Original Article

A New Perspective on the Relationship Between Anchorage and Palatal Morphology: Three-Dimensional Digital Model Analysis

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Abstract

Background: The tooth movements were generally analyzed in two dimensions on cephalometric radiographs. Nowaday, 3D digital model analysis, which does not have any harmful effects on patients, can be used to evaluate the palatal morphology and coronal tooth movements in a very comfortable and easy way. **Aims:** To investigate the effect of palatal morphology on anchorage reinforcement during intraoral molar distalization with pendulum appliance using 3D model analysis. **Materials and Methods:** The material consisted of before (T0) and after (T1) dental plaster models of Class II malocclusion patients (17 females, 3 males) treated with pendulum appliance for molar distalization and Nance appliance for anchorage. T0 and T1 digital models were superimposed using the palatal area as a reference via three points and surface-matching software, and the changes in teeth movement were calculated for left and right central incisors, first premolars, and first and second molars. Palatal morphology was evaluated at T0 on digital models as palatal inclination, palatal depth angles, and anterior hard palate area. Wilcoxon test was used to evaluate the treatment results and Spearman's correlation analysis was performed to evaluate the relationship between palatal morphology and dental movement. The upper limit for the level of significance was taken as 0.05. **Results:** Mesial movement of first premolars and distal movement of first and second molars were found to be statistically significant ($P < 0.001$). A weak negative correlation was found between the palatal inclination and the movement of first premolars ($P < 0.045$ and $P < 0.003$). Palatal depth angles and anterior hard palate area had no correlation with dental movements. **Conclusion:** Presented results supported that the mesial movement of premolar teeth decreased as the inclination of the palate increased.

Keywords: *3D analyses, anchorage, digital dental models, orthodontics, palatal morphology*

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Introduction

Maxillary molar distalization is a nonextraction treatment method to correct Angle Class II molar relationship. However, many devices have been developed and used to distalize maxillary molars.[1] Intraoral distalization mechanics, such as the pendulum, superelastic nickel–titanium open coil springs, and several other methods that do not require extensive cooperation from patients are preferred by orthodontists.[2-7] Intraoral molar distalization appliances require extra anchorage to inhibit anterior displacement of support teeth and most of these appliances use palatal anchorage.[4,8-13]

The Nance appliance is usually designed with a large acrylic button extended to cover the steepest and deepest of the anterior palatal vault. In a systematic review, Nance appliance and its variations were reported as the

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most commonly used anchorage reinforcement device for maxillary molar distalization.[14]

Despite its frequent use, studies that have assessed the effectiveness of the Nance appliance showed that it does not provide an absolute anchorage. Therefore, facing with different amounts of anchorage loss during molar distalization with intraoral molar distalization mechanics using Nance appliance as anchorage has been an unfavorable challenge for clinicians.[15,16] Kinzinger *et al*.[17] pointed out that while evaluating the anchoring effect of the appliance, individual characteristics, such as palatal morphology, palatal mucosa thickness, and depth and width of the palatal vault also deserve to be discussed. However, Bondemark and Thorneus[8] claimed that Nance appliances used in different sizes depending on the palatal morphology did not have a significant effect on the preservation of the anchorage. Despite several studies showing that hard palatal morphology varies widely,[18-20] there is no statistical evaluation of the relationship between the palatal morphology and dental changes during intraoral molar distalization with a Nance appliance for anchorage.

Recently, digital 3D model analysis has become the standard technology for the diagnosis, treatment planning, design, and manufacturing process of orthodontic appliances and evaluation of tooth movement. Numerous studies have shown that the best-fit mathematical superimposition method of maxillary casts on the identical palatal vault is very accurate and allows 3D evaluation of tooth movement, palatal asymmetry, anatomical characteristics, and morphological changes in dentistry.[15,21-27]

Therefore, the aim of this study was to investigate the effect of palatal morphology on anchorage reinforcement during intraoral molar distalization with the Nance appliance using 3D model analysis.

Materials and Methods

This retrospective study was approved by the Ethical Committee Board of Gazi University (research code: 2019-017). The sample size of this study was estimated by the G*Power Software (v3.1.3; Franz Faul, Universität Kiel, Germany). According to the power analysis with 0.05 level and 80% power, based on maxillary molar distal movements in previous studies, the needed minimum sample size was 20 for the group.[4,7,21]

The selection criteria were as following:

- Patients with fully erupted second molars.
- Bilateral Class II molar relationships.
- Treated with pendulum appliance till a super-Class I molar relationship at the end of the molar distalization.
- Anchorage must be supported with a Nance appliance that button was held in place with occlusally bonded rests on the first and second premolar in all subjects.
- Patients that have dental casts taken without the Nance appliance at the end of the molar distalization.
- The palatal mucosal integrity was preserved in maxillary digital models before (T0) and after completion molar distalization (T1).

All subjects or parents/legally authorized representatives of patients signed informed consent forms for scientific research as a regular procedure. A sample of 28 patients were collected from the archives of the Department of Orthodontics, Faculty of Dentistry, Gazi University. Eight patients were excluded from the initial sample, according to the defined criteria, particularly because of tissue impingement in T1 digital models. The final sample consisted of maxillary plaster models of 20 patients that was taken before (T0) and after molar distalization (T1). Fifteen subjects had end-to-end and five subjects had full-step bilateral Class II molar relationships at the start of treatment. Mean age was 15.1 ± 2.6 years at T0 and the mean period of molar distalization was 6.2 ± 1.5 months. In four cases, occlusal rests were removed during molar distalization to allow the distal drift of the second premolars.

Dental models before and after molar distalization were scanned using 3Shape R700 3D Scanner (3Shape Ortho System, Copenhagen K Denmark). The data were then imported into the 3Shape Ortho Analyzer software program (3Shape Ortho System, Copenhagen K Denmark). Digital models before and after molar distalization were superimposed with the 3 Shape Ortho Analyzer software using the Surface three-point method (three corresponding points at medial points of the third rugae on each model for alignment and the surface containing selected points to align the models). To determine the accuracy of the 3D superimposition, it was checked on the two-dimensional sagittal section whether the palatal vault curvature followed each other (T0–T1) or not [Figure 1].

The frontal plane was constructed to be perpendicular to the midsagittal plane on the superimposed digital dental models and the same reference plane at T0 was used at T1 models too. Thus, this plane was used to measure the anteroposterior displacement of the maxillary central incisors, first premolars, and first and second molars [Table 1, Figure 2a–c].

The description of the palatal inclination, palatal depth angles, and hard palate area was given in Table 1 and were shown in Figure 2d–f.

Statistical analysis

To identify the intra-examiner accuracy, all measurements were repeated by the same investigator (Gamze Metin-Gürsoy) at an interval of 2 weeks, and the average values of the measurements were used. The intra-examiner correlation coefficients (ICC) were also calculated.

Normal distribution of the data was checked by the Kolmogorov–Smirnov test, because the data did not present a normal distribution, nonparametric tests were used. Wilcoxon signed rank test was used to evaluate the treatment results and Spearman's correlation analysis was performed to evaluate the relationship between palatal morphology and dental movement. The level of significance was set at $P < 0.05$.

Results

The ICC was found to be between 0.895 and 1.000.

In Table 2, descriptive statistics of the distance of teeth to frontal plane and the comparison of the distances between the beginning and end of molar distalization were given. The increase in the distance of the maxillary right and left central incisors to the frontal plane was statistically insignificant. The distance of right and left maxillary first premolars to the frontal plane was increased significantly. On both sides, significant increases were observed between maxillary first and second molars and frontal plane [Table 2].

There is no correlation between the central incisor, first premolar, first and second molar movements [Table 3]. In Table 4, descriptive statistics of palatal morphology and the correlation coefficients between tooth movement and palatal morphology were given. A weak negative correlation was found between the palatal inclination and the movement of the first premolar. Both first and second premolar palatal depth angles and hard palate area did not show any correlation with the movements of teeth [Table 4].

Discussion

One of the traditional approaches for Class II molar correction and space gaining is molar distalization.

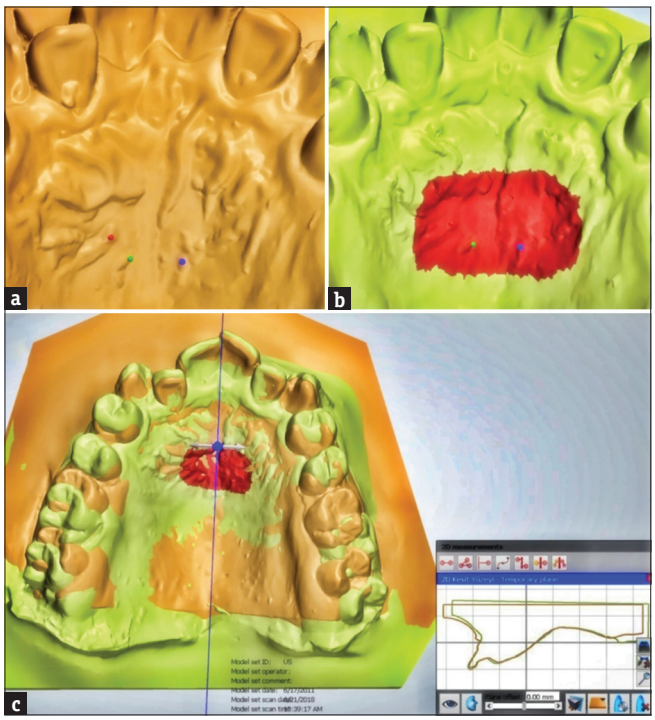


Figure 1: 3D superimposition of before (T0) and at the end of molar distalizations (T1) on digital models (a) selected three reference points on T0 (b) selected area and three reference points on T1, and (c) superimpositions and checking on the two-dimensional sagittal section

Table 1: Teeth movement were defined for left and right side according to frontal plane

	Description of the measuring distance	T1–T0	
1	Between frontal plane and midpoint on the edge of the upper central	(+) protrusion	(–) retrusion
2	Between frontal plane and the buccal cusp tip of the first premolar teeth	(+) mesialization	(–) distalization
3	Between frontal plane and the central fossa of the first molar teeth	(+) mesialization	(–) distalization
4	Between frontal plane and the central fossa of the second molar teeth	(+) mesialization	(–) distalization
	Description of the palatal inclination, hard palate area, and palatal depth angle		
1	Palatal inclination	The angle between the center of the incisive papilla, the midpoint of the left and right second rugae, and the midpoint of the left and right third rugae	
2	Palatal depht angle	The angle between the center of the dento-gingival junctions of right premolar teeth, the deepest point of the palatal vault on the midpalatal raphe at the level of the right and left premolar teeth, and the center of the dento-gingival junctions of left premolar teeth	
3	Hard palate area	The area of the level of dento-gingival junction of premolar teeth between the lowest point of incisive papilla at the anterior border and the center of the dento-gingival junction of the second premolar at the posterior border	

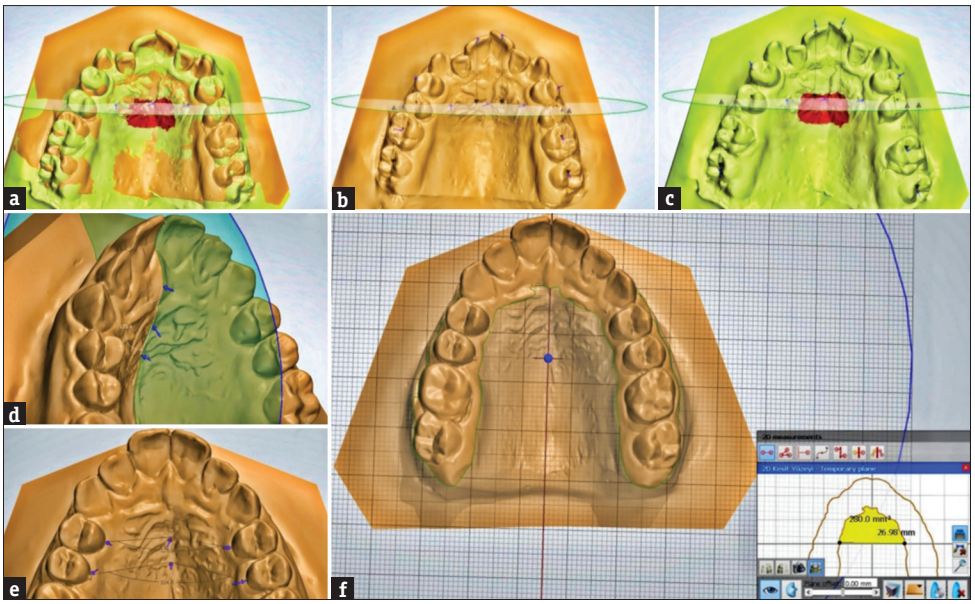


Figure 2: Constructed frontal plane to determine the distalization or mesialization amounts of the central incisors, first premolars, and first and second molars (a) superimposed models (b) digital model of T0 (c) digital model of T1 (d) palatal inclination on T0 digital model (e) palatal depth angles on T0 digital model, and (f) Calculation of the hard palate area

Table 2: Distance (mm) to frontal plane at T0 and T1

Parameter		T0 Mean±SD (*n*=20)	T1 Mean±SD (*n*=20)	T1–T0 Mean±SD (*n*=20)	Wilcoxon test *P*
Central incisor	Right	17.64±3.13	17.77±3.02	0.13±0.35	0.122
	Left	18.02±2.84	18.22±2.65	0.2±0.4	0.58
First premolar	Right	3.4±1.46	4.6±1.54	1.19±0.89	0.000*
	Left	3.18±1.52	4.72±1.9	1.54±1.19	0.000*
First molar	Right	12.62±1.92	17.24±2.57	4.93±2.25	0.000*
	Left	12.62±1.92	16.76±2.58	4.13±1.83	0.000*
Second molar	Right	22.88±2.13	27.36±2.78	4.47±1.68	0.000*
	Left	22.81±2.36	26.66±3.09	3.85±1.8	0.000*

*$P \leq 0.05$

Table 3: Correlation analysis between first molar distalization and second molar, first premolar, and central incisor movement

Spearman's correlation analysis	Left incisor		Left first premolar		Left first molar		Left second molar	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Left incisor			0.339	0.143	–0.291	0.213	–0.047	0.845
Left first premolar	0.339	0.143			–0.012	0.961	0.073	0.759
Left first molar	–0.291	0.213	–0.012	0.961			0.818	0.00*
Left second molar	–0.047	0.845	0.073	0.759	0.818	0.00*		
Spearman's correlation analysis	**Right incisor**		**Right first premolar**		**Right first molar**		**Right second molar**	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Right incisor			0.170	0.473	0.087	0.716	–0.435	0.056
Right first premolar	0.170	0.473			0.245	0.298	0.149	0.531
Right first molar	0.087	0.716	0.245	0.298			0.732	0.00*
Right second molar	–0.435	0.056	0.149	0.531	0.732	0.00*		

*$P \leq 0.05$

Nowadays miniscrews are popular devices providing effective anchorage for molar distalization. However, due to the difficulties of their placement, conventional anchorage devices such as Nance appliance which is placed in the palatal rugae area are still used.[28,29]

Table 4: Descriptive statistics of palatal morphology and correlation analysis between palatal morphology and teeth movement

Spearman's correlation analysis	Mean±SD	Right central incisor		Left central incisor		Right first premolar		Left first premolar		Right first molar		Left first molar	
		r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Palatal inclination (°)	169.16±7.57	–0.266	0.257	–0.129	0.589	–0.414	0.045*	–0.621	0.003*	0.027	0.91	0.105	0.659
Palatal depth angle between first premolar (°)	109.33±11.27	0.26	0.915	–0.222	0.347	0.137	0.565	–0.263	0.262	0.087	0.715	0.089	0.71
Palatal depth angle between second premolar (°)	94.17±7.62	–0.268	0.254	–0.07	0.769	0.188	0.427	–0.261	0.266	–0.003	0.99	0.042	0.86
Hard Palate Area (mm^2)	286.54±40.93	0.11	0.645	0.152	0.523	–0.017	0.945	–0.389	0.09	–0.156	0.51	0.039	0.87

*$P \leq 0.05$

Kinzinger *et al*.[17] noted that reciprocal distalization force was transferred along the dental arch via interproximal contacts. With this, the anterior region could be indirectly affected by the reciprocal force of the Nance appliance because of the resilience of the palatal mucosa. Researchers pointed out palatal mucosa thickness and palatal vault morphology should be considered to prevent anchorage loss.[17] In a previous systematic review, the authors suggested that the loss of anchorage occurred more markedly in the incisors than the premolars, which might be related to the inadequate palatal depth.[30] Thus, the purpose of this study was to investigate the effect of palatal inclination, palatal depth, and hard palate area on anchorage reinforcement for intraoral distalization mechanics with the Nance appliance using 3D model analysis.

The tooth movements were generally analyzed in two dimensions on cephalometric radiographs and dental cast photocopies in previous studies.[8,31] Nowadays, coronal movement of all teeth in 3D can be accurately presented and measured.[32] In previous studies, several methods and references have been suggested for 3D maxillary digital models. Landmark-based superimposition and surface-based superimposition were the most commonly used 3D superimposition techniques in the orthodontic field.[21,24,26,32-35] The 3D superimposition technique, which does not have any harmful effects on patients, can be used to evaluate hard palate morphology and tooth movements in a very comfortable and easy way.[21,34] However, as the technology evolves more detailed studies will be needed.

This study investigated the effects of pendulum appliance on anchorage area like many previous studies. However, in this study, the data obtained using new technologies allow a more detailed evaluation of palatal morphology and anchorage control. Jang *et al*.[36] reported that the maxillary dental casts can be reliably superimposed using the medial points of the third rugae and the palatal vault for constructing landmarks for superimposition. On the other hand, this study suggests that the experience of the researcher who makes measurements in 3D evaluations is considered to be very important. If the anatomical details of the evaluated models are obvious and the measurements are carried out by a single researcher, the standardization and repeatability of the measurements will be high. In this study, a single researcher evaluated the models and the high ICC showed the reliability of the measurements.

This study preferred to use three anatomical points on the third rugae for superimposition and the area containing the specified three points that were large enough to ensure the accuracy of the superimposition. For the successful 3D superimposition, palatal mucosa integrity must be preserved at T1 digital models. Unfortunately, eight patients were excluded from this study for palatal mucosa integrity was damaged because of Nance appliances.

Many studies have been reported the stability of the palatal rugae as reference points for pre- and post-treatment dental comparisons on digital models.[26,32] Although the change of the palatal rugae has been shown in long-lasting cephalometric studies with growing patients, medial rugae points, especially on third rugae, have been suggested as reliable anatomic points without being affected by orthodontic treatment type. The stability of the first and second rugae was found to be less reliable because they were affected by orthodontic treatment.[37,38] In this study, the third rugae was used for superimpositions.

In this study, the growth potentials were not taken into consideration because of the chronological ages of patients (15.1 ± 2.6 years) and the short duration of the molar distalization (6.2 ± 1.5 months). Therefore, no significant growth was expected because of the short duration of the treatment and using palatal rugaes as reference was suggested to be reliable.

In this study, the frontal plane was used to measure the anteroposterior displacement of the maxillary central incisors, first premolars, and first and second molars. The frontal plane was constructed on superimposed

digital models and reflected in both T0 and T1 models automatically. The difference between the distances between T0 and T1 models gave the distalization and mesialization values.

Jang *et al*.[36] used the midpoints of the central incisor edge for measuring the displacement of the central incisor by the ruga-palate-superimposition method and the miniscrew-superimposition method. Researcher claimed that there is not a difference between two superimposition methods about the displacement of the central incisors.

This result indicates that the midpoint of the incisor edge is suitable as a reliable point in the evaluation of the incisor teeth movement. In this study, the right and left incisor teeth movements were measured at the midpoint of the incisal edge similar to the previous study.[36] The rotational movements and inclinations of the teeth can be measured by the three-dimensional superimposition method. However, these measurements were not evaluated to focus on the main purpose of the study. Also, it should be taken into account that only the crown movements can be evaluated in this method and it is a limitation of the 3D model superimposition.

Most of the cephalometric and dental model analyses demonstrate protrusion and labial tipping of the maxillary incisors after molar distalization with pendulum appliance. As movements of the roots are also evaluated to determine the inclination, labial tipping of the central incisors is a common finding in cephalometric studies.[4,39,40]

In line with a previous study, the amount of protrusion of the incisor teeth in this study (right incisor: 0.13 mm and left incisor: 0.2 mm) was found insignificant.[40] Differences in the amount of the central incisor protrusion can be because of the use of different methods. However, Nalcaci *et al*.[21] showed that there were no significant differences in three analysis techniques between cephalometric, dental model photocopy, and 3D digital model.

During intraoral molar distalization, the mesial movement of premolars has been shown several times in previous studies.[4,39] Occlusal rests are held responsible from the mesial movement of the anchorage teeth. Usually, the occlusal rests are removed from the second premolars at the end of the distalization phase and the premolars are allowed to drift posteriorly.[39] In this retrospective study, the second premolars were not included in the measurements of anchorage loss as the occlusal rests were removed in some cases before taking dental casts during the distalization phase.

In this study, on digital models, mean distalization values for left and right first molar were 4.13 and 4.93 mm, respectively. Anchorage loss in left and right first premolar was found as 1.54 and 1.19 mm, respectively. These values are consistent with previous studies of the pendulum appliance using the Nance appliance for anchoring.[4]

The negative correlation between the right and left first premolar teeth and palatal inclination is the most significant finding of this study. It means that the steeper the anterior region of the maxilla, the more anchorage loss occurs in the premolar teeth. This can be explained by the differences in the distribution of force vectors from the Nance appliance. However, palatal depth variability had no relation with molar distalization or anchorage loss. Although the size of the Nance appliance may vary in proportion to the anterior hard palate area, there is no correlation between the hard palate area and teeth movement in the results of this study. In the light of all these data, it can be interpreted that the anchorage loss as a result of the resilience of the mucosa in the palate with a steep anterior inclination is because of the transfer of reciprocal forces to the teeth. In addition, whether palatal asymmetries are effective in these anchorage losses should be evaluated with new studies.

Therefore, the relationship between the palatal morphology and dental movements was investigated using new technologies. New technologies and analysis might provide significant benefits for new and important information about classical mechanics. 2D or 3D cephalometric radiographs have been used successfully in orthodontic research, but the major disadvantage of the cephalometric analysis is the radiation exposure for patients.[41] Nowadays, the most important issue of orthodontics is to reduce or not be exposed to radiation in growing orthodontic patients.

One of the limitations of this study was the lack of similar studies to compare or discuss the results related to palatal morphology using 3D superimposition methods.

Conclusion

The palatal depth and hard palate area showed no relationship with loss of anchorage, although the palatal inclination had a negative correlation with the first premolar teeth during intraoral molar distalization performed with the Nance device. Therefore, when palatal inclination decreases, it could be recommended to use additional anchor-enhancing mechanics.

Authors contributions

Gamze Metin-Gürsoy collected the data, contributed to data measurement and the statistical analysis, and

writing the article. Tuba Tortop contributed to reviewing the literature and critical revision of the article and supervised the study.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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