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Three-dimensional analysis of soft and hard tissue changes after mandibular setback surgery in skeletal Class III patients

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The three-dimensional (3D) changes of bone, soft tissue and the ratio of soft tissue to bony movement was investigated in 8 skeletal Class III patients treated by mandibular setback surgery. CT scans of each patient at pre- and post-operative states were taken. Each scan was segmented by a threshold value and registered to a universal three-dimensional coordinate system, consisting of an FH plane, a mid-sagittal plane, and a coronal plane defined by PNS. In the study, the grid parallel to the coronal plane was proposed for the comparison of the changes. The bone or soft tissue was intersected by the projected line from each point on the gird. The coordinate values of intersected point were measured and compared between the pre- and post-operative models. The facial surface changes after setback surgery occurred not only in the mandible, but also in the mouth corner region. The soft tissue changes of the mandibular area were measured relatively by the proportional ratios to the bone changes. The ratios at the mid-sagittal plane were 77 ~ 102% ($p < 0.05$). The ratios at all other sagittal planes had similar patterns to the mid-sagittal plane, but with decreased values. And, the changes in the maxillary region were calculated as a ratio, relative to the movement of a point representing a mandibular movement. When B point was used as a representative point, the ratios were 14 ~ 29%, and when Pog was used, the ratios were 17 ~ 37% ($p < 0.05$). In case of the 83rd point of the grid, the ratios were 11 ~ 22% ($p < 0.05$).

(**Key words**: 3D analysis, 3D coordinate system, 3D registration)

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INTRODUCTION

Recently, with advancements in orthognathic surgical techniques, surgery cases have increased, including those performed to correct the underlying skeleton in Class III patients. The consequent facial appearance is of great importance, even when the patient's chief purpose in treatment is not concerned with cosmetics. A more accurate prediction of the surgical result therefore comprises an essential part of the diagnosis and treatment planning of orthognathic surgery.

Friede et al.[1] insisted that the precision of the surgical prediction is influenced by the type of surgery and the amount of surgical movement. The result of mandibular setback surgery was relatively predictable in comparison with maxillary or double-jaw surgery. Hershey and Smith[2] have shown that soft tissue changes could be predicted from the skeletal changes, according to the interplay of the cephalometric landmarks of the hard and soft tissue profiles. In general, mandibular setback surgery caused a 90% soft tissue change at the chin and lower lip relative to the amount of bony movement.[3,4] Cephalometric analysis provided a more delicate surgical prediction through the adjustment of various treatment options and contributed to successful management of the cases.

The evaluation and prediction of surgical treatment, however, was usually limited to two-dimensional assessments. After surgery, the facial soft tissue was altered on all three dimensions, which caused a significant difference between the prediction and the surgical result.[5]

McCance et al.[6] tried to analyze the soft tissue changes after surgery in three dimensions using a laser scan. Moss et al.[7] suggested that the laser scan could be an effective tool to evaluate the three-dimensional (3D) changes after orthodontic treatment. However, the laser scan could not reveal the relations between the soft tissue and the underlying hard tissue. McCance et al.[8] investigated the soft tissue changes after orthognathic surgery using a CT scan. He showed that the soft tissues consistently followed the pattern of hard tissue movement in the midline and the ratio of soft tissue change to hard tissue change was measured by the distance from the midline. He also concluded that the radial measurement from the center of rotation of the head could not be directly comparable to the linear measurements on a lateral cephalometric radiograph.

In this study, we proposed a novel approach of registering inter-patient CT scans in the universal 3D coordinate system and investigating the 3D changes of bone, soft tissue, and the ratios of soft tissue to bony movement after mandibular setback surgery.

MATERIAL AND METHODS

Sample selection

The sample was comprised of adult patients who had been received mandibular setback surgery to correct their malocclusion. Severe asymmetry cases were excluded. Five male and three female patients were selected. The range of patient age was from 19 years 2 months to 31 years 5 months.

CT scan and data storage

CT scans of each patient at pre- and post-operative states were taken. The post-operative CT scan was performed at 11 ~ 28 weeks after surgery. CT data acquisition was performed using a Somatom Plus 4 (Siemens, Erlangen, Germany) with a 1.5 mm section interval, a 1 mm slice thickness in spiral mode, and a 512 by 512 matrix with exception of three cases of which the slice thicknesses were 0.3, 0.6 and 1.3 mm respectively. The scan was carried out at the Department of Diagnostic Radiology at Seoul National University Hospital. The scanned field of view (FOV) was from the cranium vault to the chin. The resultant two-dimensional image data were stored in Digital Imaging and Communications in Medicine (DICOM) format, the international standard for interconnecting medical imaging devices on standard networks.

Data processing

Fig 1 shows the overall procedure of the system. 3D image was reconstructed from the CT-slice image using V-works (Cybermed Inc., Seoul, Republic of Korea). The bony parts were segmented out from each slice image using a threshold value of 176 HU (12 bit depth). The soft tissue parts were segmented using a threshold value of -285 HU.

For the comparison of quantitative changes, a universal coordinate system was proposed as follows; FH plane was defined with both Po and left Or, and used as a horizontal plane. Then a midsagittal plane

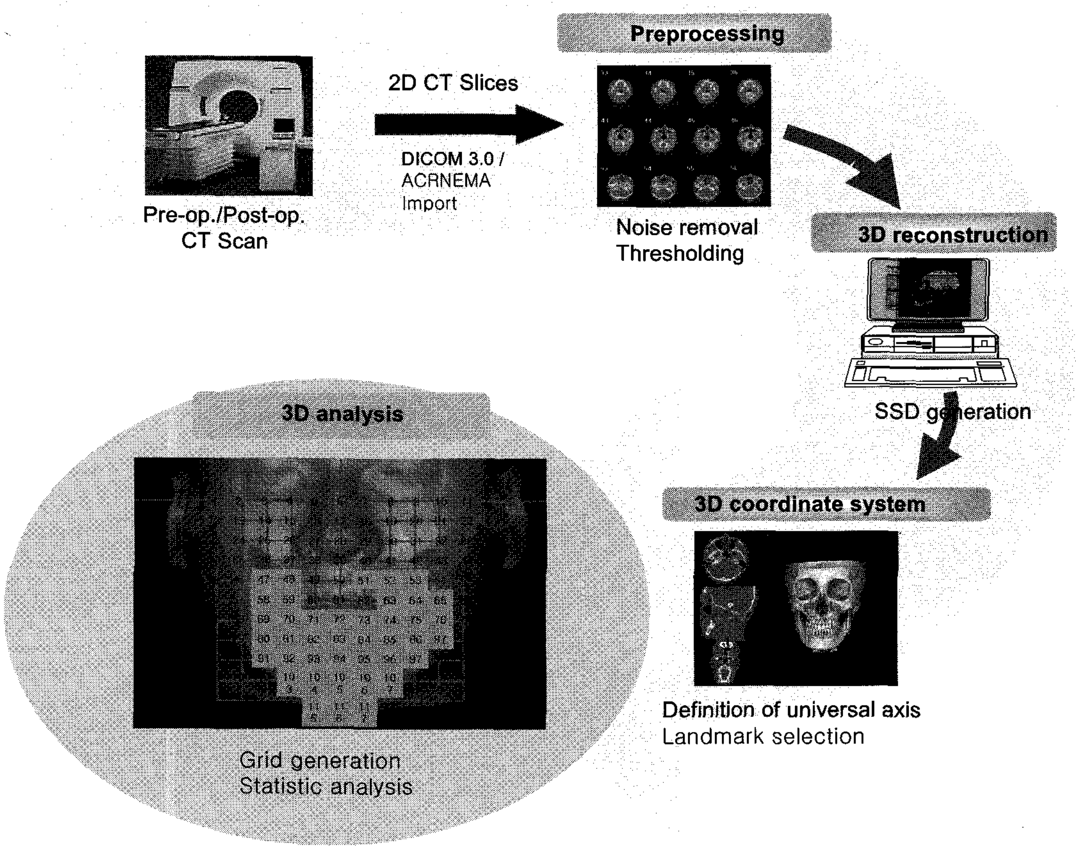


Fig 1. Schematic workflow diagram for data processing.

Table 1. Landmarks used for the common coordinate system

Landmark	*Definition*
Po_{lt}	The highest point on the upper margin of the left external auditory meatus
Po_{rt}	The highest point on the upper margin of the right external auditory meatus
Or_{lt}	The lowest point on the lower margin of left orbit
Nc	The highest point of crista galli
FS_{lt}	The geometric center of left Foramen Spinosum
FS_{rt}	The geometric center of right Foramen Spinosum
PNS	The most posterior point of the palatine bone at the midline

was constructed perpendicular to FH plane with 2 points (mid-point of both foramen spinosum and crista galli). Finally, a plane including PNS, perpendicular to FH plane and midsagittal plane simultaneously, was used as a coronal plane. Table 1 summarizes the landmarks used in this study.

The coordinate system of each 3D surface shaded display (SSD) model was converted into the universal coordinate system. Additional landmarks were defined for the grid generation and evaluation of the mandibular

Table 2. Additional representative landmarks

Landmark	*Definition*
ANS	The most anterior point on the maxilla at the level of the palate
A	The most posterior point on the curve between ANS and Pr, but most anterior point of the maxilla in the horizontal plane
Pr	The transition point between the crown of the upper central incisor and the alveolar projection
U1	The midpoint of the incisal edge of the upper central incisor
L1	The midpoint of the incisal edge of the lower central incisor
Id	The transition point between the crown of the lower central incisor and the alveolar projection
B	The most posterior point on the curve between Id and Pog, but most anterior point of the mandible in the horizontal plane
Pog	The most anterior point on the symphysis of the mandible
Me	The most inferior point on the symphysis of the mandible in the medial plane

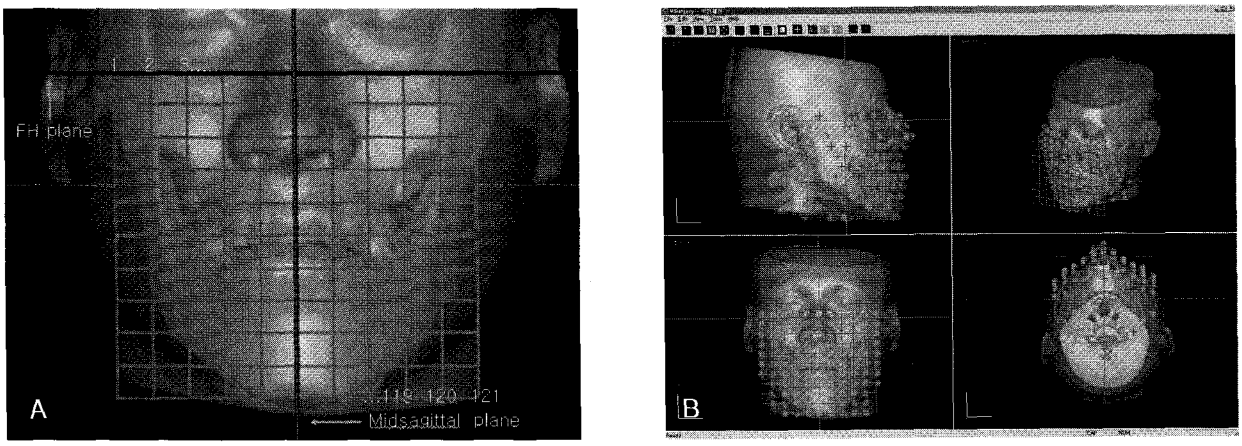


Fig 2. Grid generation and point projection. **A,** Grid generation; **B,** projection point onto the skull and soft tissue model.

movement. Table 2 shows the additional representative landmarks. Surface models for bony the parts and soft tissue parts were exported to V-Surgery (Cybermed Inc., Seoul, Republic of Korea) with the common coordinate system.

Measurement

For an analysis of the surgical changes, a grid was formed parallel to the coronal plane. The upper border of the grid was FH plane, lower border was Me, left border was left Po, and right border was right Po. The grid was also created perpendicular to FH plane, in front of the surface model of the soft tissue part (Fig 2). Then, the length from Me to FH plane was divided into 10 equal parts. Finally 11 horizontal lines were generated including the upper and lower border lines. The length from left Po to the midsagittal plane and the length form right Po to the midsagittal plane were compared. The shorter length was chosen and evenly divided into 5 parts. Mirroring those points on the basis of the midsagittal plane, new corresponding points were generated. Similarly 11 vertical lines were also created. The 121 points for measuring the surgical changes were defined by the intersection of these lines.

All points were projected onto the coronal plane

Table 3. Mean and standard deviation (SD) of coordinate value difference of points which make up the coordinate system (mm)

Landmark	*X axis*		*Y axis*		*Z axis*	
	Mean ± SD	*p*	*Mean ± SD*	*p*	*Mean ± SD*	*p*
Po_{lt}	−0.06 ± 0.76	0.84	−0.15 ± 1.87	0.83	0.00 ± 0.00	0.35
Po_{rt}	−0.13 ± 1.44	0.81	−0.19 ± 1.01	0.62	0.00 ± 0.00	0.35
Or_{lt}	−0.75 ± 1.28	0.14	−0.52 ± 1.11	0.23	0.00 ± 0.00	0.35
Nc	0.00 ± 0.00	0.35	0.03 ± 1.06	0.69	0.03 ± 0.88	0.92
FS_{lt}	0.06 ± 0.41	0.71	−0.25 ± 1.04	0.52	−0.10 ± 0.17	0.14
FS_{rt}	−0.06 ± 0.41	0.71	−0.34 ± 0.53	0.12	0.08 ± 0.41	0.60
PNS	0.14 ± 0.83	0.65	−0.00 ± 0.00	0.35	−0.35 ± 0.67	0.18

All the values were obtained by subtraction of the pre-operative coordinate value from the post-operative coordinate value.

through the skull and soft tissue. The coordinates of all the intersected points on the skull and the soft tissue from the projected ray were exported to a Microsoft EXCEL™ file using V-Surgery. If there was no crossing with the skull and soft tissue, the point was regarded as missing.

According to the DICOM protocol, x axis was defined in the left-right direction, y axis in the antero-posterior direction, and z axis in the caudal-cephalic direction. The y axis value was analyzed for the antero-posterior changes after surgery. The x and z axis values were analyzed for the reproducibility of the grid.

Statistics

For the reproducibility test of the proposed coordinate system, all the landmarks used for the coordinate system construction and located at the maxilla were tested using paired *t*-test. For the reproducibility of the grid, every grid point including the boundary points were compared by paired *t*-test.

The ratios of soft tissue changes were calculated and evaluated through 2 methods. The first calculated the ratio of the soft tissue movement to the skull movement at the corresponding grid points. The second method obtained the ratio of soft tissue movement to the skull movement at an additional representative point, i.e. B, Pog or grid number 83. Paired *t*-test was performed to compare the matched points between pre- and post-operative states. The movement ratios according to the setback distance of representative points were also calculated.

RESULTS

Errors of defining the coordinate system

The mean and standard deviation (SD) of the coordinate deviation to define the universal coordinate system are summarized in Table 3. In viewpoint of the mean and standard deviation (SD) of the coordinate deviation, x axis ranged from −0.75 ± 1.28 to 0.06 ± 0.41, y axis from −0.52 ± 1.11 to 0.03 ± 1.06 and z axis from −0.35 ± 0.67 to 0.03 ± 0.88 (scale; mm). The *p* values are also provided in Table 3. The deviations of x, y, z coordinates of measured points were 0 ~ 0.5 mm, and there was no significant difference with every point between pre- and post-operative models.

Table 4 lists the movement of additional landmarks by mandibular setback surgery. There was no difference in the maxillary region. However, in the mandibular region (L1, Id, B, Pog, Me), the landmarks moved significantly in the y and z directions ($p < 0.05$).

Reproducibility test between pre- and post-operative grids

X coordinates of Po contributing to the horizontal axis of the grid were identical between pre- and

Table 4. Movement of additional landmarks by mandibular setback surgery

Landmark	*X axis*		*Y axis*		*Z axis*	
	Mean ± SD	*p*	*Mean ± SD*	*p*	*Mean ± SD*	*p*
ANS	-0.13 ± 1.22	0.77	-0.30 ± 0.52	0.14	-0.25 ± 0.88	0.44
A	0.13 ± 1.21	0.78	-0.19 ± 1.06	0.62	-0.40 ± 1.59	0.50
Pr	0.11 ± 1.17	0.81	-0.28 ± 0.50	0.15	-0.62 ± 2.40	0.49
U1	0.07 ± 1.14	0.87	0.26 ± 1.64	0.67	-1.27 ± 1.82	0.09
L1	0.87 ± 1.52	0.42	-7.97 ± 1.52	0.00 *	-3.48 ± 1.79	0.00 *
Id	1.13 ± 2.73	0.28	-7.48 ± 1.16	0.00 *	-2.9 ± 1.29	0.00 *
B	1.17 ± 2.31	0.19	-6.70 ± 1.84	0.00 *	-4.93 ± 2.18	0.00 *
Pog	1.22 ± 2.16	0.15	-5.94 ± 2.19	0.00 *	-4.41 ± 1.64	0.00 *
Me	0.62 ± 1.19	0.45	-5.95 ± 2.29	0.00 *	-3.80 ± 1.19	0.00 *

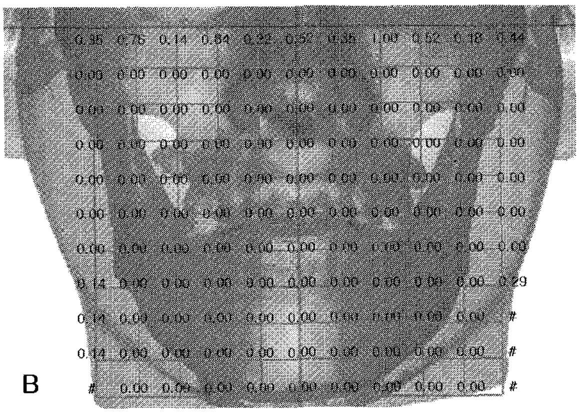
* $p < .05$.

Table 5. Mean, standard deviations and *p* values of the points constructing the pre- and post-operative grid

	Pre-operative	*Post-operative*	*Mean ± SD*	*p*
Po_{lt} (x)	61.33 ± 2.02	61.38 ± 2.23	-0.06 ± 0.76	0.84
Po_{rt} (x)	-61.17 ± 1.41	-61.05 ± 2.33	-0.13 ± 1.44	0.81
Me (z)	101.36 ± 7.54	97.56 ± 8.24	-3.80 ± 1.19	0.00 *

* $p < .05$.

A



B

Fig 3. Reproducibility of grid points by paired *t*-test. **A,** *p* value of x coordinate; **B,** *p* value of z coordinate.

post-operative states. There was no difference in distance from the midsagittal plane to Po between pre- and post-operative states. However, z coordinates of Me which constructed the vertical axis of the grid were not identical between pre- and post-operative states (Table 4, 5). Consequently, x coordinates of grid points showed no significant difference, but z coordinates showed a significant difference (Fig 3).

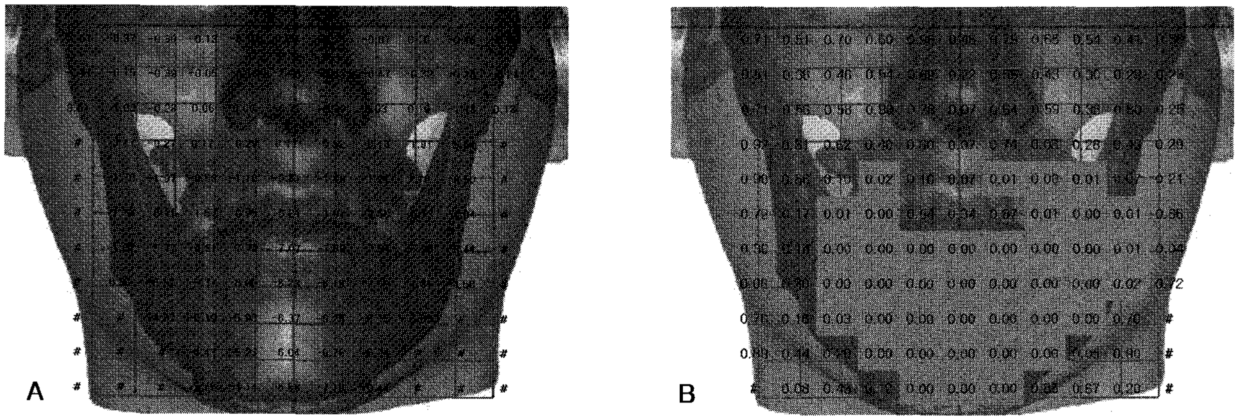


Fig 4. Bone and soft tissue changes from mandibular setback surgery. **A,** The amounts of posterior bony movement (y coordinate); **B,** paired *t*-test of the antero-posterior soft tissue movement between the pre- and post-operative states; the soft tissue changes were not confined to the mandibular area, but extended to the mouth corner.

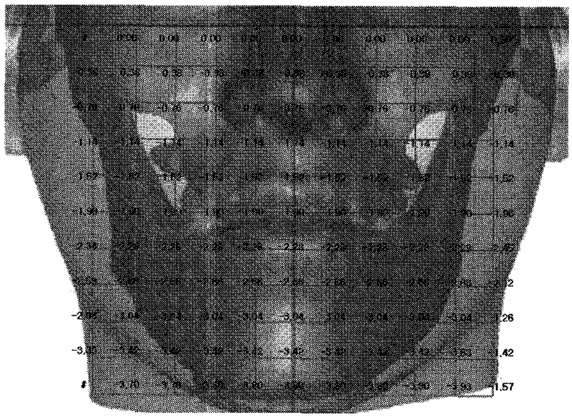


Fig 5. Mean differences of z axis coordinate.

Analysis of soft tissue change after surgery

In Table 4, the *p* values of y axis and z axis of mandibular landmarks (L1, Id, B, Pog, Me) show the posterior and superior movements of the mandible ($p < 0.05$) and the decrease in facial height. Fig 4 presents the posterior (y coordinate) bony movement and a *t*-test of the soft tissue movement. The posterior movement of the mandibular dentition was greater than that of the mandibular body, which was regarded as immediate surgical relapse and post-operative orthodontic treatment.

The distance from FH plane to Me decreased by 3.80 ± 1.19 mm (Table 5). The vertical positions of Me changed significantly. So the vertical position of each horizontal line showed a 0.38 mm cumulative decrease (Fig 5).

The representative points for mandibular movement were chosen and used to calculate the relative movement of the soft tissue (Fig 6). These points were B, Pog, or 83rd point which was defined in the grid (Fig 2). In Fig 6, the relative movements of soft tissue to the corresponding bony movement are shown.

DISCUSSION

Defining the coordinate system

In viewpoint of the mean and SD of the coordinate deviation, x axis ranged from -0.75 ± 1.28 to 0.06 ± 0.41, y axis from -0.52 ± 1.11 to 0.03 ± 1.06 and z axis from -0.35 ± 0.67 to 0.03 ± 0.88 (scale; mm), which were generally acceptable, considering that the pixel spacing of head and neck CT was 0.383 ~ 0.493 mm. Romani et al.[9] insisted that the soft tissue change under 2 mm could not be detected by orthodontists and lay people. This was also confirmed by no changes in the position of maxillary points (Table 4).

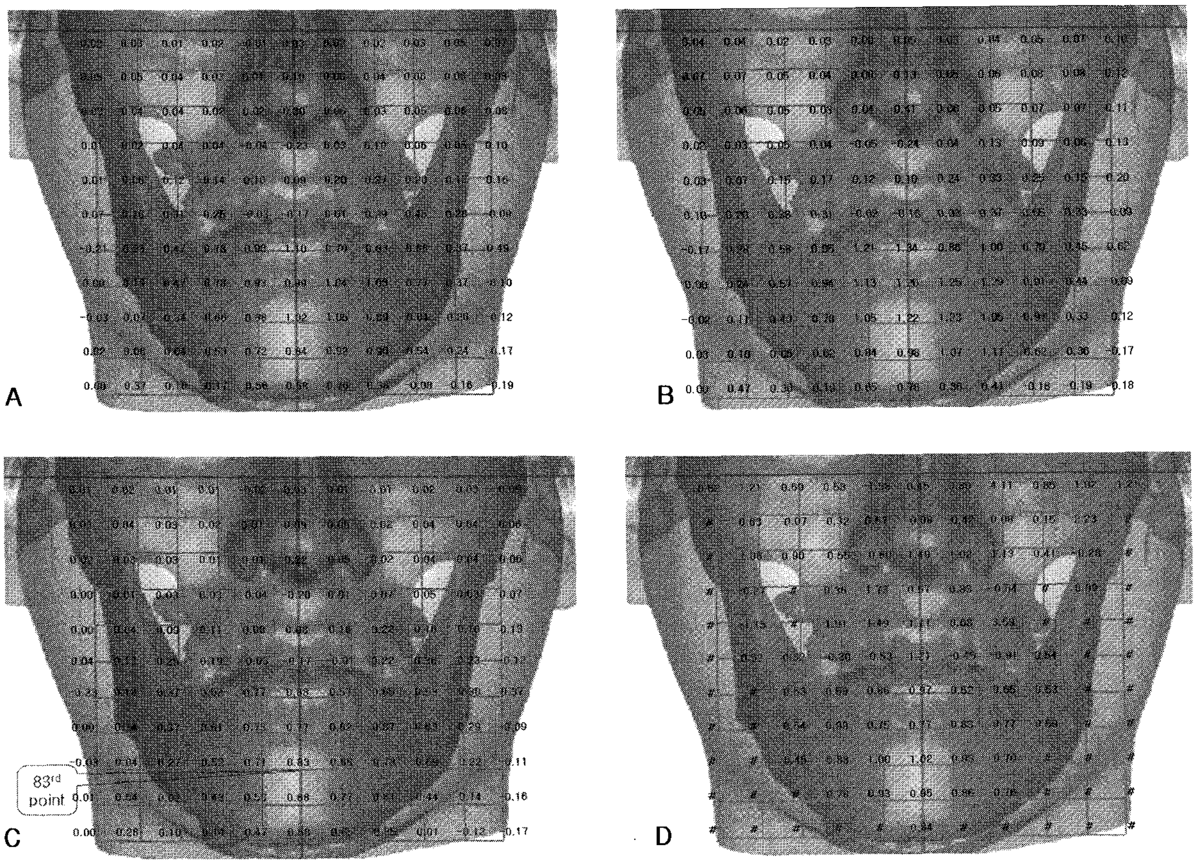


Fig 6. Relative ratios of soft tissue change to mandibular movement based on each representative point. **A,** Based on B point; **B,** based on Pog point; **C,** based on 83rd point; **D,** based on the corresponding grid points.

Mandibular movement

In Table 4, the *p* values of y axis and z axis of mandibular landmarks (L1, Id, B, Pog, Me) show the posterior and superior movements of the mandible ($p < 0.05$) and a decrease in facial height. This was because the mandible was moved according to the occlusal plane which was not parallel to FH plane. There was no significant deviation from the midsagittal plane, which was regarded as satisfying the sample selection criteria of excluding severe asymmetry cases.

Reproducibility test of the grid

X coordinates of Po contributing to the horizontal axis of the grid were identical between pre- and post-operative states. There was no difference in distance from the midsagittal plane to Po between pre- and post-operative states. The x coordinate had the same *p* values ($p = 0.23$), because the shorter line was evenly divided by 5 sections (Fig 3). The outer points of the face had different *p* values due to the missing value. The *t*-test at the midsagittal plane was not necessary, because the x coordinate of midsagittal plane was zero by definition. X coordinates of pre- and post-operative models could be inferred identical from the results of the paired *t*-test.

The distance from FH plane to Me decreased by 3.80 ± 1.19 mm (Table 5). The vertical position of Me changed significantly. So the vertical position of each horizontal line showed a 0.38 mm cumulative decrease (Fig 5). The facial height decrease was inevitable so long as the mandible was setback according to the occlusal plane, which meant that all the landmarks positioned on the mandible showed significant changes in vertical position with the same pattern. Me was chosen to define the grid because it was the lower limit of the mandible. In order to remove this approximation error, the occlusal plane should be chosen as a reference plane for the measurement, but this could cause a problem with model segmentation. There were no references to discriminate between the upper and lower parts in the cheek area. Moreover, post-operative orthodontic treatment could cause a change in tooth position, which could then cause a cascade error establishing the reference coordinates. This is because the horizontal reference plane is the first plane establishing the coordinate system.

So further studies will be required in the linear approximation method, because there are non-linear changes in the facial height according to the type of surgical methods. In this case, Table 4 shows the non-linear change which means that there were no changes in the maxillary region and significant change in the mandibular region.

Soft tissue change

After surgery, the mandibular dentition was moved posteriorly 7.37 ± 2.31 mm, B point 6.09 ± 2.52 mm, and Pog 5.23 ± 2.94 mm. The amount of setback decreased with further movement away from the midsagittal plane.

The soft tissue changes occurred mainly in the mandibular area. However, there were also significant changes in the mouth corner (Fig 4, *B*). Because the orbicularis oris muscle fibers were inserted across the mouth corner, the changes in lower lip could affect tension in the month corner.

The soft tissue changes were evaluated relative to the changes in the representative points for mandibular movement. B and Pog were selected for comparison with previous cephalometric studies. The 83rd point was selected to offset the nonlinear approximation error, resulting from the facial height decrease.

The soft tissue changes based on the representative points of mandibular movement showed a similar pattern that the farther it is located from the midsagittal plane, the smaller the movement of the soft tissue (Fig 4, *A*). However, there was a minor difference between the soft tissue change based on B or Pog, and those based on the 83rd point. In case of B or Pog, there were more changes of soft tissue from the lower lip to protuberance menti than that observed in the cephalometric study. Otherwise, in case of 83rd point, the ratio of soft tissue change is 77 ~ 88%. The ratio of change under Pog is 58 ~ 68%, which is lower than the previous change.

Due to the decrease in facial height, the vertical position of the grid points changed. Non-linear approximation according to facial height (the distance from FH plane to Me) made the vertical position of the post-operative grid points move superiorly. Therefore, the ratio could be overestimated or underestimated, because the ratio of soft tissue change on the basis of some of the fixed landmarks (B and Pog) could not reflect the change in vertical positions. The surgical changes of the points on the bony surface positioned above the greatest concavity were calculated smaller than the real movement. On the contrary, the changes of the points under the greatest concavity were calculated larger than reality. This was contrary to the point positioned on the convex surface. These differences resulted from the direction of mandibular movement, the degree of bony curvature, and the decrease in facial height.

On the other hand, on the basis of the 83rd point of the grid, the errors in bony surface according to curvature compensated for the errors of soft tissue change, which resulted in a more precise result. However, the surface of the 3D model under Pog showed such a large curvature that the ratio of change was smaller than other areas.

This made it more reasonable that the calculation of soft tissue change over its corresponding bony movement was better than that over the representative bony movement (Fig 6, *D*). The change at the midsagittal plane was 77 ~ 102%. This was similar to that shown in previous research using cephalometric radiographs.[4] The pattern of the result was not significantly changed with the distance from the midsagittal plane. The change in mouth angle, however, was exaggerated, because the movement of the maxilla was much smaller than the surgical movement of the mandible.

Consequently, the ratio of soft tissue change should be calculated in two ways; in the moving region (mandible), the ratio should be calculated by the corresponding point of bony movement. In the non-moving region (maxilla), the ratio should be calculated by the representative point. In the latter case, the ratio calculated from the grid point gave better results than that from the cephalometric point.

In this study, the soft tissue change after surgery was investigated three dimensionally. The non-linear approximation of facial height was employed to measure the soft tissue change. This approach represented an approximated model. For more accurate estimation, linear model irrespective of facial height changes would make a more exact model. In addition, to make a more precise estimation model, a larger number of samples would be needed.

CONCLUSIONS

The 3D soft tissue changes after mandibular setback surgery were estimated from CT scans. In this study, a novel approach was proposed to evaluate 3D changes of soft tissue. The result was reasonably acceptable in viewpoint of previous cephalometric radiograph studies and general clinical knowledge.

- 국문초록 -

골격성 3급 부정교합 환자의 하악골 후퇴술 시행후 안모변화에 대한 3차원적 연구

박재우 · 김남국 · 김명진 · 장영일

하악 수술로 치료한 골격성 3급 부정교합 환자의 연조직 변화를 3차원적으로 분석하였다. 수술전과 수술후에 CT를 촬영하고, 연조직과 경조직을 각각의 임계값에 따라 segmentation하였다. FH평면, 정중시상면, PNS를 포함하는 전두면을 기준으로 공통 좌표계를 구성하고, 이 좌표계를 기준으로 술전, 술후 영상을 위치시켰다. 술후의 변화를 측정하기 위해 각각의 모형에 대해 전두면에 평행한 grid를 형성하였다. Grid 내의 교점에서 골조직과 연조직 모형에 투사하여 만나는 점의 좌표값을 구하고, 이를 바탕으로 술후의 변화를 측정하였다. 하악골 후퇴술시 안모의 변화는 하악골 부분에서만 발생한 것이 아니라, 구각부에서도 관찰되었다. 하악골 부위의 연조직 변화는 대응되는 골조직 이동량에 따른 상대적인 값으로 계산하였다. 정중시상면에서의 변화율은 77 ~ 102%로 나타났다 ($p < 0.05$). 정중시상면 이외의 부분의 변화양상도 이와 유사하였다. 구각부에서의 변화는 하악골의 이동을 대표할 수 있는 점의 이동량에 대한 상대적인 값으로 계산하였다. 정중시상면에서의 변화는 B점을 기준으로 14 ~ 29%이고, Pog점을 기준으로 17 ~ 37%, grid상 83번째 점을 기준으로 11 ~ 22%로 관찰되었다 ($p < 0.05$).

(주요 단어: 3차원 분석, 3차원 좌표계, 3D Registration)

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