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Validity of Three-dimensional Superimposition of Whole Face according to Different Registration Areas

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Purpose: This study was aimed to evaluate whether the size of the changed area included in the registration area affects the validity of superimposition in three-dimensional (3D) images.
Materials and Methods: Ten mannequin heads which were sectioned to simulate maxillary and mandibular setback surgery were used. A total of 30 images, including 10 initial images, 10 images after moving both middle and lower faces, and 10 images after moving only lower face, were obtained. The 9 landmarks which consisted of the bilateral and midline landmarks of the upper, middle, and lower faces respectively were used. Each 3D image obtained after simulation was superimposed 3 times according to the different 3 registration areas. The one-way ANOVA and post-hoc analysis were performed.
Result: In the case of moving middle and lower faces, there was no significant difference in all markers when superimposition was performed based on no changed area and forehead area. However, in the case of superimposition by the whole face, all measurements showed a significant difference ($P<0.05$) except for Pn ($P>0.05$). In the case of moving only lower face, all measurements did not show a significant difference regardless of the registration area.
Conclusion: The validity of 3D superimposition in 3D images could be affected by the size of changed areas included in the registration area. In the postoperative evaluation of mandibular surgery, the registration area does not affect the accuracy of the 3D superposition. However, after the maxilla-mandibular surgery, the registration area should be set except for the changed soft tissue.

Key Words: Three-Dimensional Image; Mannequins

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Introduction

Recently, with the development of three-dimensional (3D) image modalities and related software, there have been many attempts to use 3D images to assess the soft tissue. The useful applications of 3D images are the evaluation of changes in soft tissue. Pre- and postoperative 3D images can be matched by means of superimposition. After superimposition of the 3D images, the growth[1-3], orthodontic treatment outcome[4-6], soft tissue changes after orthognathic surgery[7-14], and edema after surgery[15,16] can be investigated quantitatively and objectively.

The superimposition of 3D images was usually performed by the iterative closest point (ICP) algorithm on a computer program[17-20]. The superimposition using the ICP algorithm is achieved by excluding the outliers with a larger distance between the points exceeding a certain threshold by a computation process after finding the nearest points through repeated sampling, and then checking for errors during the above point exclusion process[17,19]. Thus, it is important to examine the size of the registration areas.

Maal et al.[20] compared the accuracy of registration of 3D facial photographs according to different registration procedures, surface-based registration and reference-based registration. They reported that surface-based registration is an accurate method to compare 3D photographs of the same individual at different times. Choi[21] evaluated the validity of superimposition range at 3D facial images and reported that the validity of superimposition is decreased as the superimposition range is reduced in the superimposition of 3D images for the same individual. However, Choi[21] evaluated the 3D images of the same individual without change of soft tissue. This study was conducted to determine which areas should be superimposed when assessing soft tissue changes using 3D face images after orthognathic surgery for accurate evaluation. The purpose of the present study was to determine whether the size of the registration area or the size of the changed area included in the registration area affects the validity of superimposition in 3D images. The hypothesis of this study is that the size of the registration area or the size of the changed area included in the registration area does not affect the validity of superimposition in the 3D facial image.

Materials and Methods

A total of 10 styrofoam mannequin heads with different facial shapes were used as subjects. Nine of the 12 landmarks used in the previous study[21] were selected and used in the present study. The 9 landmarks consisted of the bilateral and midline landmarks of upper face (the forehead area), middle face (the nose and the zygomatic area), and lower face (mandibular body area), respectively. To accurately identify landmarks, the markers were attached to landmarks. The markers were used by marking 'x' in red color on the circle stickers with a 5.0 mm diameter (Fig. 1).

Each styrofoam mannequin head was sectioned parallel to the Frankfort horizontal plane (FH plane) at a level of the inferior palpebra and cheilion using an electric heat cable to move the middle and the lower faces separately. The bottom and backside of each sectioned mannequin head were fixed to a metal plate manufactured into L shape with a right angle. Two additional markers were attached to the left and right corner of the metal plate, as well as the soft tissue nasion area (N′) of the mannequin head to use in setting the coordinates.

A previously validated 3D laser scanner (Vivid 910; Minolta, Tokyo, Japan) was used[22-24]. To reproduce the changes of soft tissue after orthognathic surgery, each sectioned mannequin head was simulated in two types. First, both the middle and lower faces of each mannequin were moved 5 mm backward. Next, only the lower face was moved 5 mm backward. The mannequin which reproduced the

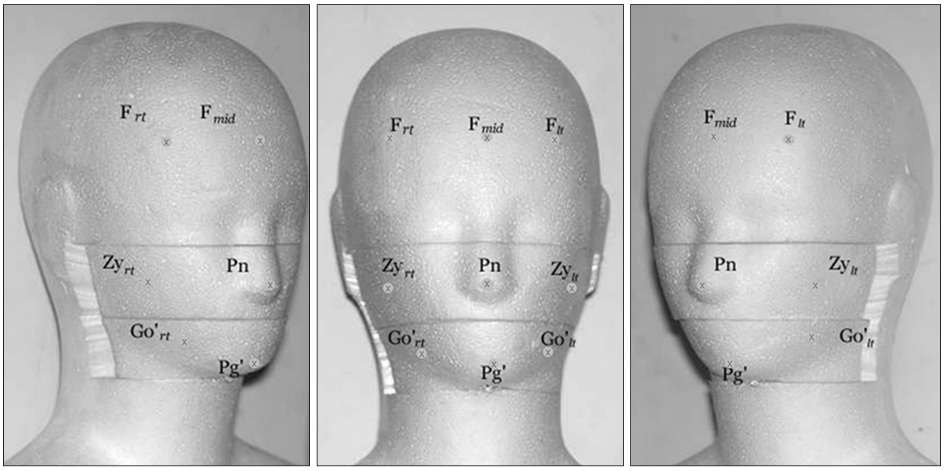

Fig. 1. Landmark used in present study: 1) Upper face: F_{rt}, right area of the forehead; F_{mid}, middle area of the forehead; F_{lt}, left area of the forehead; 2) Middle face: Zy_{rt}, right zygion area; Pn, pronasale area; Zy_{lt}, left zygion area; 3) Lower face: Go'_{rt}, right soft tissue gonion area; Pg′, soft tissue pogonion area; Go'_{lt}, left soft tissue gonion area.

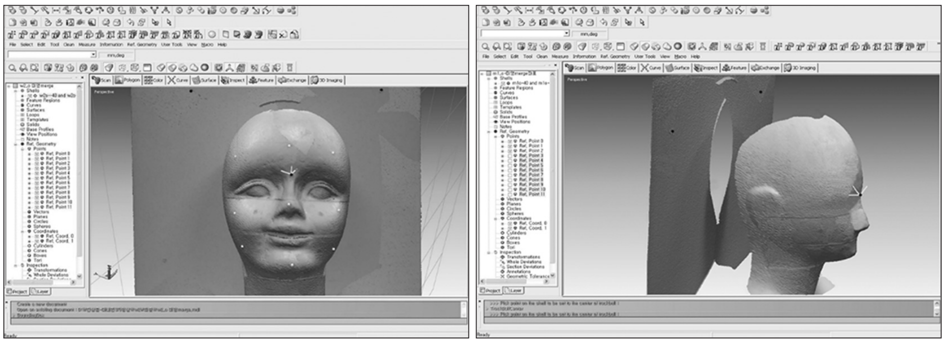

Fig. 2. Construction of three-dimensional images of the styrofoam mannequin head.

orthognathic surgery was then scanned in three directions, such as frontal and right and left 45° sides, respectively as reported in a previous study[24]. While scanning the mannequin head, the metal plate on the backside was scanned together.

The laser scan data was transferred into a 3D reverse engineering software program (RapidForm™2006; Inus, Seoul, Korea) for further processing. A total of 30 3D images, including 10 images obtained initially, 10 images obtained after moving both the middle and lower faces, and 10 images obtained after moving only the lower face, were reconstructed (Fig. 2).

To calculate the amounts of movement of each landmark, the same reference coordinates were set using the markers on the right and left corner of the posterior metal plate and the marker on N′ of the mannequin in 3D images before and after simulation. The origin coordinates (0, 0, 0) were set at the N′. The 3D distance of each landmark was calculated according to formula;

$$d = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}$$

x, y, and z: values obtained from the initial 3D images

x', y', and z': values obtained from 3D images after simulation

In the present study, the calculated 3D distance was regarded as the reference value.

The 3D images were superimposed by the ICP algorithm. Surface-based registration of 2 different 3D images was performed using the partial and whole registration function of the 3D reverse engineering software program. One 3D image after simulation was superimposed 3 times according to the different 3 registration area. To include no changed area in the registration area as many as possible, all unmoved area was used as the registration area. In the image obtained after moving the middle and lower faces, the remaining area except middle and lower faces was used as the registration area, whereas the remaining area except for the lower face was used as the registration area in the image obtained after moving the lower face. The forehead area which is from the upper part of both eyebrows to a region supposed as the hairline in the 3D images was used as the registration area. The whole face was used as the registration area in all images obtained after moving the middle and lower faces or only the lower face (Fig. 3).

The distance between the two markers on the same landmarks was measured using the function of measurement of the RapidForm program by a single operator.

Statistical analyses were performed using IBM SPSS Statistics (ver. 23.0; IBM Corp., Armonk, NY, USA). The average and standard deviation of measurements were calculated. The normality of measurement distribution was first checked using the Shapiro–Wilk test. All measurements were normally distributed. One-way ANOVA and post-analysis (Tukey method) were used to compare the differences according to the registration areas in each 3D image obtained after two types of simulations with the reference value. The level of significance was set as $P<0.05$.

Result

In order to evaluate the amounts of movement by moving both the middle and lower faces or only the lower face, the 3D distance of each landmark in the moving area was calculated. In the case of moving both the middle and lower faces, Zy_{rt}, Pn, Zy_{lt}, Go'_{rt}, Pg′, and Go'_{lt} moved 5.68 mm, 5.77 mm, 5.75 mm, 5.85 mm, 6.02 mm, and 6.42 mm, respectively. When only the lower face was moved, Go'_{rt}, Pg′, and Go'_{lt} moved 5.72 mm, 5.58 mm, and 5.31 mm, respectively.

1. Comparison of 3D Measurements according to the Different Registration Area in Case of Moving the Middle and Lower Faces

In the case of moving middle and lower faces, the measurements did not show a significant difference in all markers when superimposition was performed based on no changed area and forehead area. However, in the case of superimposition by the whole

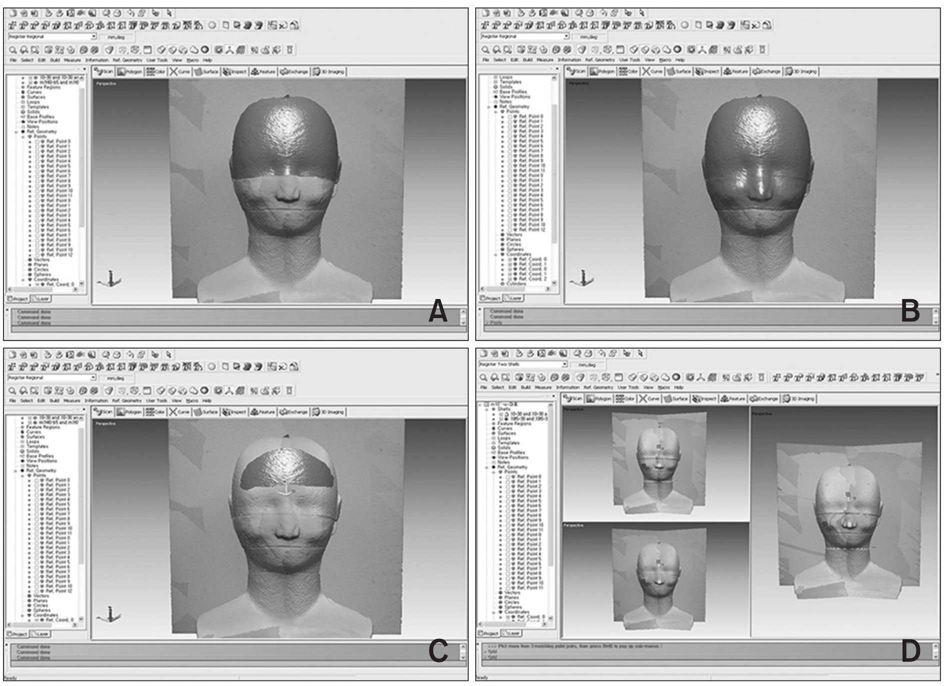

Fig. 3. Superimposition. (A) Superimposition by no changed area after moving middle and lower faces. (B) Superimposition by no changed area after moving only lower face. (C) Superimposition by the basis of the forehead area. (D) Superimposition by the basis of the whole face.

Table 1. Measurements on 3D mannequin images from the various superimposition methods and the calculated measurements (reference value) before and after moving both the middle and lower face (n=10)

	Reference value	Superimposition			P-value
		No changed area	Forehead area	Whole face	
F_{rt}	0.53±0.21[a]	0.32±0.20[a]	0.36±0.19[a]	2.55±1.52[b]	0.000
F_{mid}	0.48±0.21[a]	0.31±0.11[a]	0.31±0.13[a]	4.22±1.63[b]	0.000
F_{lt}	0.51±0.31[a]	0.32±0.21[a]	0.34±0.21[a]	3.15±1.12[b]	0.000
Zy_{rt}	5.68±1.38[a]	5.58±1.36[a]	5.59±1.40[a]	2.39±0.73[b]	0.000
Pn	5.77±1.11	5.65±1.20	5.68±1.17	5.17±1.27	NS
Zy_{lt}	5.75±1.41[a]	5.43±1.75[a]	5.43±1.76[a]	2.63±0.65[b]	0.000
Go'_{rt}	5.85±1.17[a]	5.76±1.17[a]	5.72±1.15[a]	2.69±1.01[b]	0.000
Pg'	6.02±1.24[a]	5.93±1.37[ab]	5.90±1.36[ab]	4.35±1.44[b]	0.025
Go'_{lt}	6.42±1.73[a]	6.24±1.88[a]	6.22±1.86[a]	2.99±1.31[b]	0.000

NS: statistically not significant.
F_{rt}: right area of the forehead, F_{mid}: middle area of the forehead, F_{lt}: left area of the forehead, Zy_{rt}: right zygion area, Pn: pronasale area, Zy_{lt}: left zygion area, Go'_{rt}: right soft tissue gonion area, Pg': soft tissue pogonion area, Go'_{lt}: left soft tissue gonion area.
Values are presented as mean±standard deviation.
[a,b]Different letters indicate statistically significant differences (same row).

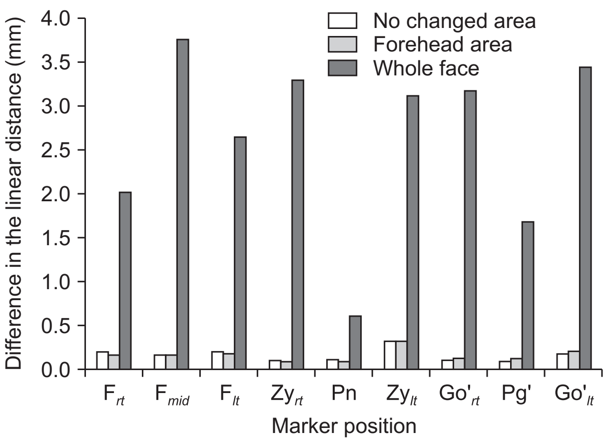

Fig. 4. The difference in the linear distance of each maker between the calculated measurement method and various superimposition methods in case of middle and lower face movement. Refer to Fig. 1 for the definition of landmarks.

face, the measurements showed a significant difference ($P<0.05$) in all markers except for Pn ($P>0.05$). The markers in no changed area, which is the upper face, were larger than the reference value, whereas the markers in the moving area, which are middle and lower faces, were smaller than the reference value (Table 1, Fig. 4).

2. Comparison of 3D Measurements according to the Different Registration Area in Case of Moving Only the Lower Face

In the case of moving only lower face, all measurements did not show significant difference regardless of the registration area (Table 2, Fig. 5).

Discussion

In order to eliminate the effects of possible motion artifacts and different head posture during laser scanning, the present study used mannequin heads with different facial shapes instead of lives. Moreover, each mannequin head was modified to move middle and lower face separately corresponding to the maxilla and mandible and then both middle and lower faces or only the lower face were moved 5 mm backward to simulate the changes of soft tissue after orthognathic surgery. The markers were attached to each landmark before laser scanning to reduce errors of landmark identification.

Although various methods to obtain 3D images of soft tissue have been introduced[25], a non-contact type 3D laser scanner (Vivid 910), which was veri-

Table 2. Measurements of the 3D mannequin images from various superimposition methods and the calculated measurements (reference value) before and after moving the lower face only (n=10)

	Reference value	Superimposition			P-value
		No changed area	Forehead area	Whole face	
F_{rt}	0.49±0.23	0.41±0.26	0.32±0.19	0.55±0.29	NS
F_{mid}	0.56±0.19	0.52±0.23	0.45±0.21	0.68±0.44	NS
F_{lt}	0.55±0.23	0.44±0.23	0.44±0.25	0.41±0.30	NS
Zy_{rt}	0.55±0.25	0.45±0.18	0.57±0.31	0.60±0.32	NS
Pn	0.54±0.28	0.34±0.18	0.50±0.26	0.66±0.65	NS
Zy_{lt}	0.50±0.18	0.33±0.16	0.41±0.23	0.56±0.49	NS
Go'_{rt}	5.72±1.06	5.28±1.16	5.52±1.08	4.88±1.59	NS
Pg'	5.58±0.70	5.26±0.94	5.41±0.89	4.89±1.56	NS
Go'_{lt}	5.31±0.86	5.20±1.06	5.51±0.90	4.68±1.33	NS

NS: statistically not significant.
F_{rt}: right area of the forehead, F_{mid}: middle area of the forehead, F_{lt}: left area of the forehead, Zy_{rt}: right zygion area, Pn: pronasale area, Zy_{lt}: left zygion area, Go'_{rt}: right soft tissue gonion area, Pg': soft tissue pogonion area, Go'_{lt}: left soft tissue gonion area.
Values are presented as mean±standard deviation.

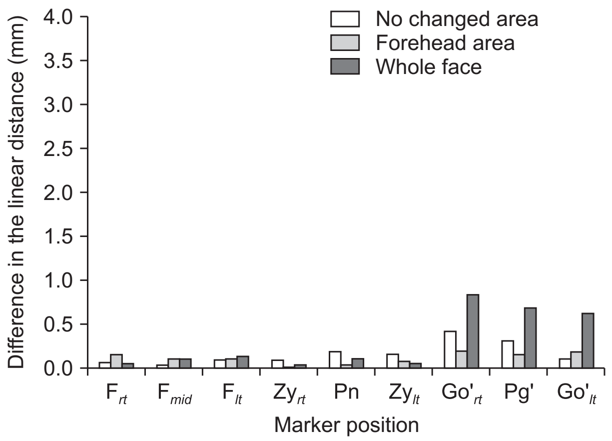

Fig. 5. The difference in the linear distance of each maker between the calculated measurement method and various superimposition methods in the case of mandibular movement only. Refer to Fig. 1 for the definition of landmarks.

fied to be accurate[22-24], was used in the present study. Song[24] examined the accuracy of a 3D image reconstruction by various 3D laser scanning angulations and the number of scanning times. Song[24] reported that the accuracy of 3D images was influenced by laser scanning angulation and the number of scanning times and suggested a method of scanning at least three times, turning at least 20° right and left, including at the front. In the present study, the images were scanned at the frontal and right and left 45° lateral positions of the subject to minimize errors in the image taking process.

In the case of moving middle and lower faces, there was no significant difference when superimposition was performed by no changed area and forehead. However, when the superimposition was performed by the whole face, the measurements showed a significant difference in all markers except for Pn, the tip of the nose (Table 1). These results did not coincide with the results of the previous study[21]. Choi[21] evaluated the images in the human with physiological movement during laser scanning, whereas the present study used the images of mannequin head without motion artifacts. Moreover, Choi[21] compared the two 3D images without changes of soft tissue, whereas the present study compared the 3D images after simulations to assess whether the size of changed regions included in the registration area affects the accuracy of 3D superimposition.

In addition, in the case of moving middle and lower faces, when superimposition was performed by the whole face, only the marker of Pn, indicating the center of the face, did not show a significant difference. The markers in the moving area, such as middle and lower faces, showed smaller values and markers in no changed area, such as the upper face, showed larger values than the reference value (Table 1). It is believed that these results were caused by the ICP algorithm superimposition in that 1) after determining the nearest points through repeated sampling in superimposition, a certain threshold in the distance between the points was determined by computation, 2) outliers with a distance between markers exceeding the threshold were excluded, 3) and the errors during the exclusion process of points were checked using the best-fit point to surface algorithm. Therefore, the accuracy of superimposition might be reduced, because the number of points involved within the threshold in the registration area was relatively small in the case of performing superimposition based on the whole face.

In the case of moving only the lower face, there was no significant difference in any superimposition method (Table 2). In this case, the changed region was less than half of the entire face, so it is considered that the different registration areas did not affect the accuracy of superimposition even when superimposing based on the whole face. This result is different from the case of superimposing after moving both the middle and lower faces. Therefore, the size of the changed region included in the registration area might affect the accuracy of superimposition in 3D images.

The results of the present study showed that the size of the changed area included in the registration area affects the validity of superimposition. In the case of orthodontic treatment with a relatively small soft tissue change of the face, consideration of the superimposition method has relatively low importance because the difference between superimposition methods according to the registration area is not large. However, for an assessment of the 3D images with a broad soft tissue change of the face, such as orthognathic surgery, the validity of superimposition could be improved when superimposition was performed based on the unchanged region rather than on the whole face.

The present study had several limitations, such as *in vitro* study and evaluation using 3D distance without directions. According to the result of the previous study[26], the upper lip can be improved considerably by mandibular setback surgery alone. Thus, the validity of superimposition in lives is necessary for future studies to identify more clues about the validity of superimposition according to the different registration areas.

Conclusion

The validity of 3D superimposition in 3D images could be affected by the size of changed areas included in the registration area. In the postoperative evaluation of mandibular surgery, the registration area does not affect the accuracy of the 3D superposition. However, after the maxilla-mandibular surgery, the registration area should be set except for the changed soft tissue.

Conflict of Interest

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

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