) were simulated at two different elongation lengths: the first was 16 mm elongation in the configuration where the elastic was stretched towards the first premolar, while the second was 24.5 mm when the elastic was stretched towards the canine, varying the force vectors according to the angle between the elastic and the occlusal plane. The elongation lengths and released forces were derived from a previous study by Castroflorio et al. [23].

Nine simulations were performed with different anchorage configurations [Figure 2]:

- Three with 16mm elongation length, as follows:
(1) Elastic parallel to the occlusal plane (α90);
(2) Elastic stretched at 20° with respect to the occlusal plane (α20);
(3) Elastic stretched at 30° with respect to the occlusal plane (α30).
- Three with 24.5 mm elongation length, as follows:
(1) Elastic parallel to the occlusal plane (β90);
(2) Elastic stretched at 20° with respect to the occlusal plane (β20);
(3) Elastic stretched at 30° with respect to the occlusal plane (β30).
- Three with pseudo-ankylosis supported by a miniscrew next to the upper second molar. The dental element was locked in the initial position, preventing unwanted movements due to the loss of posterior anchorage.
(1) Elastic anchored on the upper first premolar and parallel to the occlusal plane (α 90 anch);
(2) Elastic anchored on the upper canine and parallel to the occlusal plane (β 90 anch);
(3) Elastic anchored on the upper canine and creating a 30° angle with respect to the occlusal plane (β 30 anch).

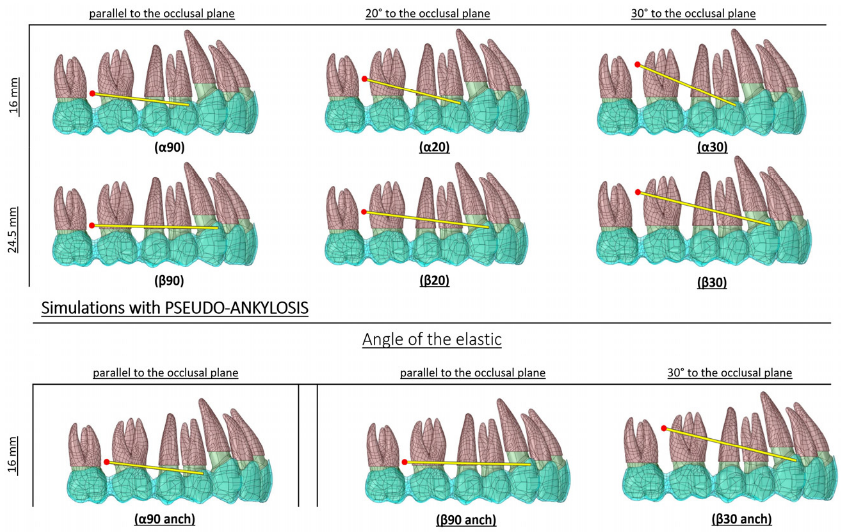

Figure 2. Configurations of the simulations.

Three-dimensional studies using CBCT have suggested that the upper first and second molar region is the most ideal and safest zone for the placement of miniscrews for maxillary molar distalization, because of the presence of a thicker buccal bone in that region [24]. Liu et al. measured the bone thickness at a distance of 5mm from the CEJ and that was the reference used for the force parallel to the occlusal plane model in this study. The model with the elastic at 20°, with respect to the occlusal plane model, is referring to the measurement performed by Liu at 11 mm distance from the CEJ, where the thickest buccal bone was observed. The elastic at 30°, with respect to the occlusal plane model, is simulating the presence of an infrazygomatic TAD, according to the indications provided by Liou et al. [25]. Therefore, the proper miniscrew insertion area in the infrazygomatic crest is at 14 to 16 mm above the maxillary occlusal plane.

Data regarding tooth displacement, aligner deformation, equivalent stress of the periodontal ligament, and the contact pressure between the aligner and teeth were obtained by each configuration.

3. Results

All of the performed simulations were effective in distalization movements; differences between models were detected mostly in the anterior region of the arch. Considering the anchorage of a Class I elastic on the first premolar, the resulting side effect was a buccal movement of the canine. This result was confirmed by the anti-clockwise deformation detected on the aligner in the canine region. This deformation became larger as the angle between the elastic vector and the occlusal plane increased: the deformation registered was 0.044 mm when the elastic was applied parallel to the occlusal plane; it became 0.058 mm and 0.06 mm when the angle was 20° and 30°. All results are expressed in Tables 2–5 and Figures 3 and 4.

Table 2. Tooth displacement (min/max).

Configuration	Max (mm)	Localization	Min (mm)	Localization
α 90	0.092634	U5 crown	0.000166	U4 buccal root
α 20	0.094285	U5 crown	0.000155	U2 palatal root
α 30	0.094184	U5 crown	0.000157	U2 palatal root
β 90	0.095492	U5 crown	0.000172	U5 buccal root
β 20	0.096133	U5 crown	0.000303	U4 palatal root
β 30	0.095814	U5 crown	0.000273	U4 palatal root
α 90 anch	0.093408	U5 crown	0.000000	U7
β 90 anch	0.095966	U5 crown	0.000000	U7
β 30 anch	0.096463	U5 crown	0.000000	U7

Table 3. Element 1.1 incisal displacement.

Configuration	X (mm)	Y (mm)	Z (mm)	Total (mm)
α 90	−0.015	−0.044	0.013	0.048
α 20	−0.015	−0.044	0.013	0.048
α 30	−0.015	−0.043	0.013	0.048
β 90	−0.026	−0.064	0.021	0.072
β 20	−0.028	−0.065	0.023	0.075
β 30	−0.029	−0.065	0.023	0.075
α 90 anch	−0.015	−0.044	0.013	0.048
β 90 anch	−0.026	−0.064	0.021	0.072
β 30 anch	−0.029	−0.065	0.023	0.075

Table 4. Element 1.3 cusp displacement.

Configuration	X (mm)	Y (mm)	Z (mm)	Total (mm)
α 90	−0.044	0.009	0.052	0.045
α 20	−0.058	0.003	0.008	0.059
α 30	−0.060	−0.000	0.014	0.061
β 90	−0.096	0.062	−0.001	0.063
β 20	−0.028	0.052	0.010	0.060
β 30	−0.041	0.042	0.015	0.061
α 90 anch	−0.043	0.010	0.005	0.044
β 90 anch	−0.009	0.062	−0.001	0.063
β 30 anch	−0.041	0.043	0.015	0.062

Table 5. Element 1.6 mesio-buccal cusp displacement.

Configuration	X (mm)	Y (mm)	Z (mm)	Total (mm)
α 90	−0.002	0.062	−0.016	0.064
α 20	−0.007	0.060	−0.015	0.062
α 30	−0.009	0.058	−0.014	0.060
β 90	−0.009	0.068	−0.017	0.071
β 20	−0.010	0.065	−0.017	0.068
β 30	−0.011	0.063	−0.016	0.066
α 90 anch	−0.0001	0.064	−0.017	0.066
β 90 anch	−0.008	0.069	−0.018	0.072
β 30 anch	−0.009	0.065	−0.017	0.068

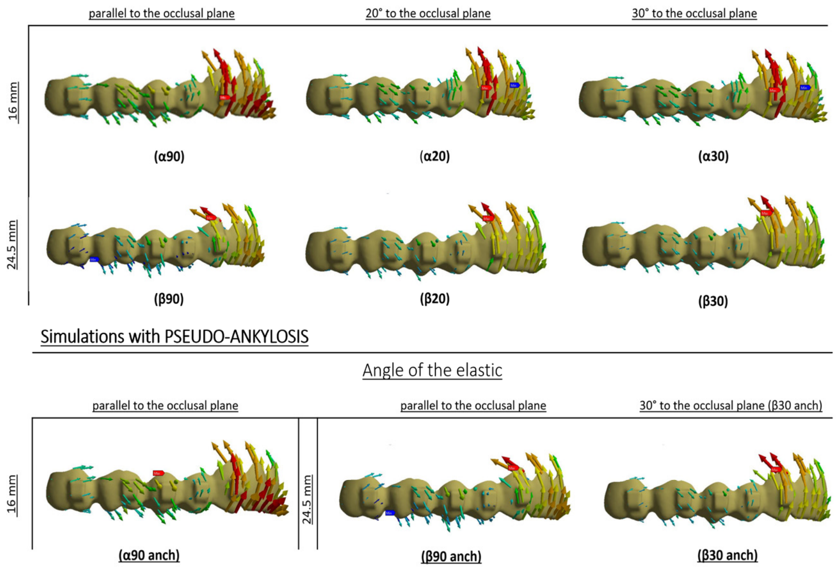

Figure 3. Aligner deformation.

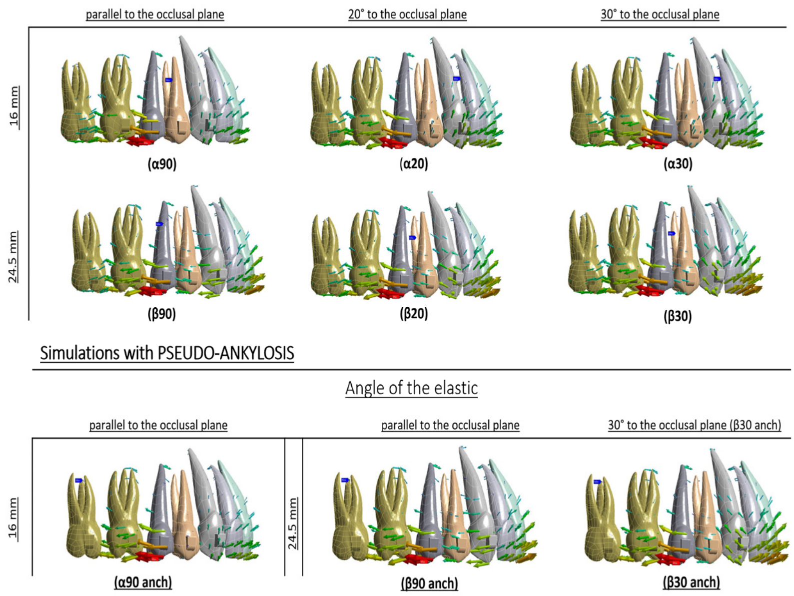

Figure 4. Tooth displacement.

When the Class I elastic was anchored on the canine, distal displacement (from 0.04 to 0.06, depending on elastic inclination) of the canine, as well as a deformation of the aligner in the distal direction, were observed.

As the angle between the elastic and the occlusal plane increased, a more intrusive movement of the canine was highlighted. Interestingly, while this vertical component was null in the configuration with the elastic parallel to the occlusal plane (α90), it was maximum (0.016 mm) when the elastic was tilted at 30°, with respect to the occlusal plane.

The distalization movements of the second premolars and first molars were more efficient when the elastics were parallel to the occlusal plane. Values registered were similar in both elements: the distalization movement of 1.6 ranged from 0.062 with α90 to 0.058 with α30 while ranged from 0.072 with α90 to 0.70 with α30 in 1.5. Moreover, with these configurations, the pressure between the teeth and aligner on the second premolar attachment mesial surface reaches the maximum value (3435.42 g/cm^2 in α90 situation), while it decreases as the angle between the elastic and the occlusal plane increases (2744.57 g/cm^2 in α20 and 2681.34 g/cm^2 in α30 configuration).

A greater anterior anchorage loss was observed when the elastic was anchored on the canine, with a proclination (0.015 mm) of the upper central incisor, 30% higher than in the simulation in which the elastic was anchored on the first premolar (0.026 mm).

No significant changes in the pattern of teeth movement were detected in the pseudo-ankylosis simulation, with the exclusion of any mesial movement of the upper second molar. However, a slightly better performance was measured in terms of distalization of the second premolar and first molar, and a greater contact pressure on the mesial surface of the second premolar attachment was revealed (3680.05 g/cm^2 in α90, 5155.89 g/cm^2 in β90, and 3812.31 g/cm^2 in β30).

4. Discussion

The use of interradicular buccal skeletal anchorage, in Class II non-extraction treatments with aligners, could reduce issues of patient compliance, which provides a consistent intraoral anchorage unit and allows the desired tooth movements, reducing unwanted movement of the anterior teeth. The results of the present FEM study support the use of TADs as anchorage units. Previous in vitro and in vivo studies by our team demonstrated that a proper treatment design, including attachments on all of the distalizing teeth and the use of Class II elastics, could provide an anteroposterior correction of about 3 mm in a reliable way [6,9,10]. However, it was demonstrated that the worst undesired effect of the mechanics was represented by huge posterior anchorage loss when starting premolar distalization [26]. Therefore, the use of TADs could be the solution to avoid posterior anchorage loss. The use of Class I elastics could be more acceptable by patients with respect to Class II interarch elastics, because they are less visible and, therefore, more esthetic, therefore reducing patient compliance issues. Furthermore, Class II elastics reduce lingual tipping of the anterior teeth but aggravated mesial tipping of the posterior teeth [27]. It must be reminded that clear aligners provide a good control of the lower incisors' final position, despite the use of Class II elastics [28].

Regarding the performance of the analyzed configurations in determining the programmed distalization movement of the second premolars and first molars, the configurations that guarantee the best result are those in which the rubber band is parallel to the occlusal plane. In these configurations, it is possible to detect the greater component of displacement in the distal direction of the first molar and second premolar compared to those with the elastic positioned on the same element but at different angles. This is confirmed by the value of the contact pressure between the teeth and the aligner on the mesial surface of the attachments of the second premolar, which is the maximum when the elastic is parallel, and progressively decreases as the angle, with respect to the occlusal plane, increases.

Regarding anterior anchorage loss, the greatest proclination of the incisors is observed in configurations with the elastic positioned at the level of the canine. In fact, these configurations present a total displacement of the incisal edge of the central incisor that is approximately 30% greater than those with the rubber band on the premolar. Looking at the displacement vectors, the lateral incisor is less affected by this side effect.

Considering this, configurations with the rubber band positioned on the canine may be more indicated in Class II Division 2 malocclusions, where the side effect of proclination of the central incisors, which is greater in these configurations, may help correct their initial retroclination. The choice of elastic angulation with respect to the occlusal plane should be reduced to the configuration with the elastic parallel and at 30°. The 30° elastic results in a greater intrusive component at the canine level and is, therefore, preferable in cases where this movement is required [Table 3].

From analyzing the configurations with the elastic on the first premolar, the one with the elastic parallel to the occlusal plane results in the least vestibular movement of the canine and is, therefore, the only one to be considered. Given the lesser extent of proclination at the incisor level compared to configurations with the rubber band on the canine, it may be preferable in Class II Division 1, where incisors are already proclined.

Class II elastics have been used in various clinical trials to avoid pro-inclination of the incisors during sequential distalization with aligners [9,10,21,28]. In FEM simulations previously conducted by Rossini et al. [6], it was observed that anchoring class II elastics on precision cuts of the first premolar resulted in a proclination of the incisors of approximately 0.05 mm when the aligner was inserted. This anterior anchorage loss is in line with the one observed in the present study, when Class I elastics are stretched between the TAD and the first upper premolar (approximately 0.048 mm). On the other hand, the proclination of the incisors with Class II elastics is significantly lower than the one detected with Class I elastics stretched from the TAD to the upper canine (9pprox.. 0.070 mm).

The use of the buccal interradicular TAD and Class I elastics could be of help in reducing anterior anchorage loss. However, a loss of posterior anchorage occurred, with a mesial movement of the upper second molar. This effect is related to the elasticity of the aligner material producing a bowing effect during the retraction of the premolars [29,30]. Based on this, pseudo-ankylosis of the upper second molar was simulated [31]. A slightly better performance was measured in terms of distalization of the second premolar and first molar, and a higher contact pressure between the teeth and aligner at the mesial surface of the attachment on the second premolar.

FEM studies represent one of the best ways to independently understand and improve clear aligner biomechanics. However, in vitro and in vivo study results may differ. Aligner thermoplastic material, friction phenomena, thermoforming procedures, appliance insertion and removal, and the intraoral environment are all factors affecting aligner mechanical properties. Unfortunately, most of these factors cannot be reproduced in FEM analysis or are patented and not disclosed by companies. As a further limitation of this study, occlusal forces derived by functional and parafunctional contacts were not considered. Therefore, future FEM studies should be conducted integrating those missing data to produce models that are closer to the real clinical setting.

FEM analyses represent the real initial moment of the force application; in other words, the first second of the force application and the results should be considered in this view.

High-quality clinical trials are required to confirm FEM-derived force systems. Additionally, the study could be improved and integrated by examining other possibilities, such as simulations with other attachment designs.

5. Conclusions

Based on this study and considering its limitations, it can be concluded that:

- The variation of the force angle determined by different vertical locations of the mini-screw and elastic anchorage on the first premolar, rather than on the canine, can influence the pattern of tooth movement, particularly at the level of the canines.
- In terms of anterior anchorage loss, the use of Class I elastics anchored on the canine can be of help in promoting the incisors' proclination when required (Class II, division 2), while Class I elastics anchored on the first premolar can be of help when proclination needs to be corrected (Class II, division 1).

- Buccal interradicular TADs and Class I elastics cannot prevent posterior anchorage loss.
- The pseudo-ankylosis of the upper second molars can improve the amount of distalization movement achieved by the first molar and second premolar, avoiding any posterior anchorage loss.

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Data Availability Statement: All data are provided in the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kravitz, N.D.; Kusnoto, B.; BeGole, E.; Obrez, A.; Agran, B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. *Am. J. Orthod. Dentofac. Orthop.* **2009**, *135*, 27–35. [CrossRef] [PubMed]
2. Rossini, G.; Parrini, S.; Castroflorio, T.; Deregibus, A.; Debernardi, C.L. Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review. *Angle Orthod.* **2015**, *85*, 881–889. [CrossRef] [PubMed]
3. Haouili, N.; Kravitz, N.D.; Vaid, N.R.; Ferguson, D.J.; Makki, L. Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign. *Am. J. Orthod. Dentofac. Orthop.* **2020**, *158*, 420–425. [CrossRef] [PubMed]
4. De Ridder, L.; Aleksieva, A.; Willems, G.; Declerck, D.; Cadenas de Llano-Pérula, M. Prevalence of Orthodontic Malocclusions in Healthy Children and Adolescents: A Systematic Review. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7446. [CrossRef] [PubMed]
5. Daher, S. Dr. Sam Daher's Techniques for Class II Correction with Invisalign and Elastics Align Technology, Santa Clara, Ca, USA. 2011. Available online: https://s3.amazonaws.com/learn-invisalign/docs/06840000000Fp2xAAC.pdf (accessed on 15 April 2011).
6. Rossini, G.; Schiaffino, M.; Parrini, S.; Sedran, A.; Deregibus, A.; Castroflorio, T. Upper second molar distalization with clear aligners: A finite element study. *Appl. Sci.* **2020**, *10*, 7739. [CrossRef]
7. Fischer, K. Invisalign treatment of dental Class II malocclusions without auxiliaries. *J. Clin. Orthod.* **2010**, *44*, 665–672. [PubMed]
8. Schupp, W.; Haubrich, J.; Neumann, I. Class II correction with the Invisalign system. *J. Clin. Orthod.* **2010**, *44*, 28–35. [PubMed]
9. 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. [CrossRef] [PubMed]
10. Garino, F.; Castroflorio, T.; Daher, S.; Ravera, S.; Rossini, G.; Cugliari, G.; Deregibus, A. Effectiveness of composite attachments in controlling upper-molar movement with aligners. *J. Clin. Orthod.* **2016**, *50*, 341–347.
11. Saif, B.S.; Pan, F.; Mou, Q.; Han, M.; Bu, W.; Zhao, J.; Guan, L.; Wang, F.; Zou, R.; Zhou, H.; et al. Efficiency evaluation of maxillary molar distalization using Invisalign based on palatal rugae registration. *Am. J. Orthod. Dentofac. Orthop.* **2022**, *161*, e372–e379. [CrossRef]
12. Arveda, N.; de Felice, M.E.; Derton, N.; Lombardo, L.; Gatto, R.; Caruso, S. Management of Class III Extraction with the Miniscrew-Supported Orthodontic Pseudo-Ankylosis (MSOPA) Using Direct Tads. *Appl. Sci.* **2022**, *12*, 2464. [CrossRef]
13. Konda, P.; Sa, T. Basic principles of finite element method and its applications in orthodontics. *J. Pharm. Biomed. Anal.* **2012**, *16*, 1–4.
14. Papageorgiou, S.N.; Keilig, L.; Hasan, I.; Jäger, A.; Bourauel, C. Effect of material variation on the biomechanical behaviour of orthodontic fixed appliances: A finite element analysis. *Eur. J. Orthod.* **2016**, *38*, 300–307. [CrossRef] [PubMed]
15. Barone, S.; Paoli, A.; Razionale, A.V.; Savignano, R. Computational design and engineering of polymeric orthodontic aligners. *Int. J. Numer. Method Biomed. Eng.* **2017**, *33*, e2839. [CrossRef] [PubMed]
16. Himmlová, L.; Dostálová, T.; Kácovský, A.; Konvicková, S. Influence of implant length and diameter on stress distribution: A finite element analysis. *J. Prosthet. Dent.* **2004**, *91*, 20–25. [CrossRef] [PubMed]
17. Berutti, E.; Chiandussi, G.; Gaviglio, I.; Ibba, A. Comparative analysis of torsional and bending stresses in two mathematical models of nickel-titanium rotary instruments: ProTaper versus ProFile. *J. Endod.* **2003**, *29*, 15–19. [CrossRef]
18. De Vree, J.H.; Peters, M.C.; Plasschaert, A.J. The influence of modification of cavity design on distribution of stresses in a restored molar. *J. Dent. Res.* **1984**, *63*, 1217–1220. [CrossRef]

19. Knop, L.; Gandini, L.G.; Shintcovsk, R.L.; Gandini, M.R.E.A.S. Scientific use of the finite element method in orthodontics. *Dent. Press J. Orthod.* **2015**, *20*, 119–125. [CrossRef] [PubMed]
20. Su, M.Z.; Chang, H.H.; Chiang, Y.C.; Cheng, J.H.; Fuh, L.J.; Wang, C.Y.; Lin, C.P. Modeling viscoelastic behavior of periodontal ligament with nonlinear finite element analysis. *J. Dent. Sci.* **2013**, *8*, 121–128. [CrossRef]
21. Simon, M.; Keilig, L.; Schwarze, J.; Jung, B.A.; Bourauel, C. Treatment outcome and efficacy of an aligner technique--regarding incisor torque, premolar derotation and molar distalization. *BMC Oral Health* **2014**, *14*, 68. [CrossRef] [PubMed]
22. Gomez, J.P.; Peña, F.M.; Martínez, V.; Giraldo, D.C.; Cardona, C.I. Initial force systems during bodily tooth movement with plastic aligners and composite attachments: A three-dimen-sional finite element analysis. *Angle Orthod.* **2015**, *85*, 454–460. [CrossRef]
23. Castroflorio, T.; Sedran, A.; Spadaro, F.; Rossini, G.; Quinzi, V.; Deregibus, A. Analysis of Class II Intermaxillary Elastics Applied Forces: An in-vitro Study. *Front. Dent. Med.* **2022**, *2*, 748985. [CrossRef]
24. Liu, H.; Wu, X.; Yang, L.; Ding, Y. Safe zones for miniscrews in maxillary dentition distalization assessed with cone-beam computed tomography. *Am. J. Orthod. Dentofac. Orthop.* **2017**, *151*, 500–506. [CrossRef]
25. Liou, E.J.; Chen, P.H.; Wang, Y.C.; Lin, J.C. A computed tomographic image study on the thickness of the infrazygomatic crest of the maxilla and its clinical implications for miniscrew insertion. *Am. J. Orthod. Dentofac. Orthop.* **2007**, *131*, 352–356. [CrossRef]
26. Rossini, G. Finite Element Analysis of Clear Orthodontic Aligners' Biomechanics: From cad-fe Framework Design to Clinical Optimization. Doctoral Thesis, Polytechnic University of Turin, Torino, Italy, 2020.
27. Wang, Q.; Dai, D.; Wang, J.; Chen, Y.; Zhang, C. Biomechanical analysis of effective mandibular en-masse retraction using Class II elastics with a clear aligner: A finite element study. *Prog. Orthod.* **2022**, *23*, 23. [CrossRef] [PubMed]
28. Dianiskova, S.; Rongo, R.; Buono, R.; Franchi, L.; Michelotti, A.; D'Antò, V. Treatment of mild Class II malocclusion in growing patients with clear aligners versus fixed multibracket therapy: A retrospective study. *Orthod. Craniofac. Res.* **2022**, *25*, 96–102. [CrossRef]
29. Zhu, Y.; Hu, W.; Li, S. Force changes associated with differential activation of en-masse retraction and/or intrusion with clear aligners. *Korean J. Orthod.* **2021**, *51*, 32–42. [CrossRef] [PubMed]
30. Cheng, Y.; Gao, J.; Fang, S.; Wang, W.; Ma, Y.; Jin, Z. Torque movement of the upper anterior teeth using a clear aligner in cases of extraction: A finite element study. *Prog. Orthod.* **2022**, *23*, 26. [CrossRef] [PubMed]
31. Derton, N.; Lupini, D.; Cozzani, M. Miniscrew-Supported Orthodontic Pseudo-Ankylosis for Mesialization of a Lower Third Molar. *J. Clin. Orthod.* **2017**, *51*, 290–293.