

# Validation of three-dimensional digital model superimpositions based on palatal structures in patients with maximum anterior tooth retraction following premolar extraction

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**Objective:** This study aimed to evaluate the superimposition accuracy of digital modes for measuring tooth movement in patients requiring anterior retraction after premolar extraction based on the proposed reference regions. **Methods:** Forty patients treated with bilateral maxillary first premolar extraction were divided into two groups: moderate retraction (< 7.0 mm) and maximum retraction ( $\geq$  7.0 mm). Central incisor displacement was measured using cephalometric superimpositions and three-dimensional (3D) digital superimpositions with the 3rd or 4th ruga as the reference point. The Wilcoxon signed-rank test and linear regression analyses were performed to test the significance of the differences and relationships between the two measurement techniques. **Results:** In the moderate retraction group, the central incisor anteroposterior displacement values did not differ significantly between 3D digital and cephalometric superimpositions. However, in the maximum-retraction group, significant differences were observed between the anteroposterior displacement evaluated by the 3rd ruga superimposition and cephalometric methods ( $p < 0.05$ ). **Conclusions:** This study demonstrated that 3D digital superimpositions were clinically as reliable as cephalometric superimpositions in assessing tooth movements in patients requiring moderate retraction. However, the reference point should be carefully examined in patients who require maximum retraction.

**Key words:** Digital models, Cephalometrics, Dental cast analysis, Palatal ruga

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## INTRODUCTION

Dental casts play an important role in occlusion analysis and treatment planning in orthodontics. Digital casts have rapidly replaced conventional casts due to storage problems and difficulties in accessing data. The accuracy of digital models and the reliability of the model analysis have been proven in previous studies.<sup>1-3</sup> The recent development of three-dimensional (3D) diagnostic orthodontic programs has enabled the use of 3D digital models for the diagnosis, treatment planning,<sup>4</sup> design, and fabrication of orthodontic appliances.<sup>5</sup> Moreover, treatment outcomes can be quantitatively evaluated by superimposing pre- and post-treatment 3D models.<sup>6-10</sup>

Studies have described several options for superimposing digital models, which can be classified into landmark-based or surface-based types.<sup>11</sup> The accuracy and precision of these methods were assessed by using stable miniscrews. However, it was not possible to retain the miniscrews implanted for evaluation throughout the treatment in all patients. Therefore, an area of high anatomical stability through which tooth movement occurs should be identified. Accordingly, the palatal rugae, palatal vault, or a combination thereof have been suggested as reference points for digital 3D model superimposition, since the palatal rugae were used for personal identification several years ago and showed adequate reliability.<sup>12-14</sup> These structures were assumed to be stable during orthodontic treatment. However, the evidence supporting this hypothesis, especially in cases involving both tooth extraction and maximum retraction, is insufficient.

The possible amount of incisal retraction following extraction has increased owing to recent developments in the field of orthodontic mini-implants. Therefore, in extraction cases involving substantial tooth movement, the palatal rugae close to the anterior teeth can be deformed by tooth movement.<sup>15-18</sup> To eliminate this effect, posterior structures, such as the 3rd ruga and dorsal area, were recommended as reference regions for model superimposition. However, the accuracy of model superimposition using the 3rd palatal ruga needs to be investigated, particularly in patients requiring maximum retraction.

This study investigated models of patients who required maxillary anterior tooth retraction following extraction of the maxillary first premolars. Patients were categorized into moderate and maximum retraction groups, and the accuracy of digital model superimpositions performed using the palatal rugae as the reference point was evaluated in both groups. The displacement was measured using cephalometric superimposition and the proposed 3D digital superimposition method. Our null hypothesis was that there would be no difference in

central incisor displacement between the two groups.

## MATERIALS AND METHODS

This study followed the guidelines of the Declaration of Helsinki and was approved by the Institutional Review Board of Yonsei University Dental Hospital (2-2021-0033).

### Participants

Forty patients who visited Yonsei University Dental Hospital between 2009 and 2016 were selected. Nine patients were male and 31 were female, with a mean age of 21.4 years. The inclusion criteria were as follows: patients whose pre-treatment and post-treatment digital models and radiographs were available; no obvious air bubbles on the tooth and palatal surfaces of the dental casts; extraction of first premolars; age of at least 17 years with an erupted permanent dentition; absence of maxillofacial deformities, congenital maxillary tooth anomalies, or impacted teeth; dental crowding of less than 4 mm; patients who did not require orthognathic surgery or large-scale dental or palatal expansion; and no history of orthodontic treatment.

The amount of central incisor retraction was measured on lateral cephalometric radiographs, and 7 mm was detected as the bisecting line; thus, the subjects were divided into two groups. Sample size calculation was performed according to a previous study.<sup>12</sup> Finally, 20 participants with retractions less than 7 mm were assigned to the moderate-retraction group, while the remaining 20 participants with retractions of 7 mm or more were assigned to the maximum-retraction group. All patients had maxillary miniscrews inserted to perform retraction in the maximum-extraction group, and additional anchorage appliances were applied only if necessary in the moderate-retraction group.

### Measurements

The number and types of right and left palatal rugae were investigated according to the classification and distribution of palatal rugae used in a previous study.<sup>15</sup>

### *Lateral cephalometric radiographs superimposition*

Pre- and post-treatment lateral cephalometric radiographs were traced using a conventional transparent acetate paper. During pretreatment tracing, the line passing through the maxillary central incisal tip and the mesiobuccal cusp tip of the 1st molar was considered to be the occlusal plane and defined as the X-axis, and the line perpendicular to the occlusal plane that passed through the sella (S) was defined as the Y-axis.

Pre- and post-treatment lateral cephalometric radiographs were superimposed along the palatal plane,

which was registered at the anterior nasal spine according to the method proposed by Ricketts<sup>19</sup> (Figure 1). Changes in the position of the most prominent upper maxillary central incisor tip were measured along the X- and Y-axes.

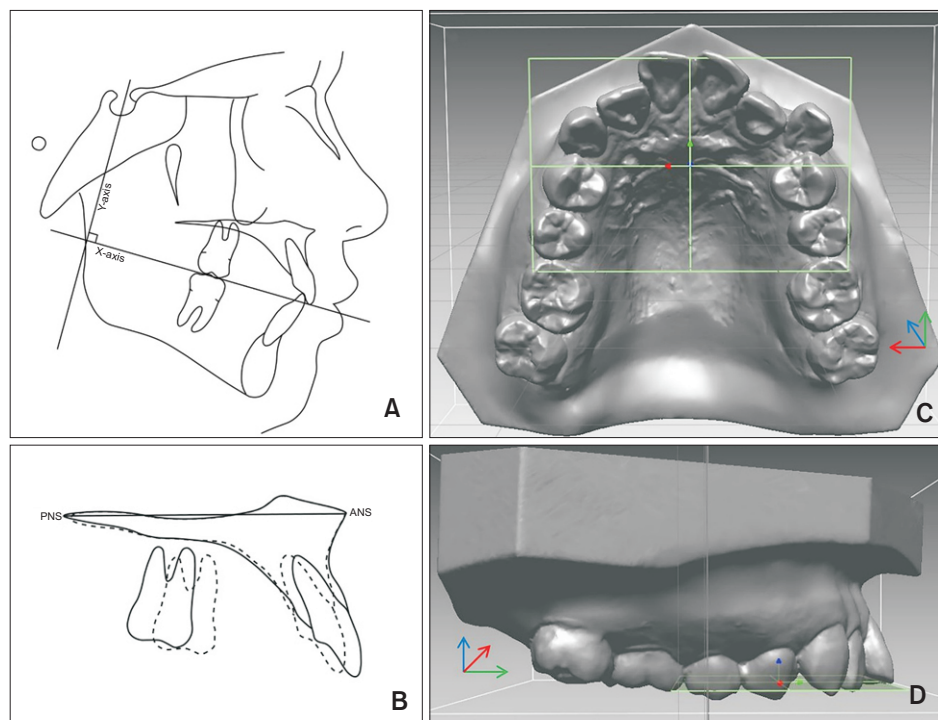
#### Digital model superimposition

Pre- and post-treatment plaster models of enrolled patients that were produced from alginate impressions were collected, and digital model images were obtained using an Orapix 3D scanner (Orapix Co., Ltd., Seoul, Korea). Reference planes were defined in the same manner for both digital models and lateral cephalometric radiographs. In the pretreatment model, the occlusal plane, which passes through the tip of the central incisor and the mesiobuccal cusp tips of the maxillary first molars, was considered to lie perpendicular to the midpalatal raphe. In this plane, the X-axis was considered to run in the anteroposterior direction, Y-axis was considered to run in the vertical direction, and Z-axis was considered to run in the transverse direction. Positive values on the

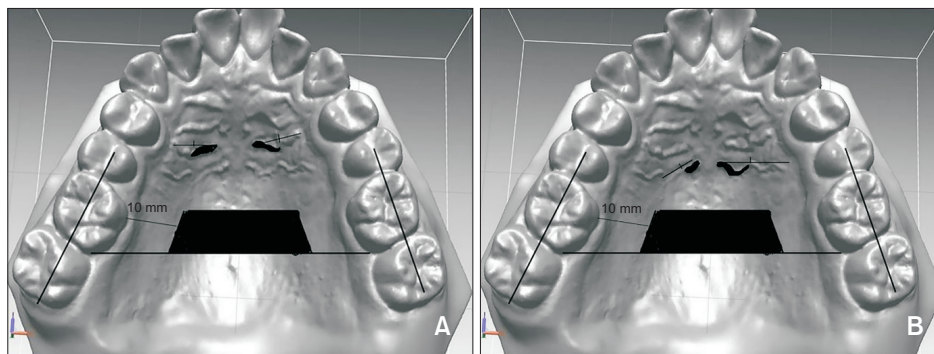
X- and Y-axes corresponded to posterior and extrusion movements, respectively (Figure 2).

Rugae classification was performed before superimposition according to the method described in a previous paper.<sup>15,20</sup> Ruga without specific instructions refers to primary ruga in this study, which is the basic type and has high prominence. This type of ruga is at least 5 mm in length. The secondary ruga was 3–5 mm in length and less prominent than the primary ruga. Fragmentary ruga, whose length was between 2 and 3 mm, was not applied in the digital model superimposition.

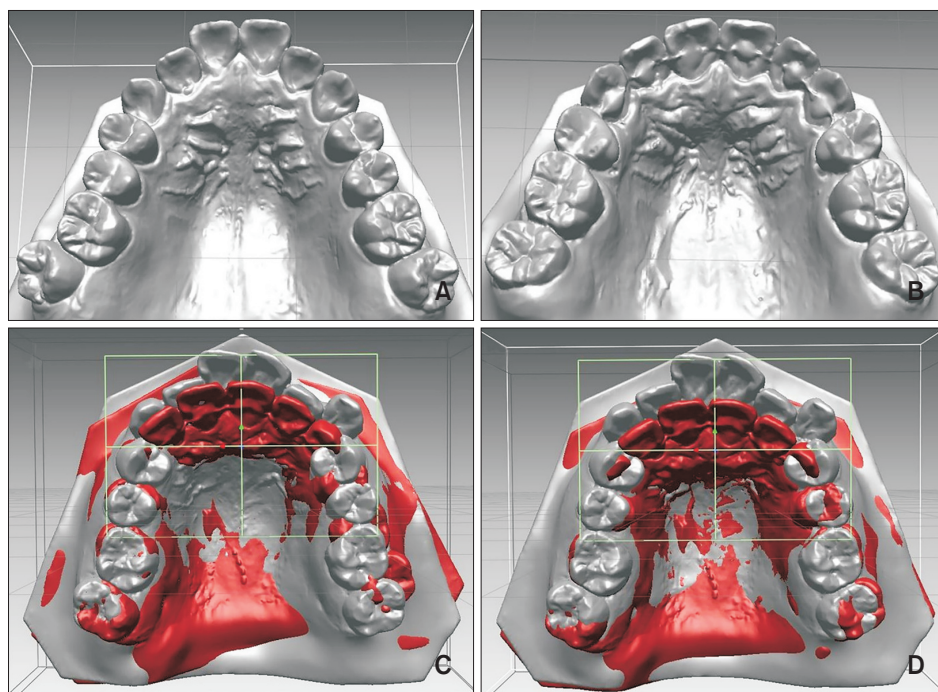
Two superimposition methods are used. The 3rd palatal ruga was superimposed using the medial half of the total length of the 3rd palatal ruga and palatal vault as reference areas. The 4th palatal ruga was superimposed using the medial half of the total length of the 4th palatal ruga and posterior palatal vault as reference areas (Figure 2). The anterior boundary of the reference palatal vault area was considered as the line connecting the interdental contact points between the 2nd premolar and 1st molar on either side, and the posterior boundary



**Figure 1.** Reference co-ordinate system for measuring the amount of tooth movements. **A** and **B**, Reference co-ordinate system for cephalometric superimposition. **A**, X-axis: a line through the maxillary central incisor tip and the mesio-buccal cusp tip of the first maxillary molar on the initial cephalogram. Y-axis: plane perpendicular to X-axis through Sella. **B**, Superimposition of the maxilla along the palatal plane registered at anterior nasal spine (ANS). **C** and **D**, Reference co-ordination system for three-dimensional digital superimposition. The green box is the occlusion plane perpendicular to midpalatal raphe, which passes through tip of the central incisor and mesio-buccal cusp tip of the first maxillary molars. The green, blue, and red arrows indicate the X, Y, and Z axes, respectively. **C**, Occlusal view. **D**, Sagittal view. PNS, posterior nasal spine.



**Figure 2.** Definition of landmarks for the superimposition of three-dimensional digital model. **A**, Superimposition using third ruga: medial 1/2 of third ruga and the following regional palatal vault. **B**, Superimposition using fourth ruga: medial 1/2 of fourth ruga and the following regional palatal vault. Palatal vault region, Anterior border line - the line connecting the interdental contact points between the 2nd premolar and 1st molar on either side. Posterior border line - the line connecting the interdental contact points between the 1st and 2nd molars on either side. Lateral border line - the anteroposterior lines are 10 mm away from the lines in contact with the palatal gingival margins of the posterior teeth and parallel to occlusal line through central groove of the posterior teeth bilaterally.



**Figure 3.** In maximum retraction case, change of the ruga and digital superimposition. **A**, Pre-treatment. **B**, Post-treatment. **C** and **D**, Tooth movement of superimposed three-dimensional models in the maximum retraction case. **C**, Superimposition using the third ruga. **D**, Superimposition using the fourth ruga.

was considered as the line connecting the interdental contact points between the 1st and 2nd molars on either side. The lateral boundaries were defined as follows: the anteroposterior lines were located 10 mm away from the lines in contact with the palatal gingival margins of the posterior teeth and parallel to the occlusal line passing through the central groove of the posterior teeth on both sides. The 1st secondary ruga, located posterior to the 3rd primary ruga, was used as the reference area in patients in whom the 4th primary palatal rugae were

absent. Maxillary incisor tip displacement was measured along the X- and Y-axes using the 3rd and 4th palatal rugae superimposition models in both groups (Figure 3). Changes in the position of the maxillary central incisor along the z-axis were excluded from the results.

#### *Comparative analysis of tooth movement measured with the digital model and lateral cephalometric radiograph superimpositions*

Maxillary central incisor displacements along the X-

and Y-axes were investigated in each group using the two superimposition methods. The results were compared with their corresponding movements measured on lateral cephalometric radiographs, and differences were recorded as  $\Delta$  in absolute values and analyzed.

The same measurements were repeated after two weeks on 10 models randomly chosen by the same investigator, and the intraclass correlations between the first and second superimposition trials were calculated.

### Statistical analysis

All statistical analyses were performed using the SPSS software (version 25.0; IBM Corp., Armonk, NY, USA). The movement values of the incisors along the X- and Y-axes were measured using cephalometric radiographs and superimposed digital 3D models, and the differences between the measurements were compared. Paired *t*-test or Wilcoxon signed-rank test was performed depending on the Shapiro–Wilk test results. A simple linear regression analysis was performed to test the correlation between the two measurement techniques. Statistical significance was set at  $p < 0.05$ .

## RESULTS

The intraclass correlation coefficients were 0.98 and 0.97 for cephalometric measurement along the X-axis and Y-axis, respectively. Moreover, the intraclass correlation of the 3rd ruga superimposition measurements were 0.99 and 0.91 along X-axis and Y-axis, and 0.99 and 0.98

for the 4th ruga superimposition, respectively.

Shapiro–Wilk’s test showed that the measurement values in all groups were not normally distributed; thus, the Wilcoxon signed-rank test was performed.

In the moderate-retraction group, the Wilcoxon test found no significant differences between the upper incisor movements along the X- and Y-axes measured using cephalometric superimpositions and digital model superimpositions using the 3rd palatal ruga ( $p > 0.05$ ). No significant difference was observed in the movements along the X-axis between the 4th ruga superimpositions and cephalometric superimpositions; however, significant differences were observed in movements along the Y-axis (Table 1).

In the maximum-retraction group, a significant difference was observed between the lateral cephalometric radiographs and 3rd ruga digital model superimpositions for maxillary central incisor movement along the X-axis ( $p < 0.05$ ). The displacements measured according to the 4th ruga digital model superimpositions were not different when compared with those of the cephalometric superimpositions. No statistically significant differences were observed between superimposition methods in movement along the Y-axis using either method. The 3rd palatal ruga superimpositions showed a significantly larger difference along the X- and Y-axes compared to the 4th palatal ruga superimpositions ( $p < 0.05$ ) (Table 1).

Figure 4 shows the linear regression models generated for the cephalometric and digital model superimpositions. In the moderate-retraction group, comparisons of

**Table 1.** The displacement of the central incisor was measured according to cephalometric superimposition and 3D digital superimposition (Unit: mm)

Variables	X-ray superimposition		3D digital superimposition				$\Delta$ Ceph-3rd ruga digital		$\Delta$ Ceph-4th ruga digital	
	Ceph		3rd ruga digital		4th ruga digital		3rd ruga digital		4th ruga digital	
	Median (25%, 75%)	Median (25%, 75%)	Median (25%, 75%)	<i>p</i> -value <sup>†</sup>	Median (25%, 75%)	<i>p</i> -value <sup>‡</sup>	Median (25%, 75%)	<i>p</i> -value <sup>§</sup>	Median (25%, 75%)	<i>p</i> -value <sup>§</sup>
Moderate retraction group										
Xd	3.86 (2.84, 4.95)	3.70 (3.05, 5.00)	0.18		4.10 (2.65, 4.98)	0.54	0.24 (0.12, 0.27)		0.16 (0.10, 0.43)	0.53
Yd	1.00 (0.52, 1.57)	0.90 (0.51, 1.60)	0.70		0.95 (0.43, 1.38)	0.02*	0.08 (0.02, 0.20)		0.14 (0.05, 0.32)	0.08
Maximum retraction group										
Xd	8.18 (7.24, 9.43)	7.45 (6.43, 8.78)	0.02*		7.85 (6.93, 9.30)	0.06	0.50 (0.17, 1.00)		0.14 (0.08, 0.27)	0.001*
Yd	1.64 (0.78, 2.16)	1.50 (0.33, 2.75)	0.43		1.40 (0.58, 2.30)	0.15	0.33 (0.16, 0.60)		0.17 (0.05, 0.33)	0.01*

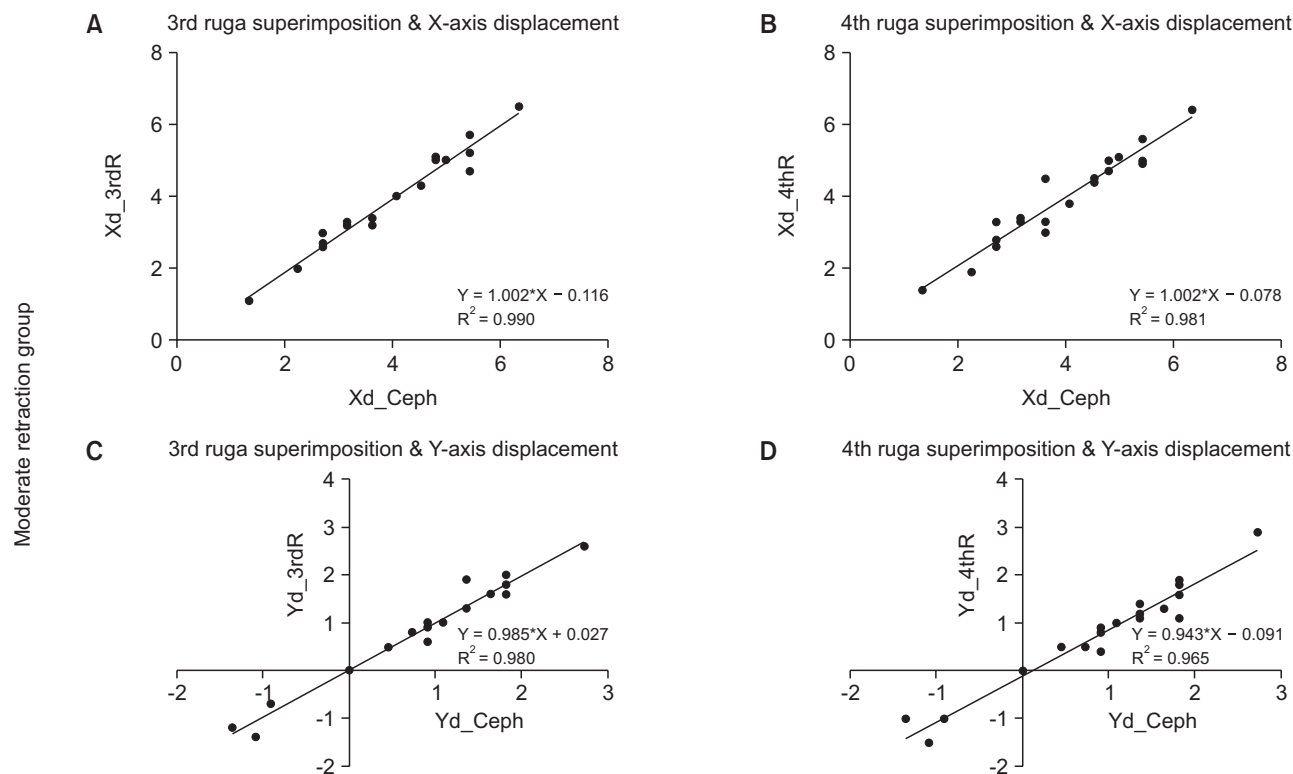
$\Delta$ Ceph-3rd ruga digital, difference in tooth movement between the lateral cephalometric radiographs and the 3rd palatal ruga superimposition;  $\Delta$ Ceph-4th ruga digital, difference in tooth movement between lateral cephalometric radiographs and the 4th palatal ruga superimposition; 3D, three-dimensional; Xd, horizontal movements of central incisor; Yd, vertical movements of central incisor.

\* $p < 0.05$ .

<sup>†</sup>Significance between cephalometric superimposition and 3D superimposition using 3rd ruga.

<sup>‡</sup>Significance between cephalometric superimposition and 3D superimposition using 4th ruga.

<sup>§</sup>Significance between  $\Delta$ Ceph-3rd ruga digital and  $\Delta$ Ceph-4th ruga digital.



**Figure 4.** Scattergrams and regression lines for the central incisor movements measured on the cephalogram and three-dimensional digital model. **A, B, C** and **D**, in the moderate retraction group. **E, F, G** and **H**, in the maximum retraction group. **A** and **E**, Horizontal movements of central incisor (Xd). X-axis: cephalometric superimposition (Xd\_cep); Y-axis: 3rd ruga digital superimposition (Xd\_3rdR); **B** and **F**, Horizontal movements of central incisor. X-axis: cephalometric superimposition; Y-axis: 4th ruga digital superimposition (Xd\_4thR); **C** and **G**, vertical movements of central incisor (Yd). X-axis: cephalometric superimposition; Y-axis: 3rd ruga digital superimposition (Yd\_3rdR); **D** and **H**, vertical movements of central incisor. X-axis: cephalometric superimposition; Y-axis: 4th ruga digital superimposition (Yd\_4thR).

the regression lines for the central incisor movements observed on the lateral cephalometric radiographs with the superimpositions of the 3rd and 4th palatal rugae showed that adequate correlational coefficients were obtained while measuring the superimpositions ( $R^2 > 0.92$ ). In the maximum-retraction group, the regression lines of the lateral cephalometric radiographs and digital model superimpositions revealed that the  $R^2$  values for central incisor movements along the X-axis were 0.65 and 0.98 for the 3rd and 4th palatal ruga superimpositions, respectively, demonstrating a relatively stronger correlation in the latter method (Figure 4).

## DISCUSSION

The digital 3D model itself has advantages, such as real-size information and risk- and cost-free transfer, when compared with 2D images. Superimposed digital 3D dental models provide a more convenient medium for measuring the tilt, rotation, and angulation of the

anterior teeth and molars, which are difficult to observe on conventional cephalometric radiographs or plaster casts. Moreover, these evaluations aid in the evaluation of treatment progression using dental models alone, thus preventing unnecessary exposure to radiation during monitoring.

The selection of stable reference structures is a challenge associated with digital model superimpositions, and none of the anatomical landmarks has been designated as the gold standard. Recent studies have suggested the 3rd rugae to be the reference region for digital superimposition, and its reliability has been evaluated using relatively stable miniscrews and fused images of cephalometric tracing and digital models<sup>12,21,22</sup>; however, concomitant palatal ruga alterations due to tooth movement have been reported by several studies.<sup>21,23,24</sup> The lateral end of the palatal rugae tended to move due to tooth movement in patients who underwent first pre-molar extraction.<sup>25</sup>

A previous study investigated the morphological fea-

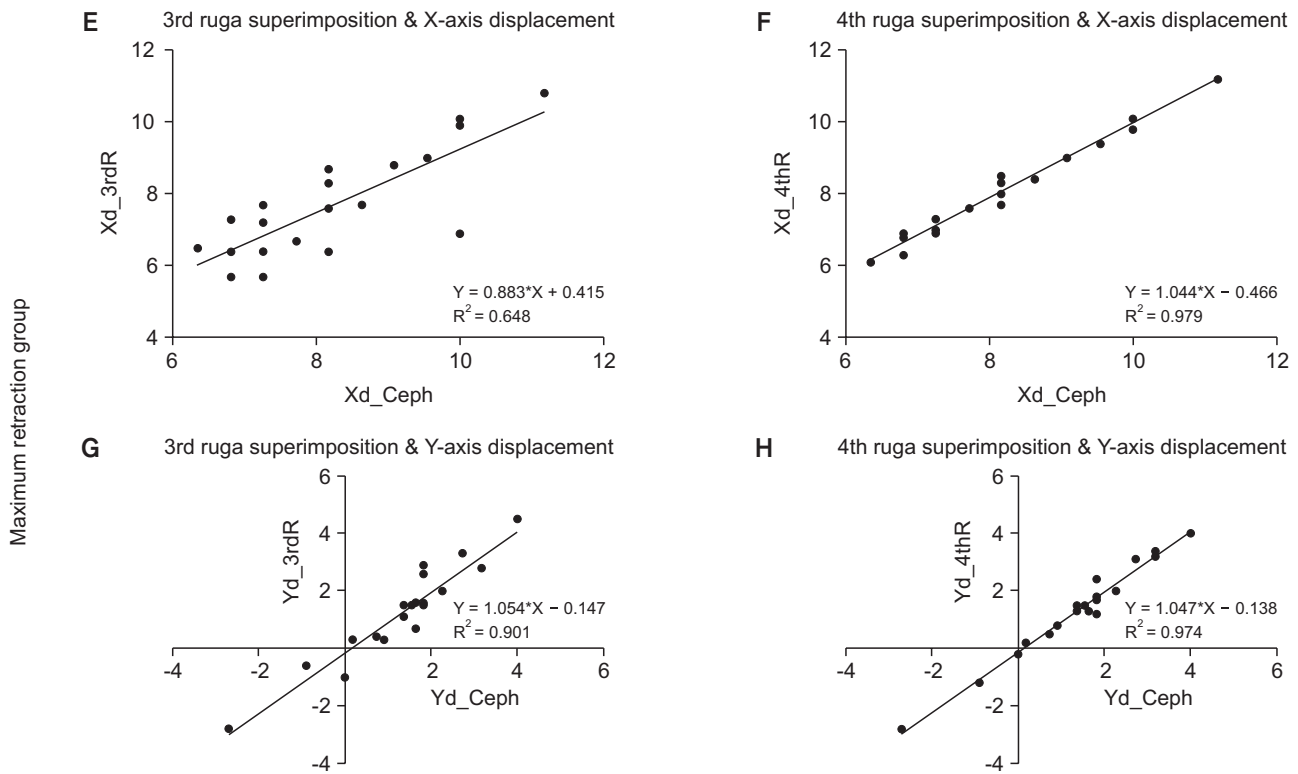


Figure 4. Continued.

tures of the palatal rugae in South Korean patients and found that 43.5% of the patients had three primary palatal rugae, while 36.1% had four.<sup>15</sup> Moreover, the number of rugae may influence the position of the 3rd primary palatal rugae. When an additional ruga is present posterior to the 3rd primary palatal ruga, the 3rd ruga tends to be located more anteriorly than in patients without an additional ruga.<sup>15</sup> If the 3rd palatal ruga is located anteriorly, its position is more likely to change owing to orthodontic tooth movement, similar to the first two rugae. In such cases, it is unwise to use a 3rd ruga as a reference point. Accordingly, this issue should be considered when determining whether the 3rd palatal ruga should be used as a reference point for digital model superimpositions.

In this study, the medial half of the 3rd or 4th palatal ruga and posterior palatal vault were used as reference areas for digital model superimpositions. Compared to the lateral ends of the rugae, the medial half of the rugae is more resistant to tooth movement. However, an increase in the posterior movement of the anterior teeth could result in displacement of the 3rd palatal ruga. Thus, digital model superimpositions that use the 4th palatal ruga as a reference point were included in this study. In patients without a 4th primary palatal ruga, a secondary ruga posterior to the 3rd primary palatal ruga

was used as the reference point. Fragmentary palatal rugae were not used as reference points since thinner and less pronounced rugae are more likely to be displaced owing to tooth movement.<sup>25</sup>

In addition to the palatal rugae, the palatal vault and mushroom-shaped palatal area were used as reference points.<sup>26,27</sup> However, using the palatal vault as the only reference is impractical since this area has insufficient shape characteristics, which can cause rotation errors during superimposition. The posterior limit of the palatal vault in our study was defined more anteriorly than that in a previous study<sup>21</sup> to address the concern that the thick, soft tissue covering the hard palate posterior to the 1st molar may result in deformations during impression acquisition.

The assessment of the efficacy of the digital model superimpositions in the moderate-retraction group revealed no statistically significant differences between the superimpositions obtained with either the 3rd or 4th palatal ruga and lateral cephalometric radiograph superimpositions; however, there were minor differences in the Y-axis between the above-mentioned measurement methods when the 3rd ruga was used (Figure 2). In other words, 3D superimposition methods are valuable for evaluating horizontal tooth movement in patients requiring moderate retraction.

Conversely, in the maximum-retraction group, the 3rd ruga superimposition method did not achieve a reliable outcome when compared with the lateral cephalometric method, while the 4th ruga method showed acceptable performance. The median of the difference was significantly higher in the digital superimpositions that used the 3rd palatal ruga (0.5 mm) than in those that used the 4th palatal ruga (0.1 mm;  $p < 0.05$ ). Digital superimpositions yielded lower anteroposterior tooth movement values compared to radiographic superimpositions, possibly due to anterior tooth retraction, which resulted in posterior movement of the medial portion of the 3rd palatal ruga. Therefore, the anterior tooth movement was underestimated when the medial portion of the 3rd palatal ruga was used as a reference point. Accordingly, using the 3rd palatal ruga as a reference point in patients requiring maximum retraction could diminish the accuracy of the 3D model superimposition. In such cases, the palatal rugae posterior to the 2nd premolar, such as the 4th palatal ruga or secondary ruga, should be used as references.

Data on anterior tooth movement obtained from cephalometric radiographs and 3D superimpositions were examined using linear regression analysis, which revealed that the  $R^2$  values of the X-axis movements measured using the 3rd and 4th palatal ruga superimpositions were 0.648 and 0.979, respectively, in the maximum-retraction group. These results indicate that a greater degree of linearity was observed when superimpositions were performed with the 4th palatal ruga, which may be attributed to the fact that this ruga was less affected by tooth movement. Moreover, when we analyze the 4th palatal ruga only in both superimpositions, all  $R^2$  values were higher than 0.96, indicating a better correlation with cephalometric superimpositions.

Most previous studies on rugae displacements or superimpositions focused on the first three rugae and demonstrated that the 3rd ruga and mesial half were more reliable due to their 'locational advantage' as they are located farther away from the displaced teeth.<sup>21,28</sup> Several researchers have attempted to discover more accurate superimpositions, and some have developed weighted ruga superimpositions that combine the pairs of the first to third rugae under certain rules.<sup>28</sup> According to the results of this study, the 4th ruga is a potentially important reference region for standard or weighted superimpositions.

In this study, cephalometric radiograph superimpositions measuring central incisor movements were used to verify the efficacy of the 3D superimposition. It has been known that the cephalometric radiograph has its inherent limitations, such as single sagittal view, distortion, blurring, and anatomic structure overlap, and an absolute standard is required to assess 3D digital model

superimposition accuracy. If three or more orthodontic mini-implants are inserted and used as reference points, superimpositions would be more accurate.<sup>12,21</sup> However, orthodontic mini-implants were not used in this study due to ethical issues. Additionally, this study was limited by potential errors arising from dimensional changes in the impression material and thermal expansion of the dental cast, in addition to human error. Therefore, a complete intraoral scanning should be performed in future studies. During growth, the height and width of the alveoli increase, and the direction or shape of the palatal rugae can change; however, there is no consensus yet on whether these changes exist.<sup>13,29,30</sup> Thus, the study findings apply to non-growing patients and should be confirmed in a growing patient sample.

## CONCLUSIONS

In conclusion, in the moderate-retraction group, there was no significant difference between the anteroposterior central incisor displacements measured using the 3rd or 4th ruga method and cephalometric superimpositions. In the maximum-retraction group, incisor anteroposterior movements measured by the 3rd palatal ruga superimpositions were significantly different from those measured by the cephalometric method, while the 4th ruga method had a median difference of 0.14 mm.

In patients requiring moderate anterior tooth retraction, the 3D superimpositions proposed were as effective as lateral cephalometric radiographs. If the anterior teeth retractions are large, the palatal rugae located posterior to the 3rd ruga should be selected as reference points to improve the superimposition accuracy.

## CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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## SUPPLEMENTAL VIDEO

A video presentation of this article is available at [www.e-kjo.org](http://www.e-kjo.org).



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