Assessment of 3D superimposition of digital model in extraction case based on morphological study of palatal rugae

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Table of contests

List of table

List of figure

ABSTRACT

Assessment of 3D superimposition of digital model in extraction case based on morphological study of palatal rugae

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This study was composed of two experiments. The purposes of the two investigations were (1) to analyze the morphological characteristic of palatal ruga as landmarks for superimposition of dental casts and (2) to evaluate the accuracy of digital superimposition in the moderate and maximum retraction group

343 patients (114 males, 299 females, mean age 25.6 years) who had digital model were chosen to analyze the number and distribution of palatal ruga as well as the position of the third primary ruga. 40 participants(9 males, 31 females, mean age 21.4 years) treated with extraction of bilateral maxillary first premolars were divided into two groups, a moderate retraction group (<7 mm) and a maximum retraction group (≥7.0 mm), based on the amount of maxillary incisor. Displacement of the central incisors was measured by the cephalometric superimposition and the pro-posed superimposition technique (third ruga-palate-

superimposition method, forth ruga-palate-superimposition) in two groups. Paired t-test and correlation analysis were performed to determine whether a significant difference exist between the two measuring techniques. We acquired following conclusions.

1. Approximately 43.5% have three primary palatal rugae, and 36.1% have four.
2. When there is an additional primary or secondary ruga posterior to the 3rdprimary palatal ruga, the anterior and posterior limits of the 3rdprimary palatal ruga are located more anteriorly compared to those in the individuals without an additional posterior ruga ($P< 0.05$).
3. In the moderate retraction group, the displacement of the central incisors measured using the third and forth ruga-palate-superimposition and that measured with cephalometric super imposition did not show much difference, while the maximum retraction group had significantly different results depending on the two methods.($P<0.05$)
4. In the maximum retraction group, the mean difference in tooth movement along the X-axis between the lateral cephalometric radiographs and the 3rd palatal ruga superimposition was 0.7 mm, and that with the 4th palatal ruga superimposition was 0.2 mm, with the 3rd palatal ruga superimposition showing a significantly larger difference ($P< 0.05$).

Based on the above results, it may be concluded that the number of the palatal rugae vary greatly among the population, and that this number affects the anteroposterior position of the 3rdprimary palatal ruga. When assessing the tooth movements in the patients with a moderate retraction, the 3D superimposition methods proposed in this study may be clinically accurate and reliable as cephalometric superimposition for assessing orthodontic tooth

movement in extraction case. However, when the amount of the incisor movement was over the 7mm, the 3^{rd} palatal ruga superimposition method was imprecise. In such cases, the superimposition should be performed using the palatal rugae located posterior to the 2^{nd} premolar as the reference points, taking into account the number and position of the rugae in each patient.

key words: palatal ruga, digital superimposition, incisor retraction, cephalometric superimposition

Assessment of 3D superimposition of digital model in extraction case based on morphological study of palatal rugae

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I. INTRODUCTION

In orthodontics, dental casts play an important role in the analysis of occlusions and the establishment of treatment plans. Dental casts can be used to obtain information about the number of teeth, the size, deformities, tooth rotation, arrangement, symmetry of the dental arches, shape of the palate, and frenum position. They can also be used to ascertain the relationship between the maxillary and mandibular teeth, consistency of the midline, and angulation of the tooth .

In recent dental practice, the conventional dental casts are being rapidly replaced by the digital models in order to improve storage and data accessibility. A three-dimensional (3D) digital model can be obtained by scanning the oral cavity directly using laser beams, or by scanning a dental cast. Previous studies have compared the digital models and conventional dental casts for their accuracy in measuring linear distances,[1-5] such as the width,[6] height,[3] overjet and overbite,[7, 8] and intermolar and intercanine width of the teeth ;[8, 9] the results of the digital model measurements have been found to be almost identical to those of the conventional dental casts.[5, 10]

The development of 3D diagnostic programs in Orthodontics has enabled the application of the 3D digital models in diagnosis and treatment planning[11] as well as the design and manufacture of orthodontic devices using digital models.[12-14] Invisalign® (Align Technology, Santa Clara, California) uses digital dental models to manufacture sets of transparent, removable orthodontic devices customized to fit an individual's teeth. Insignia® (Ormco, Orange, California) manufactures digital customized brackets with the appropriate thickness and angle measurement for each patient's teeth by the analysis of a digital model.[15] Incognito® (3M-Unitek, Monrovia, California) utilizes a bending art system (BAS), in which a robot arm is used to manufacture the orthodontic wire by employing digital models and a virtual alignment function.[16] The 3D digital models are also useful in analyzing the difference between a planned set-up model and the actual treatment results, in order to qualitatively evaluate the treatment outcomes of the customized devices fabricated using CAD/CAM, such as those above.[17, 18]

Recently, a method of quantitatively measuring the tooth movement during the course of treatment has been introduced, in which, 3D models are used to analyze the pre and post-treatment tooth movements after orthodontic or orthognathic surgery.[19-21] By superimposing the pre and post-treatment digital models, it is now possible to accurately determine the vertical, horizontal, and anteroposterior movements of the individual teeth as well as their rotation. There have also been studies analyzing the changes in the arch width after treatment, and the actual space closure after extraction.[22, 23] Chong et al.[24] used digital models to evaluate the molar rotation in cases of maxillary premolar extraction.

Studies have been conducted on the stable dental structures of the digital models during orthodontic treatment in order to identify stable reference region for the superimposition of the maxillary digital models. Cha et al.[25] and Choi et al.[5] suggested reference region for superimposing some of the parts of the palatal vault, while Bailey et al.[20]and Hoggan et al.[20, 21] suggested the use of the palatal rugae as the reference points for the stable superimposition of the digital models. Recently, in studies combining two reference points, Jang et al.[26] suggested the use of the medial point of the 3rd palatal ruga and a part of the palatal vault as the reference region, and Chen et al.[27] used the medial two-thirds of the 3rd palatal ruga and a part of the palatal vault. Nevertheless, there is no consensus on which area the digital models should be superimposed for orthodontic treatment.

There have also been a number of studies on the stability of the medial point of the 3rd palatal ruga, aimed at its usefulness as a reference point for digital model superimposition; however, there have been no 3D model superimposition studies that have taken into account the morphological features of the palatal rugae, which vary in distribution and position. Masako et al.[28] investigated the morphological features of the palatal rugae in Japanese subjects, and found that the positions of the rugae were diverse, the left and the right rugae were asymmetric, and the 3rd palatal ruga was absent in approximately 10% of the subjects. Therefore, in order to establish the palatal rugae as the appropriate reference areas for digital model superimposition, the morphological features of the palatal rugae need to be explored first.

The accuracy of the digital model superimposition in the previous studies was evaluated in the subjects with either no extraction or a minimal-to-moderate retraction cases.[23, 25, 26, 29] With the recent development of the orthodontic mini-implants, the amount of incisor retraction following extraction has increased. Bailey et al.[20] reported that the extent of the tooth movement affects the stability of the palatal rugae, and Almeida et al,[19]Van der Linden,[30] and Peavy et al.[31] reported that the position of the palatal rugae was altered following orthodontic treatment. Therefore, in extraction cases involving great extents of tooth movement, the chance that the palatal rugae will move increases proportionally to the extent of tooth movement. Consequently, the previous proposal about the use of the 3rd palatal ruga as a reference point needs to be reviewed, particularly in the cases of maximum retraction.

This study investigated the morphological features of the palate in Korean subjects, and the distribution of the rugae. The patients undergoing orthodontic treatment after tooth extraction were categorized into a moderate-retraction group and a maximum-retraction group, and the efficacy of the digital model superimposition using the palatal rugae as the reference regions was evaluated for the two groups.

II. MATERIAL AND METHOD

1. Sample

1) Analysis of the anatomical features of the palatal rugae

The present study was approved by Ethical Committee of Yonsei University Graduate School of Dental Hospital. Of the patients who visited the Department of Orthodontics at the Yonsei University Dental Hospital between January 2009 and May 2015, 343 patients were selected for whom digital model from the initial visit was available and the following criteria were satisfied:

1. At least 17 years old, and the permanent dentition
2. No maxillofacial deformities, and no necessity of orthognathic surgery
3. No congenital defects of the teeth from the maxillary incisors to the second molars
4. No impacted teeth
5. No history of orthodontic treatment
6. Crowding of no more than 4 mm.

Table 1. Sample description for morphologic study of palatal rugae

Variable		
Mean age(±S.D)		25.6(±8.2)
Sex	Male (N)	114
	Female (N)	299
Total (N)		343

2) Validity of the digital model superimposition

Of the adult patients who visited the Department of Orthodontics at the Yonsei University Dental Hospital between January2008 and May 2015, a total of 40 patients were selected as the subjects for this part of the study. The subjects were divided into two groups according to the amount of the retraction of the central incisor. Based on the lateral cephalometric radiograph measurements, 20 subjects with less than 7 mm of retraction were assigned to the moderate retraction group, and 20 subjects with 7 mm or more were assigned to the maximum retraction group. The selection criteria were as follows:

1. Digital models available from pre- and post- treatment
2. Radiographs available from before and after treatment
3. Permanent dentition
4. No defects of the teeth from the maxillary incisors to the second molars
5. No air bubbles on the teeth or the palatal surface of the dental cast
6. Extraction of the 1st premolar due to protrusion
7. Patient who did not undergo palatal expansion or large dental expansion.

Table 2. Sample description for 3D digital model superimposition

		Group		
		Moderate retraction group	Maximum retraction group	Total
		Mean(±SD)	Mean(±SD)	Mean(±SD)
Ages (years)		21.3(±7.5)	22.3(±6.1)	21.38(±6.8)
Sex	Male(N)	7	2	9
	Female(N)	13	18	31
Total(N)		20	20	40

2. Measurements

1) Analysis of the anatomical features of the palatal rugae

Classification and distribution of the palatal rugae

The method of Masako et al.[28] was used to classify the palatal rugae into three types: primary, secondary, and fragmentary.

- Definition of the ruga zone: The medial boundary of the rugae was defined as the midline of the hard palate; the lateral boundary, as the point of the termination of the most lateral ruga; the anterior boundary, as the anterior aspect of the primary ruga; and the posterior boundary, as the posterior aspect of the ruga closest to the 1st molar.
- Primary ruga: At least 5 mm in length, with a high prominence and originating in the medial three-quarters of the ruga zone.
- Secondary ruga: At least 3 mm and less than 5 mm in length, and low prominence than the primary ruga.
- Fragmentary ruga: At least 2 mm and less than 3 mm in length (Fig 1.).

The number and types of the right and left palatal rugae of the subjects were investigated according to the above classification system, and the number and distribution of the primary rugae in the subjects was also investigated.

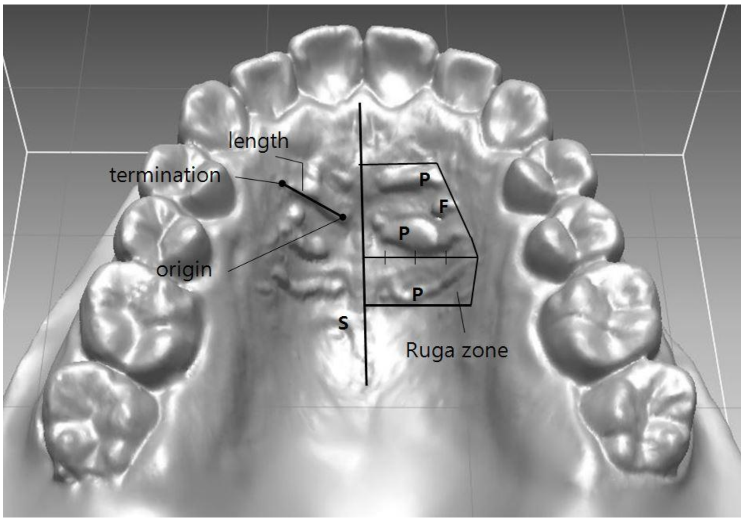


Fig 1. Classification of the ruga. P: primary ruga. It is 5mm or more in length and the origin exists within medial 3/4 of the ruga zone. S: secondary ruga. F: fragmentary ruga. The box zone: ruga zone.

Position of the 3rd primary ruga

The anterior and posterior limits of the 3rd primary ruga were measured in the digital model (Fig. 2).The lines which are perpendicular to the median line and pass through interdental contact points were drawn as well as the lines bisecting each tooth. The part of each tooth anterior to the bisecting line was defined as m, and the posterior part of the tooth, as d. The anterior limit of the 3rd primary ruga was represented as the line perpendicular to the median line from the most anterior point on the 3rd primary ruga recorded as the position in relation to the teeth. The posterior limit of the 3rd primary ruga was represented in the same order. In addition, the differences in the positions of the 3rd ruga were investigated depending on the presence of additional rugae posterior to the 3rd primary ruga.

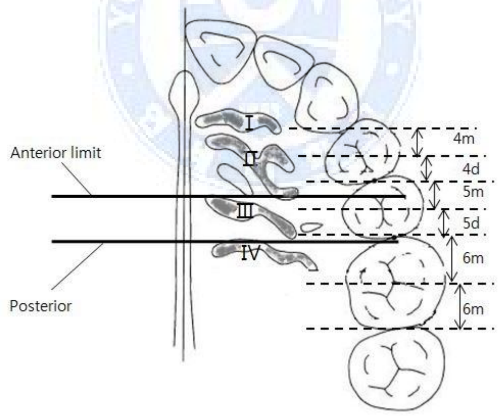


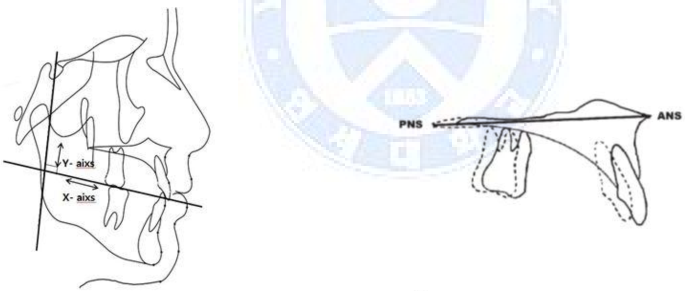
Fig 2. Measurement of the anterior limit and posterior limit of the third ruga. The anterior limit of the third primary ruga was represented as the line perpendicular to the median line from the most anterior point on the third primary ruga recorded as the position in relation to the teeth. The posterior limit of the third primary ruga was represented in the same order. The part of each tooth anterior to the bisecting line was defined as m, and the posterior part of the tooth, as d. (4m: mesial zone of first premolar. 4d:distal zone of first premolar)

2) Validity of the digital model superimposition

Superimposition of the lateral cephalometric radiographs

The pre and post-treatment lateral cephalometric radiographs were traced on conventional transparent acetate paper. On the pre-treatment tracing, the line passing through the maxillary central incisal tip and the mesio-buccal cusp tip of the 1st molar was considered as the occlusal plane, and was defined as the X-axis. The line perpendicular occlusal plan through the Sella (S) was defined as the Y-axis (Fig. 3).

Pre and post-treatment lateral cephalometric radiographs were superimposed along the palatal plane registered at anterior nasal spine (ANS), according to the method suggested by Richetts[32] (Fig 3.). The change in the position of the maxillary central incisor tip was measured along the X- and Y-axes.



A B

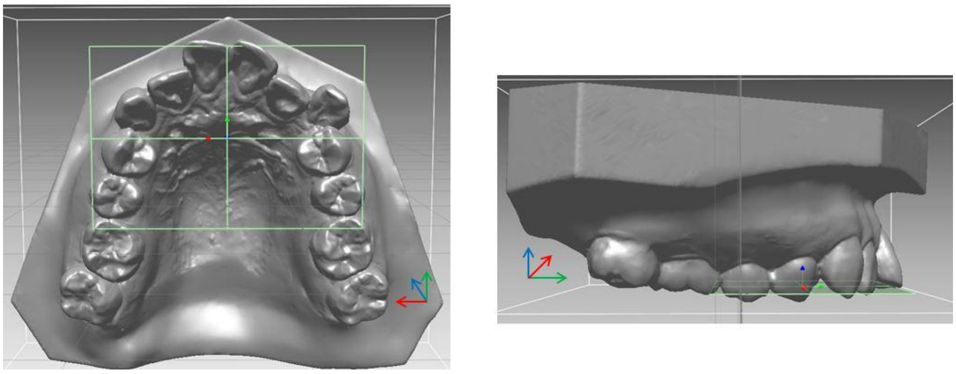
Fig 3. Reference co-ordinate system for cephalometric superimposition. A, X-axis: a line through the maxillary central incisor tip and the mesio-buccal cusp tip of the first maxillary molar on the initial cephalogram. Y-axis: plane perpendicular to X-axis through Sella;
B, Superimposition of the maxilla along the palatal plane registered at ANS according to Ricketts.(1975)[32]

Model Scanning

Impressions for maxillary dental cast were taken using alginate impression material at pre- and post- treatment. Dental casts were made with dental stone and then scanned by the Orapix 3D scanner (Laser slit-type noncontact 3D scanner, Orapix Co Ltd, Seoul, South Korea; accuracy ± 20μm), and the data were stored as stereolithography (STL) files. Based on scanned data, superimposition and analysis 3D images performed using a 3D reverse modeling software program (Rapidform 2006, INUS Technology Inc, Seoul, South Korea).

Digital Model Superimposition

The reference planes were defined in the digital models identical to those in the lateral cephalometric radiographs. In the pre-treatment model, the occlusal plane was defined perpendicular to midpalatal raphe, which passes through tip of central incisor and mesio buccal cusp tip of maxillary first molars (Fig. 5) Within this plane, the X-axis was defined in the anteroposterior direction, the Y-axis in the vertical direction, and the Z-axis in the transverse direction. The positive values on the X- and Y-axes corresponded to the posterior and extrusion movements, respectively.

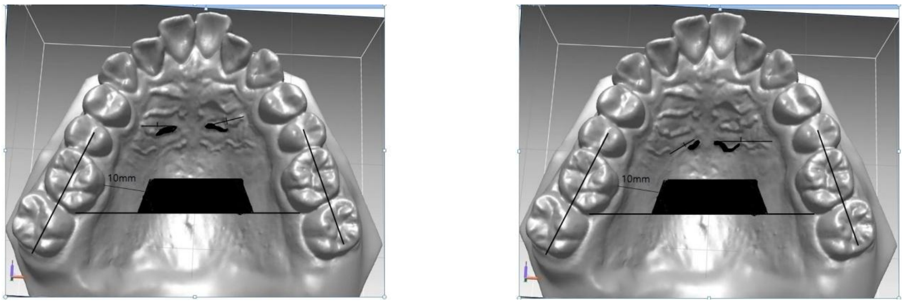


A B

Fig 4. Refenence co-ordination system for measuring the amount of tooth movements. The green box is occlusion plane perpendicular to midpalatal raphe, which passes through tip of central incisor and mesio buccal cusp tip of maxillary first molars. The green arrow is X-axis. The blue arrow is Y-axis. A, occlusal view; B, sagittal view.

Two methods of superimposition were selected. The 3rd palatal ruga superimposition method was performed using the medial half of the total length of the 3rd palatal ruga and the palatal vault as reference areas. The 4th palatal ruga superimposition method was performed using the medial half of the total length of the 4th palatal ruga and the posterior palatal vault as reference areas (Fig5.). The anterior boundary of the reference palatal vault area was defined as the line connecting the interdental contact points between the 2nd premolar and the 1st molar on either side; the posterior boundary was defined as the line connecting the interdental contact points between the 1st and 2nd molars on either side; the lateral boundaries were defined as anteroposteior lines are 10 mm 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. In cases where the 4thprimary palatal rugae were absent, the 1stsecondary ruga posterior to the 3rd primary ruga was used as the reference area instead. Displacement of the maxillary incisors tip was measured along the X- and Y-axes using the

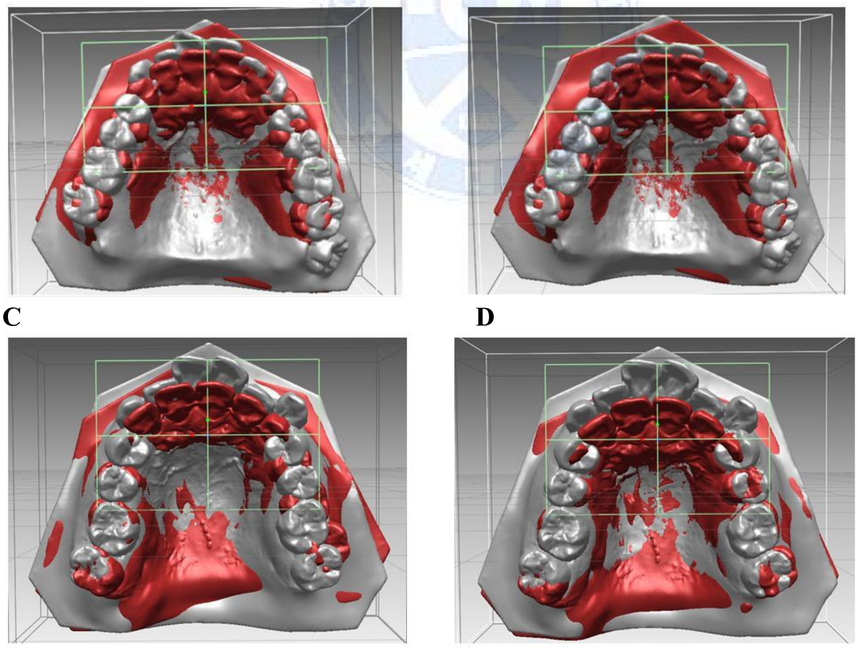
3^{rd} and 4^{th} palatal rugae superimposition models in both the moderate and the maximum retraction groups (Fig. 5).



A **B**

Fig 5. Definition of Landmarks for superimposition of 3D digital model. A, Superimposition using third ruga: medial 1/2 of third ruga and the following regional palatal vault; B, Superimpositon using fourth ruga: medial 1/2 of third ruga and the following regional palatal vault. Palatal vault region, Anterior border line- line connecting the interdental contact points between the 2nd premolar and the 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 anteroposteior lines are 10 mm 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

A **B**



C **D**

Fig 6. Tooth movement of superimposed three-dimensional models for each method.
A and B, moderate retraction case; C and D, maximum retraction case. A and C, Superimposition using third ruga; B and D, Superimposition using fourth ruga.

Comparative analysis of the tooth movements between the digital model and lateral cephalometric radiograph superimpositions

The amount of movement of the maxillary central incisors in the X and Y directions was investigated for each group using both the superimposition methods. The results were compared with the amount of movement observed from the lateral cephalometric radiograph measurements, and the differences, if any, were tested for significance. The changes in the position of the maxillary central incisors in the Z-axis were excluded from the results.

3. Statistical analysis

The mean number of palatal rugae on the left and the right sides were compared using a paired t-test. A chi-square test was performed for the frequency analysis and the analysis of the position of the 3rdprimary palatal ruga,.

The mean horizontal and vertical incisor movements were measured on the cephalometric radiographs were compared with that measured on the superimposed 3D digital models; Paired t-test and correlation analysis were performed to determine whether significant differences existed between the two measuring techniques. To evaluate the reproducibility of the superimposition, upon randomly chosen 10 models, the same measurement was repeated 2 weeks later by same investigator and the intraclass correlation between the first and the second superimposition trials was calculated.

III. Results

Analysis of the anatomical features of the palatal rugae

1. Distribution of the palatal rugae

The mean number of the primary rugae on the right side was 3.5, and that on the left, 3.4 (Table 3). There were an average 1.3 secondary rugae on the right side and 1.2 on the left with no significant bilateral difference. ($P > 0.05$).

The number of the primary palatal rugae ranged from 1 to 6, with 43.5% of the subjects had three primary rugae and 36.1% had four primary rugae (Table 4); 11.1% of the patients had two or fewer primary palatal rugae. There were no significant differences in the number of the primary palatal rugae between the right and the left palates.

Table 3. Mean number of the primary, secondary and fragmentary ruga

Ruga	Right(N=343)		Left(N=343)		P-value
	Mean	S.D	Mean	S.D	
Primary	3.5	0.8	3.4	0.6	*
Secondary	1.3	0.8	1.2	0.8	NS
Fragmentary	1.0	0.9	1.3	1.2	NS

NS, no significance; * P<0.05

Table 4. Frequency of the various numbers of the primary rugae

Number of primary rugae	Right(N=343)		Left(N=343)		Total Mean %	P vaule
	Obs. No.	%	Obs. No.	%		
1	3	0.9	2	0.6	0.8	NS
2	30	8.7	41	11.8	10.3	NS
3	150	43.7	148	43.2	43.5	NS
4	120	35.0	129	37.6	36.1	NS
5	35	10.2	23	6.8	8.5	NS
6	5	1.5	0	0	0.8	NS
Total	343	100	343	100	100	

NS, no significance; * P<0.05

2. Position of the 3rd primary palatal ruga

Among the patients with at least three primary palatal rugae, the frequency of the occurrence of another ruga posterior the 3rd primary ruga was investigated (Table 5). The number of patients with at least one primary or secondary ruga posterior to the 3rd primary ruga was 242 (78%) on the right side, and 213 (72%) on the left; there were no significant differences in the occurrence between the right and the left sides.

The position of the 3rd primary palatal ruga showed a significant difference depending on the presence of an additional posterior ruga ($P < 0.05$). In cases with the additional posterior rugae, the anterior limit was located further anteriorly on both the right and the left sides. Similarly, the posterior limit was also located further anteriorly in cases with the additional rugae posterior to the 3rd primary palatal ruga (Table 6).

Table 5. Frequency of the third primary ruga, a ruga whether it has additional posterior ruga or not

	Number of primary ruga>3	Number of primary ruga=3			Total (N)
		Posterior secondary ruga	No more posterior ruga	P value	
Right	160(52%)	82(26%)	68(22%)	NS	310(100%)
Left	152(51%)	62(21%)	86(28%)	NS	300(100%)

NS, no significance; * P<0.05

Table 6. Relative position of third primary ruga in relation with the contact point of first and second premolar , a ruga whether it has additional posterior ruga or not

Relative positon of 3rd ruga	Number of ruga=3		Number of ruga>3		P-value
	Right	Left	Right	Left	
Anterior limit of 3rd ruga					
Anterior	39(57%)	35(40%)	212(88%)	171(80%)	*
Posterior	29(43%)	51(60%)	30(12%)	43(20%)	*
Posterior limit of 3rd ruga					
Anterior	1(1%)	2(2%)	60(25%)	52(24%)	*
Posterior	67(99%)	84(98%)	182(75%)	162(76%)	*
Total	68	86	242	214	

* P<0.05

Validity of the digital model superimposition

3. Comparative analysis of the tooth movements between the digital model and lateral cephalometric superimposition

In the moderate retraction group, the results of the paired t-test showed no statistically significant differences between the vertical and horizontal upper incisor movements assessed by cephalometric and the digital model superimpositions by either the 3rd or the 4th palatal rugae superimposition methods (P> 0.05).

However, in the maximum retraction group, there were statistically significant differences in the lateral cephalometric radiograph superimpositions for the movement of the maxillary central incisor along the X-axis, and this difference was evident in the both the 3rd and the 4th palatal rugae superimposition methods (P< 0.05); there were no statistically significant differences for movement along the Y axis (Table 7). In the maximum retraction group, the mean difference in tooth movement along the X-axis between the lateral cephalometric radiographs and the 3rd palatal ruga superimposition was 0.7 mm, and that with the 4th palatal ruga superimposition was 0.2 mm, with the 3rd palatal ruga superimposition showing a significantly larger difference (P< 0.05).

In the moderate retraction group, based on the comparison of the regression line for the central incisor movements in the lateral cephalometric radiographs with the 3rd and the 4th palatal rugae superimpositions, adequate correlation coefficient was obtained for the movements of all of the teeth (R^2>0.92). This means that incisor movements measured by the radiograph superimposition as well as the 3rd and 4th palatal rugae superimposition methods were all statistically equivalent (Fig 7.). In the maximum retraction group, the regression line of the lateral cephalometric radiograph and digital model superimpositions revealed that the R^2 value for central incisor movements along the X-axis was 0.646 for the 3rd palatal ruga superimposition method and 0.9758 for the 4th palatal ruga superimposition method, demonstrating a relatively stronger linearity for the latter method (Fig. 8).

Table 7. Displacement of the central incisor measured on the according to cephalograms superimposition and 3D digital superimposition. (Unit: mm)

	X-ray superimposition		3D digital superimposition						ΔCeph-3rd Ruga digital	ΔCeph-4th Ruga digital	P value[c]
	Ceph		3rd Ruga digital			4th Ruga digital					
	Mean	S.D	Mean	S.D	P value[a]	Mean	S.D	P value[b]	Mean(±SD)	Mean(±SD)	
Moderate retraction group											
Xd	3.3	2.6	3.2	2.5	0.07	3.3	2.6	0.39	0.2(±0.02)	0.3(±0.06)	0.42
Yd	0.5	1.3	0.5	1.3	0.39	0.4	1.3	0.07	0.1(±0.02)	0.2(±0.03)	0.17
Maximum retraction group											
Xd	8.2	1.8	7.7	2.2	0.01*	8.1	2.0	0.04*	0.7(±0.5)	0.2(±0.02)	0.004*
Yd	1.4	2.2	1.4	2.8	0.56	1.4	2.5	0.25	0.4(±0.1)	0.2(±0.03)	0.004*

* $P<0.05$

ΔCeph-3rd Ruga digital: the difference in tooth movement between the lateral cephalometric radiographs and the 3rd palatal ruga superimposition

ΔCeph-4th Ruga digital: the difference in tooth movement between the lateral cephalometric radiographs and the 4th palatal ruga superimposition

Xd : horizontal movements of central incisor; Yd: vertical movements of central incisor

P value[a]: significance between cephalometric superimposition and 3D superimposition using 3rd ruga

P value[b]: significance between cephalometric superimposition and 3D superimposition using 4th ruga

P value[c]: significance between Δ cephalometric superimposition- 3D superimposition using 3rd ruga and Δcephalometric superimpostion-3D superimposition using 4th ruga

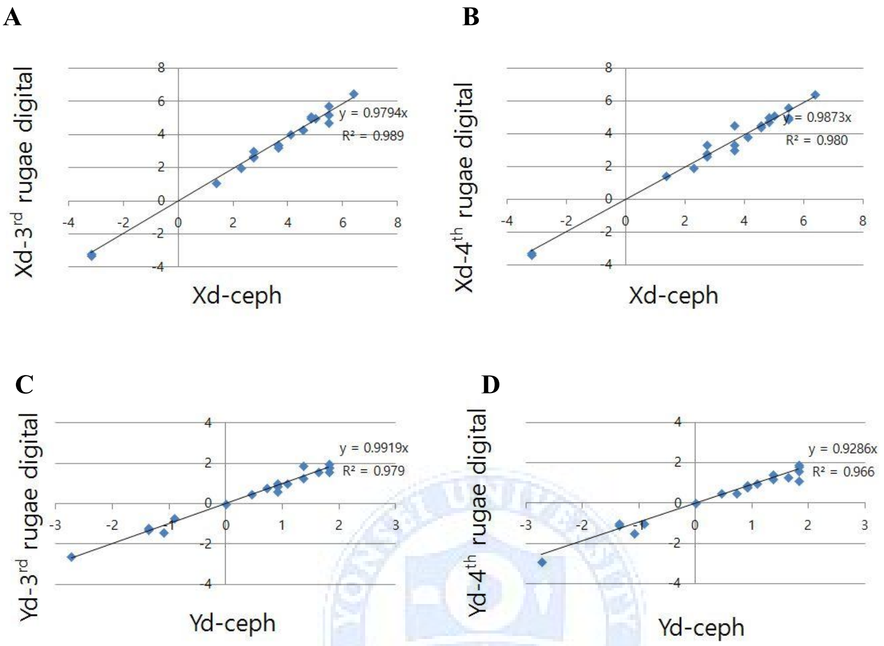


Fig.7 Scattergrams and regression lines for the central incisor movements measured on the cephalogram and three-dimensional digital model in moderate retraction group.

A, Horizontal movements of central incisor (Xd). X-axis: cephalogram superimposition (Xd-ceph) Y-axis:3rd ruga digital superimposition; B, Horizontal movements of central incisor. X-axis: cephalogram superimposition Y-axis: 4th ruga digital superimposition; C, vertical movements of central incisor (Yd). X-axis: cephalogram superimposition(Yd-ceph) Y-axis: 3rd ruga digital superimposition; D, vertical movements of central incisor. X-axis: cephalogram superimposition Y-axis: 4th ruga digital superimposition

A

B

C

D

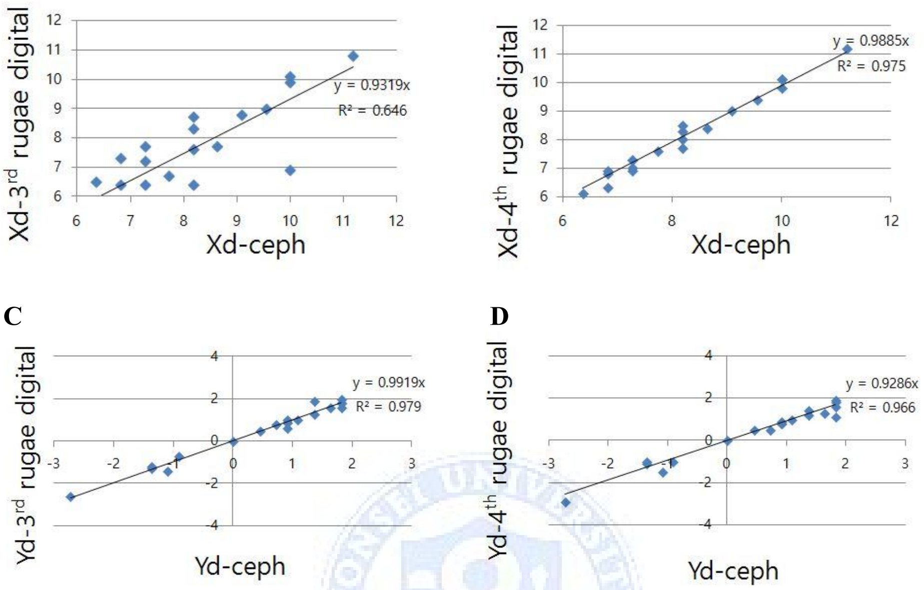


Fig.8 Scattergrams and regression lines for the central incisor movements measured on the cephalograms and three-dimensional digital model in maximum retraction group.

A, horizontal movements of central incisor (Xd). X-axis: cephalogram superimposition (Xd-ceph) Y-axis:3rd ruga digital superimposition; B, Horizontal movements of central incisor. X-axis: cephalogram superimposition Y-axis: 4th ruga digital superimposition; C, vertical movements of central incisor (Yd). X-axis: cephalogram superimposition(Yd-ceph) Y-axis: 3rd ruga digital superimposition; D, vertical movements of central incisor (Yd). X-axis: cephalogram superimposition Y-axis: 4th ruga digital superimposition

IV. Discussion

The superimposition of the serial lateral cephalometric radiographs has been conventionally used to evaluate orthodontic tooth movements. However, by the superimposition of the radiographs, it is only possible to assess the vertical and anteroposterior movements of the incisors and the molar teeth in the sagittal plane. Therefore, it is difficult to achieve a three-dimensional understanding of the actual dental closure, including the patterns of the tooth rotation, after the extraction. Several methods employing orthodontic digital models have been attempted in order to resolve this drawback. By performing the 3D evaluation of the superimposed digital dental models, it is possible to verify the tilting, rotation, and angulations of the anterior teeth and the molars, which had been difficult to observe with the conventional cephalometric radiographs. Additionally, it is possible to observe the course of the treatment progression using dental models alone, thus avoiding unnecessary exposure to radiation during the monitoring processes.

One of the challenges in digital model superimposition is the selection of the stable reference structures. A majority of the previous studies have evaluated the stability of the palatal rugae during orthodontic treatment. According to Peavy et al[31], the mucous membrane containing the palatal rugae is tightly fixed to the underlying periosteum and around the neck of the teeth. The closer the rugae are to the teeth, the more prone they are to "stretch" in the direction that their associated teeth move. Van der Lindene et al.[30] also said that rugae are closer to the moving teeth are affected more. Jang et al.[26] reported that the medial and lateral aspects of the palatal rugae tend to move distally, extrusively, and medially during the closure of an extraction space. They also reported that the displacement of the ruga increased in proportion with the tooth movement, and that the smallest change in the medial aspect of the 3rd palatal ruga. Hoggan et al.[21] reported that the medial and lateral sides of the 3rd palatal ruga could be used as the reference areas for the movement of the maxillary anterior teeth and the molars. Conversely, Peavy et al.[31] suggested that the lateral part of the palate could not be used as a stable reference point, highlighting the fact that the lateral ends of the palatal rugae moved in correspondence with the tooth movements in the case of a patient who underwent the 1st premolar extraction. The authors suggested that the 'O point' on the midsagittal line was influenced less by tooth movement, and that it could be used as the reference point.

Various reference areas have been experimented in previous studies investigating the superimposition of digital models. Till date, there has been no consensus on the stable maxillary structures that are unaffected by orthodontic treatment. In extraction cases, Cha et al.[25] suggested using only the palatal vault as the reference area and applying a best-fit matching method for the 3D model superimposition.[5, 25] Thiruvenkatachari et al.[23] also identified a mushroom-shaped area of the palate as the possible reference point in the pre and post-treatment models. However, it is undesirable to use the palatal vault as the only reference area since palatal vault area has insufficient shape characteristics, causing rotation errors during the superimposition. Recently, methods using the 3rd palatal ruga and the palatal vault together as the reference region, have been suggested.[21, 33] Jang et al.[26] investigated the stable reference points for the superimposition digital models, and concluded that the medial point of the 3rd palatal ruga and a part of the palatal vault could be used as the stable reference points. Chen et al.[27] suggested that an accurate superimposition could be achieved using the medial third of the 3rd palatal ruga and the palatal vault posterior to the 3rd palatal ruga.

Although recent studies have focused on the 3rd palatal ruga as the reference point for digital superimposition, there have been no studies yet on the morphological features, frequency, and distribution of the palatal rugae. The present study investigated the morphological features of the palatal rugae in South Korean individuals, and found that 43.5% of the patients had three primary palatal rugae, while 36.1% had four (Table 4). Approximately 11.1% of the patients had two or fewer primary palatal rugae. These findings are similar to those of a study by Masako et al.[28] Should the number of the primary palatal rugae be less than two, there will be challenges in the selecting a stable reference point for digital superimposition.

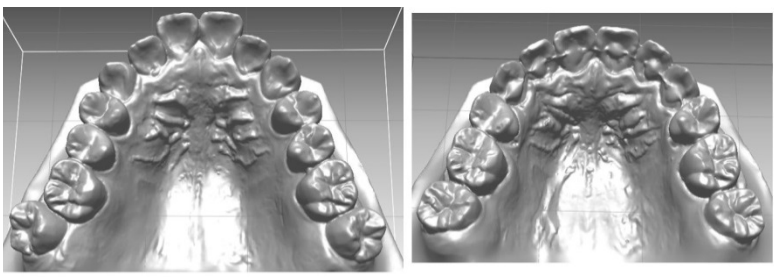
This study also investigated whether there were any differences in the position of the 3rdprimary palatal rugae depending on the number of rugae. The results were very interesting; we identified significant differences in the position of the 3rd palatal rugae depending on the presence of additional rugae posterior to it (Table 4). The proportion of the patients with another primary or secondary ruga posterior to the 3rdprimary palatal ruga was relatively high (78% for the right side and 72% for the left). In such cases, the proportions of the cases where the anterior limit of the 3rd palatal ruga was positioned anterior to the 2nd premolar were 80% and 88% for the left and right, respectively; the proportions of the cases where the posterior limit was positioned anterior to the 2nd premolar were 24% and 25% for the left and right sides, respectively. Conversely, in cases where the 3rdprimary palatal ruga was the most posterior ruga, the proportions were far lower ($P< 0.05$); the proportions of cases where the anterior limit was positioned anterior to the 2nd premolar were 57% and 40% for the left and right sides, respectively, and those where the posterior limit was positioned to posterior to the 2nd premolar were 1% and 2% for the left and right sides, respectively. In other words, when there was an additional ruga posterior to the 3rdprimary palatal ruga, the 3rd ruga tended to be located relatively anteriorly than in patients without an additional ruga, where the 3rd primary ruga tended to be located relatively posteriorly. The position of the rugae is an important element in the stability of the rugae, with the more anteriorly positioned rugae being more affected by the anterior teeth movement. Thus, if the 3rd palatal ruga is located anteriorly, it is more likely to undergo a change in its position due to the orthodontic tooth movement, and it will, therefore, be imprudent to use it as a reference point. In the previous studies, the 3rd palatal ruga was used as the reference point for digital superimposition, regardless of its position. However, the present study has shown that the anteroposterior position of the 3rd primary palatal ruga changes depending on the presence of the additional ruga posterior to the 3rdprimary palatal ruga. Therefore, when superimposing the digital models, this discrepancy needs to be taken into account in deciding the suitability of the 3rd palatal ruga as reference point.

In the present study, the reference areas used for the digital model superimposition were the medial half of the 3rd or the 4th palatal ruga and the posterior palatal vault. The reason for using the medial half of the rugae is because the lateral end tends to be highly affected by the tooth movement.[19, 26, 31] Moreover, using a broader superimposition area including the medial half of the rugae, rather than a single reference point as was used in the study by Jang et al.,[26] was expected to increase the accuracy of the superimposition. In addition, if the amount of anterior teeth movement was large, the 3rd palatal ruga might be displaced. Thus, the digital model superimposition using the 4th palatal ruga as a reference was also attempted in this study. In cases with no 4th primary palatal ruga, a secondary ruga posterior to the 3rd primary palatal ruga was used as the reference point. The fragmentary palatal rugae were not used as reference points because the thinner, less pronounced ruga are more likely to be displaced as a result of tooth movement[31]. The posterior limit of the palatal vault region in our study was defined further anteriorly than in the study by Jang et al.[26] This was done to address the concerns that the thick soft tissue covering the hard palate posterior to the 1st molar may lead to a deformation during impression acquistion.

In the assessment of the efficacy of the digital model superimposition, the moderate retraction group showed no statistically significant differences in the superimposition obtained by either the 3rd or the 4th palatal ruga superimposition methods compared with lateral cephalometric radiograph superimposition (Table 7). In other words, in the evaluation of the tooth movement in the patients with a moderate retraction, the 3D superimposition methods suggested in this study are clinically as useful as the superimposition using the lateral cephalometric radiographs. This is the same conclusion drawn in the previous studies by Jang et al., Cha et al., and Chen et al.[25-27]

Conversely, in the maximum retraction group there was a statistically significant difference in X-axis movement of the central incisor in both of the digital superimposition methods compared to the radiograph superimposition (Table 7). The average difference was significantly higher for the digital superimposition using the 3rd palatal ruga (0.7 mm) in comparison to the digital superimposition using the 4th palatal ruga (0.2 mm; $P< 0.05$). Digital superimposition tended to produce lower values for the anteroposterior tooth movements compared to the radiograph superimposition; this might have been because of the retraction of the anterior teeth, causing posterior movement of the medial end of the 3rd palatal ruga. This caused the movement of the anterior teeth to be underestimated when this point was used as a reference. In the previous studies which reported that the results of the 3D digital dental model superimposition were reliable, the amount of the retraction of the anterior teeth were approximately 3 mm (3.1 mm ,Jang et al.[26] and 2.7 mm ,Cha et al.[25]) indicating that these were cases with minimal or moderate retraction. The patients in the maximum retraction group in the present study had a mean posterior movement of the anterior teeth of 8.24mm ± 1.8 mm. In cases where the extraction of the 1st premolar and the maximum retraction of the six anterior teeth was done, the 3rd palatal ruga located anterior to the 1st premolar moves together with the anterior teeth, thus reducing the accuracy of the digital superimposition using the 3rd palatal ruga as the reference point (Fig. 9). Therefore, in cases with maximum retraction, it is necessary to select a reference region located further posteriorly where it is less affected by the anterior teeth movement. The superimposition should be performed using the palatal rugae located posterior to the 2nd premolar as the reference points,

The movement of anterior teeth obtained by the cephalometric radiograph superimposition and the 3D superimposition methods were measured by the linear regression analysis, which revealed that the R^2 value for the X-axis movement measured by the 3rd palatal ruga superimposition method was 0.646, and that by the 4th palatal ruga superimposition method was 0.976. This means that it is showing a greater linearity when the superimposition was performed using the 4th palatal ruga as the reference point. This is thought to be because the 4th palatal ruga, being further posterior than the 3rd palatal ruga, is less affected by the tooth movement.



A **B**

Fig.9 Change of the ruga in maximum retraction case (a) pre-treatment (b) post-treatment

In the present study, the movement of the central incisor measured by the cephalometric radiograph superimposition was used to verify the efficacy of the 3D superimposition methods. However, since the cephalometric radiographs may contain errors such as blurring, overlapping of anatomic structures, magnification, this lacks to be an absolute standard to assess the accuracy of the 3D digital dental model superimposition. If three or more orthodontic mini-implants were inserted and used as reference points, the superimposition would be more accurate.[26, 27] However, orthodontic mini-implants was not performed in the present study because of ethical issues. Additionally, this study is also limited by the potential error due to the dimensional change of impression material, thermal expansion of the dental cast, and human errors. There is no consensus regarding the changes in the palatal rugae during the process of growth.[33, 34] Therefore, the sample in the present study were obtained from patients who were not expected to have an apparent growth. During growth, the height and width of the alveolar processes increase and the direction or shape of the palatal rugae can possibly change.[34, 35] Thus, there is a limitation in applying this superimposition method to the growing children.

V. Conclusions

1. Approximately 43.5% have three primary palatal rugae, and 36.1% have four.
2. When there is an additional primary or secondary ruga posterior to the 3^{rd}primary palatal ruga, the anterior and posterior limits of the 3^{rd}primary palatal ruga are located more anteriorly compared to those in the individuals without an additional posterior ruga (P< 0.05).
3. In the moderate retraction group, the displacement of the central incisors measured using the third and forth ruga-palate-superimposition and that measured with cephalometric super imposition did not show much difference, while the maximum retraction group had significantly different results depending on the two methods.(P<0.05)
4. In the maximum retraction group, the mean difference in tooth movement along the X-axis between the lateral cephalometric radiographs and the 3^{rd} palatal ruga superimposition was 0.7 mm, and that with the 4^{th} palatal ruga superimposition was 0.2 mm, with the 3^{rd} palatal ruga superimposition showing a significantly larger difference (P< 0.05).

Based on the above results, it may be concluded that the number of the palatal rugae vary greatly among the population, and that this number affects the anteroposterior position of the 3^{rd}primary palatal ruga. When assessing the tooth movements in the patients with a moderate retraction, the 3D superimposition methods proposed in this study may be used as effectively in clinical practice as the lateral cephalometric radiograph superimposition method.

However, if the amounts of the incisor movement are large, the 3rd palatal ruga superimposition method is imprecise. In such cases, the superimposition should be performed using the palatal rugae located posterior to the 2nd premolar as the reference points, taking into account the number and position of the rugae in each patient.

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국문 요약

구개주름의 형태학적 분석에 기반한 발치 증례에서의 디지털 모형 중첩에 대한 평가

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고 경 민

본 연구에서는 한국인 구개의 형태학적 특징과 분포에 대해 조사하고 발치 교정 증례에서 중간 견인 그룹과 최대 견인 그룹을 나누어 세 번째 또는 네 번째 구개주름을 이용한 디지털 모형 중첩을 통해서 모델 중첩의 유효성에 대해 평가하고자 하였다.

치료 전 디지털 모델을 가지고 있는 343 명을 대상(남: 114 명, 여:299 명)으로 구개주름의 개수와 분포 그리고 세 번째 구개주름의 위치에 대해 조사하였다. 발치 교정을 완료한 성인 중 전 후 디지털 모델을 가지고 있는 40 명에 대하여 측모 두부규격 방사선 사진을 계측하여 상악 전치 견인량을 기준으로 moderate retraction group (<7.0 mm)과 maximum retraction group(>7.0 mm)으로

나누어 세 번째 구개주름(3 루개중첩법) 또는 네 번째 구개주름(4 루개중첩법)과 구개 전정 일부를 이용하여 디지털 모형 중첩을 시행하였다. 디지털 모형 중첩을 통해 상악 중절치 견인량을 측정한 다음 측모 두부규격 방사선 중첩에서의 견인량과 비교하여 둘 간의 유의성 있는 차이가 있는지 알아 본 결과 다음과 같은 결과를 얻었다.

1. 약 43.5%가 3 개의 primary 구개주름을 가졌으며 36.1%에서 4 개의 primary 구개주름이 존재하였다.
2. 세 번째 primary 구개주름 후방에 primary 또는 secondary 구개주름이 존재하는 경우, 후방에 구개주름이 존재하지 않을 때에 비해 세 번째 primary 구개주름의 전, 후방 경계는 보다 전방에 위치하였다 ($P<0.05$).
3. Moderate retraction group 에서 방사선적인 치아 이동량과 3 루개 디지털 중첩법과 4 루개 디지털 중첩법간의 치아 이동에 대한 유의한 차이가 없었던 반면에($P>0.05$) Maximum retraction group 에서는 치아 이동에 대한 유의한 차이가 있었다($P<0.05$).
4. Maximum retraction group 에서 방사선사진 중첩에 대해서 3 번째와 4 번째 루개 기준의 중첩법에 대한 상악 중절치 수평 이동량의 차이는 각각 0.7 mm, 0.2 mm 로 유의한 차이가 관찰되었다($P<0.05$).

이상의 결과로 구개주름의 개수가 다양하게 분포하고 있고, 구개주름 수에 따라 3 번째 primary 구개주름의 전후방적 위치가 변한다는 것을 알 수 있었다. 중간 견인 증례에서는 치아이동을 평가하는데 있어 본 논문에서 제시한 3D 중첩법이

측모두부방사선 중첩 사진만큼 임상적으로 유용하게 사용될 수 있을 것이다. 그러나 성인 환자 발치 증례에서 교정적인 전치부의 전후방 이동량이 큰 경우에는 세 번째 구개주름 중첩법은 오차가 존재하며, 구개주름의 개수와 위치를 고려하여 상악 제 2 소구치 후방에 존재하는 구개주름을 이용하여 중첩을 시행하여야 한다.

핵심이 되는 말: 구개주름, 디지털 모델 중첩, 전치부 견인, 방사선 중첩