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Formulation of a reference coordinate system of three-dimensional head & neck images: Part II. Reproducibility of the horizontal reference plane and midsagittal plane

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This study was performed to investigate the reproducibility of the horizontal and midsagittal planes, and to suggest a stable coordinate system for three-dimensional (3D) cephalometric analysis. Eighteen CT scans were taken and the coordinate system was established using 7 reference points marked by a volume model, with no more than 4 points on the same plane. The 3D landmarks were selected on V works (Cybermed Inc., Seoul, Korea), then exported to V surgery (Cybermed Inc., Seoul, Korea) to calculate the coordinate values. All the landmarks were taken twice with a lapse of 2 weeks. The horizontal and midsagittal planes were constructed and its reproducibility was evaluated. There was no significant difference in the reproducibility of the horizontal reference planes. But, FH planes were more reproducible than other horizontal planes. FH planes showed no difference between the planes constructed with 3 out of 4 points. The angle of intersection made by 2 FH planes, composed of both Po and one Or showed less than 1° difference. This was identical when 2 FH planes were composed of both Or and one Po. But, the latter cases showed a significantly smaller error. The reproducibility of the midsagittal plane was reliable with an error range of 0.61 to 1.93° except for 5 establishments (FMS-Nc, Na-Rh, Na-ANS, Rh-ANS, and FR-PNS). The 3D coordinate system may be constructed with 3 planes; the horizontal plane constructed by both Po and right Or; the midsagittal plane perpendicular to the horizontal plane, including the midpoint of the Foramen Spinosum and Nc; and the coronal plane perpendicular to the horizontal and midsagittal planes, including point clinoidale, or sella, or PNS.

(**Key words**: 3D landmark, Reproducibility, Horizontal reference plane, Midsagittal plane)

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INTRODUCTION

In the 1930s, Broadbent introduced his original cephalostat design to analyze the craniofacial structures from standardized frontal and lateral radiographic images.[1] Ever since, numerous authors have suggested methods of generating three-dimensional (3D) cephalometric measurements from two-dimensional (2D) cephalometric projections.

Baumrind *et al*[2,3] pioneered a mechanical research solution of paired coplanar images to improve landmark identification in three dimensions. Grayson *et al*[4] attempted 3D analysis with biplanar images. They tried to generate 3D measurements using the "vector intercept with averaging algorithm."[5] Brown and Abbott[6] demonstrated how to obtain 3D coordinate values of landmarks with a photogrammetric equation, taking cephalometric radiographs from one X-ray source. They also advised on the use of a leveling device to check for head positioning as the subject's head is rotated from one projection to another.

Kusnoto *et al*[7] invented a specially designed face bow to obtain PA, lateral, and submentovertex views. They suggested that data could be easily collected from each view, and were clinically comparable to CT data. But the images obtained from this method were merely some polygons in the form of a mesh, and not the actual 3D images.

The development of computer technology gave a chance for the orthodontist to use 3D images in treatment. The introduction of Invisalign (Align Technology Inc., Santa Clara, CA), and its related technology appealed to many orthdontists.[8-10] It was said that the reconstructed study models were used to simulate the course of orthodontic treatment and the clear aligner so called Invisalign could be fabricated from each step of the simulation. Invisalign has evoked much debate in orthodontics, when it was suggested that orthodontic treatment can be accomplished without braces. In any case, it can be certain that Invisalign evoked the introduction of 3D technology into orthodontics. Many authors tried to study the development of the devices to acquire 3D images,[11,12] to actually acquire 3D images,[13-15] to study the 3D changes according to growth and treatment, and to reconstruct orthodontic study models.[16,17] There were also studies on how to unite the different data formats.[18] In all of these studies 3D images were used to compare the relative changes and differences, but could not suggest a standardized coordinate system to evaluate the 3D images. This might be because the absolute coordinate system was not adapted to the Digital Imaging and Communication in Medicine (DICOM) standard.[19]

The patient orientation in the DICOM standard is as follows for CT scans. The direction of the CT scan is the z axis. The direction perpendicular to the floor is the y axis, and the direction of the floor is the x axis. The zero points of the x and y axes are defined as somewhere in the upper right side of the patient, but the zero point of the z axis is not defined. It is arbitrarily defined according to such factors as the condition of scan, devices, and field of scan. This means that there is no fixed coordinate system for 3D medical images.

Since there is no standardized protocol about the head position in CT scans, the head posture is likely to be different with each scan even in the same patient. This makes it impossible to superimpose the CT data of the same patient directly, which means that quantitative analysis is not feasible. Henceforth, 3D image has limited applications in clinical use as an adjunctive data in spite of the advantages of being able to show the topographic relations between dento-maxillofacial structures in all planes of space from any viewpoint.

The purpose of this study was to investigate the reproducibility of points in the horizontal and midsagittal planes, and to suggest the most stable coordinate system for 3D cephalometric analysis.

MATERIAL AND METHODS

Sample

CT scans were taken from 18 adult patients who came to Seoul National University Dental Hospital for orthognathic surgery. Eight of them were male, and the rest were female. CT data acquisition were performed using a Somatom Plus 4 (Siemens, Erlangen, Germany) at a 1.5 mm section interval, 1 mm slice thickness in the spiral mode, and a 512 by 512 matrix. The resultant 2D image data were stored in DICOM format.

Establishment of the coordinate system for coordinate value export

V works for surgery 4.0 (Cybermed Inc., Seoul,

Fig 1. Volume rendering of skull and reference points for coordinate system.

Korea) was used to select the 3D landmarks. As previously mentioned, DICOM standard does not apply an absolute coordinate system. Hence, a common coordinate system should be established before the coordinate values of 3D landmarks are extracted. Seven reference points were isolated to establish a coordinate system as a form of a volume model of 4 by 4 by 2 pixel size (Fig 1). These volume models were made to mark the reference points for coordinate system construction. The threshold value for isolation was 865.

Seven reference points were selected near the anatomic structures listed below. The order of coordinate system setting was as follows:

a> Configurations for horizontal plane (Fig 2, *A*): z coordinate value was zero.
R1, mesiobuccal cusp of left maxillary first molar; R2, mesiobuccal cusp of right maxillary first molar; R3, Incision Superius.
b> Configurations for sagittal plane (Fig 2, *B*): x coordinate value was zero.
The sagittal plane was established to include point R4 and the midpoint of R5 and R6, perpendicular to the horizontal plane.
R4, Prosthion; R5, apex of left maxillary central incisor; R6, apex of right maxillary central incisor.

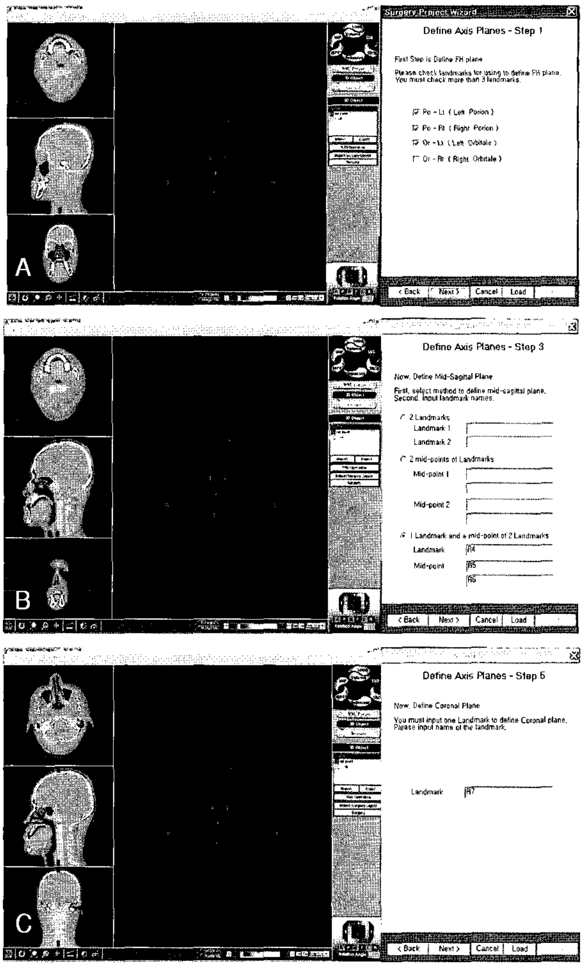

Fig 2. Steps for establishment of the common coordinate system. **A,** Point selection for the horizontal plane, point name cannot be changed in case of horizontal plane selection; **B,** point selection for the sagittal plane. In this step, the operator can select the method for defining the midsagittal plane and input the point name; **C,** point selection for the coronal plane. Operator must input the landmark names for coronal plane construction.

c> Configuration for coronal plane (Fig 2, *C*): y coordinate value was zero.
The coronal plane was established to include point R7, perpendicular to the horizontal plane and sagittal plane.
R7, Basion.

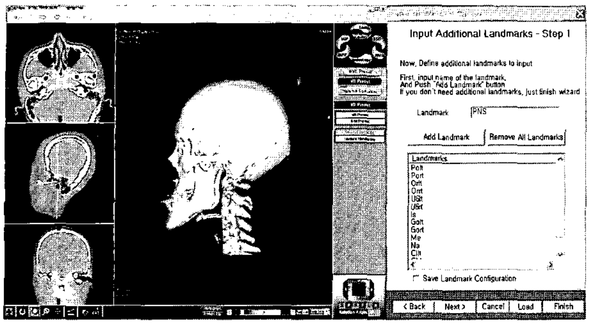

Fig 3. Selection of the volume point in the MPR window with the volume model.

Landmark selection

3D landmarks were selected in the multiplanar reformation (MPR) mode (Fig 3). The definition of each landmark has been illustrated in the previous study.[20] The landmarks used in this study are listed below:

Po Lt/Rt, the midpoint on the upper edge of porus acusticus externus; Or Lt/Rt, the lowest point on the lower margin of each orbit; U6 Lt/Rt, the mesiobuccal cusp tip of the maxillary first molar; Is, the mid-point of the incisal edge of the maxillary central incisor; Go Lt/Rt, the point on the bony contour of the gonial angle determined by bisecting the tangent angle; Me, the lowest median landmark on the lower border of the mandible - concave surface under mentum in the mid-sagittal plane; Na, the junction of the nasal and frontal bones as seen on the profile of the cephalometric radiograph, point in the midline of both the nasal root and the nasofrontal suture; Cl Lt/Rt, the most posterior point on the contour of the anterior clinoid; Nc, the most superior point of crista galli, the projection of the perpendicular lamina of the ethmoid; S, the center of sella turcica; FMS Lt/Rt, the most superior-lateral point of suture between the malar bone and the frontal bone; FS Lt/Rt, the geometric center of Foramen Spinosum which can be found in the most inferior horizontal section; FR Lt/Rt, the geometric center of Foramen Rotundum which can be found in the most anterior coronal section; Rh, the most anterior inferior point on the tips of the nasal bones; ANS, the most anterior point of the nasal floor, tip of premaxilla; PNS, the most posterior point on the hard palate.

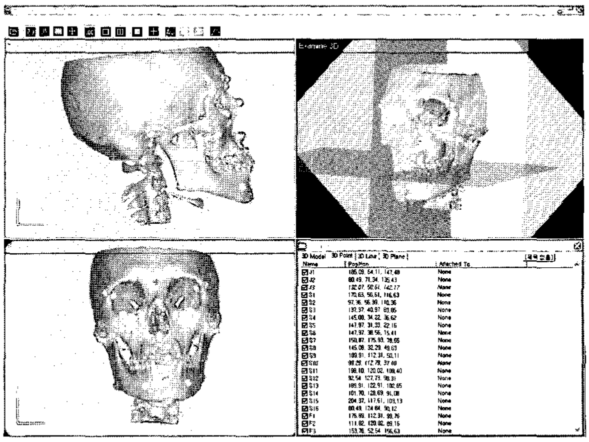

Fig 4. Project file exported to V surgery for coordinate extraction.

After selection of 3D landmarks, project files were exported to V surgery (Cybermed Inc., Seoul, Korea) to extract the coordinate values (Fig 4).

Construction of the planes and its reproducibility

All the points for plane construction were selected twice with a lapse of 2 weeks. Reproducibility was evaluated by the angle of intersection formed by the 2 planes, each of which was constructed by the same points.

a> Construction of FH planes and its reproducibility
Four FH planes were constructed with 3 out of 4 points (both Or and both Po). FH1 was defined as a plane constructed from both Or and the left Po. FH2 was defined from both Or and the right Po. FH3 was defined from both Po and the left Or. FH4 was defined from both Po and the right Or. Each plane was constructed twice in the same individual, and the angle of intersection of the plane was calculated for reproducibility. The angle of intersection between FH1 and FH2, and that between FH3 and FH4 were also compared.

b> Construction of the horizontal planes and its reproducibility
Five horizontal planes were selected on the basis of the possibility of choosing the projected line in 2D cephalometric radiography. The 5 planes were as

Table 1. Mean, standard deviation, and standard error of the coordinate value difference between first and second selection of which the points used for horizontal plane construction (scale: mm)

	X axis		*Y axis*		*Z axis*	
	Mean ± SD	*SE*	*Mean ± SD*	*SE*	*Mean ± SD*	*SE*
Po (left)	-0.15 ± 1.14	0.79	-0.01 ± 0.84	0.58	0.01 ± 1.24	0.86
Po (right)	0.32 ± 0.91	0.67	-0.09 ± 0.76	0.53	-0.07 ± 0.86	0.59
Or (left)	-0.45 ± 1.70	1.21	-0.30 ± 0.93	0.67	-0.37 ± 1.03	0.75
Or (right)	0.04 ± 1.74	1.19	-0.15 ± 1.04	0.72	-0.28 ± 1.08	0.77
U6 (left)	0.06 ± 0.55	0.38	0.52 ± 0.82	0.67	-0.06 ± 0.46	0.32
U6 (right)	-0.10 ± 0.51	0.36	0.43 ± 0.74	0.59	0.29 ± 0.66	0.50
Is	0.19 ± 0.60	0.44	0.06 ± 0.58	0.40	-0.32 ± 1.32	0.93
Go (left)	-0.28 ± 0.85	0.62	0.50 ± 0.98	0.76	-0.24 ± 1.62	1.13
Go (right)	0.08 ± 0.70	0.49	0.28 ± 1.63	1.14	0.11 ± 2.15	1.48
Me	-0.09 ± 0.36	0.25	0.05 ± 1.13	0.78	-0.45 ± 1.32	0.96
Na	-0.06 ± 1.14	0.78	-0.24 ± 1.00	0.71	0.52 ± 2.58	1.81
Cl (left)	0.06 ± 0.46	0.32	-0.32 ± 0.98	0.71	-0.25 ± 0.56	0.42
Cl (right)	0.02 ± 0.44	0.30	-0.16 ± 0.97	0.67	-0.08 ± 0.38	0.27
Nc	-0.05 ± 0.73	0.51	-0.19 ± 1.30	0.90	-0.22 ± 0.60	0.44
S	-0.19 ± 0.86	0.61	-0.27 ± 0.97	0.69	-0.05 ± 0.72	0.49

SD, Standard deviation; *SE*, standard error.

follows and the reproducibility was evaluated with the angle of intersection:

Occlusal plane, the plane constructed through the mesiobuccal cusps of both maxillary first molars and Incision Superius; Mandibular plane, the plane constructed from both Go and Me; S-Cl plane, the plane constructed from both clinoidale and S; Na-Cl plane, the plane constructed from both clinoidale and Na; Nc-Cl plane, the plane constructed from both clinoidale and Nc.

c> Construction of the midsagittal plane and its reproducibility

The midsagittal plane was selected as the plane perpendicular to the most reproducible horizontal plane evaluated in the previous section. It also included 2 out of the 8 points which were thought to be in the midsagittal plane. These points were FMS (the midpoint of both frontomalar suture), Na, FS (the midpoint of both Foramen Spinosum), FR (the midpoint of both Foramen Rotundum), Nc, Rh, ANS, and PNS. The reproducibility was evaluated as the angle of intersection of the 2 planes with the same composition.

Statistics

The angle of intersection of the horizontal planes was analyzed by ANOVA. The angle of intersection between FH1 and FH2, and that between FH3 and FH4 were tested by paired *t* test. The angle of intersection between FH1 and FH2, and that of FH3 and FH4 were also compared by paired *t* test. The angle of intersection of the midsagittal plane was also calculated.

RESULTS

Reproducibility of landmarks for plane construction

The reproducibility of landmarks was defined as the mean, standard deviation (SD), and standard error (SE) of the difference, which was the same as in Part I.[20] The reproducibility of landmarks for the horizontal plane is shown in Table 1. The error range was 0.30 ~ 1.21 mm in the x axis, 0.53 ~ 1.14 mm in the y axis, and 0.27

Table 2. Mean, standard deviation, and standard error of the coordinate value difference between first and second selection of which the points used for midsagittal plane construction (scale: mm)

	X axis		*Y axis*		*Z axis*	
	Mean ± *SD*	*SE*	*Mean* ± *SD*	*SE*	*Mean* ± *SD*	*SE*
FMS	-0.17 ± 0.89	0.62	-0.29 ± 1.81	1.26	-0.36 ± 1.08	0.78
FS	0.02 ± 0.32	0.22	-0.13 ± 0.45	0.32	-0.21 ± 0.90	0.64
FR	0.20 ± 0.98	0.69	-0.01 ± 0.87	0.60	0.25 ± 1.48	1.03
Rh	0.01 ± 0.69	0.47	-0.46 ± 0.99	0.75	-0.70 ± 1.13	0.92
ANS	0.03 ± 0.96	0.66	-0.26 ± 0.55	0.42	-0.37 ± 1.41	1.00
PNS	-0.04 ± 0.95	0.65	0.43 ± 0.55	0.48	-0.16 ± 0.60	0.42

The landmarks included in Table 1 were not presented. *SD,* Standard deviation; *SE,* standard error.

Table 3. Reproducibility of the horizontal reference plane

	θ (°)	Subset*
FH1	1.34 ± 0.80	1
FH2	1.21 ± 0.61	1
FH3	1.15 ± 0.79	1
FH4	1.07 ± 0.69	1
Occlusal plane	1.46 ± 0.90	1
Mn. plane	1.23 ± 0.65	1
S-Cl plane	21.97 ± 23.12	2
Na-Cl plane	2.04 ± 1.56	1
Nc-Cl plane	1.41 ± 1.15	1

* Duncan's homogeneous subsets (Subset for alpha = .05).

Table 4. Paired *t* test of the angle between FH1 and FH2 and angle between FH3 and FH4 (scale:°)

	First selection	*Second selection*	*p-value*
FH1 Vs FH2	1.17 ± 0.78	0.64 ± 0.42	0.07
FH3 Vs FH4	0.76 ± 0.66	0.41 ± 0.35	0.07

Table 5. Paired *t* test of the difference between the angles composed of FH1 and FH2, FH3 and FH4

	FH1 and FH2	*FH3 and FH4*	*p-value*
θ (°)	0.96 ± 0.74	0.53 ± 0.40	0.003**

** $p < 0.01$.

~ 1.81 mm in the z axis. Table 2 shows the reproducibility of landmarks for the midsagittal plane. The error range was 0.22 ~ 0.78 mm in the x axis, 0.32 ~ 1.26 mm in the y axis, and 0.42 ~ 1.81 mm in the z axis.

Reproducibility of the horizontal plane

There was no significant difference in the reproducibility of the horizontal plane except for the S-Cl plane. The range of the intersection angle was 1.07 ~ 2.04° (Table 3). The angle of intersection between FH1 and FH2 was 1.17 ± 0.78° at first selection, and 0.64 ± 0.42° at second selection. The angle of intersection between FH3 and FH4 was 0.76 ± 0.66° at first selection, and 0.41 ± 0.35° at second selection. There was no significant difference between the first and second selections ($p < 0.05$) (Table 4).

Data from the first selection and the second selection were consolidated since there were no statistical differences between the 2 data sets. The angle of intersection formed by FH1 and FH2, and that formed by FH3 and FH4 were compared by paired *t* test, which showed that the angle of intersection between FH3 and FH4 was statistically smaller ($p < 0.01$) (Table 5).

Reproducibility of the midsagittal plane

FH4 was selected as the horizontal reference plane

Table 6. Mean and standard deviation of the intersection angle of the midsagittal planes constructed on the basis of FH4 as a horizontal reference plane (Mean ± SD: mm)

	FMS	*Na*	*FS*	*FR*	*Nc*	*Rh*	*ANS*
Na	1.87 ± 1.25						
FS	0.86 ± 0.54	0.76 ± 0.45					
FR	1.43 ± 1.09	1.02 ± 0.80	1.78 ± 1.71				
Nc	17.73 ± 13.97	1.61 ± 1.54	0.80 ± 0.30	1.47 ± 1.44			
Rh	1.26 ± 0.68	3.80 ± 2.48	0.61 ± 0.28	0.75 ± 0.47	0.93 ± 0.59		
ANS	1.51 ± 1.20	18.43 ± 26.45	0.80 ± 0.55	0.97 ± 0.52	1.49 ± 1.49	5.83 ± 5.50	
PNS	1.76 ± 1.83	1.32 ± 1.05	1.96 ± 1.60	12.67 ± 15.87	1.93 ± 2.05	0.91 ± 0.97	0.98 ± 1.08

for the construction of the midsagittal plane since the difference of the intersection angle was smallest despite showing no statistical significance. The reproducibility of the midsagittal plane was favorable with an error range of 0.61 to 1.93° except for 5 establishments (FMS-Nc, Na-Rh, Na-ANS, Rh-ANS, and FR-PNS). The most reproducible plane was the plane constructed with FS and Rh (Table 6).

DISCUSSION

There was no significant difference in the reproducibility of the horizontal plane except for the S-Cl plane. The FH planes were more reproducible than the other planes on the basis of the mean and SD of the angle of intersection. The range of the angle of intersection was 1.07 ~ 2.04° (Table 3).

The reproducibility of the horizontal plane might be mainly determined by the spatial relationship of the points that constructed the plane, not the reproducibility of the points themselves. The reproducibility of S point and Cl points were relatively high compared with other landmarks. However, these 3 points were so closely arranged that minor errors in landmark positioning made big changes in the plane orientation. Although there was no statistical significance, the pattern of the intersection angle in the horizontal planes reflected this trend. The reproducibility of Nc-Cl plane, which was constructed with highly reproducible points, was lower than that of FH plane, which was constructed with low reproducible points, and so on.

There was no statistical difference in the angle of intersection between FH1 and FH2 between the first and second selection. This was also true in the angle of intersection between FH3 and FH4 ($p < 0.05$) (Table 4). Henceforth, the 2 data sets were consolidated and the angle of intersection formed by FH1 and FH2, and that formed by FH3 and FH4 were compared by paired t test. Although the difference of intersection angle was minute, the angle of intersection between FH3 and FH4 was statistically smaller ($p < 0.01$) (Table 5). This meant that the FH planes constructed from both Po and one Or was more stable than that taken from both Or and one Po. So FH4 was selected as the horizontal reference plane for the construction of the midsagittal plane since the difference of the intersection angle was smallest despite of no statistical significance.

Eight landmarks were selected since these were considered in the midsagittal plane by definition. The midsagittal plane was defined as a plane perpendicular to FH4 plane, and included the 2 points out of 8 landmarks. Reproducibility of the midsagittal plane was favorable with an error range of 0.61 to 1.93° except for 5 establishments (FMS-Nc, Na-Rh, Na-ANS, Rh-ANS, and FR-PNS). These 5 cases showed low reproducibility because of the close spatial relationship. The hypothesis applied in the horizontal plane was also available in the case of the midsagittal plane. Notably, when the 2 points were very close in the anteroposterior relationship, a subtle difference of the x coordinate could make a big difference in the plane direction. This may be exaggerated when the difference of the y coordinate is small. Furthermore, the line connected by the 2 points for the midsagittal plane construction could be perpendicular to the horizontal reference plane, i.e. FH4. In this case, the possibility to generate the plane perpendicular to FH4 plane increased infinitely. It meant it was impossible to set the midsagittal plane.

The most reproducible combinations were FS-Rh (0.61 ± 0.28°), FR-Rh (0.75 ± 0.47°), Na-FS (0.76 ± 0.45°), FS-Nc (0.80 ± 0.30°), FS-ANS (0.80 ± 0.55°). The combination of Nc and FS might be the most recommendable points to be used as a midsagittal plane. Point Na showed low reproducibility of the point itself. Point Rh and/or ANS could be out of midsagittal plane in the patient with midfacial deformities.

Now, 2 reference planes have been established for the 3D coordinate system. The last plane to be defined was the coronal plane. The coronal plane could be defined as a plane simultaneously perpendicular to the horizontal and midsagittal planes, including the point which might be most reproducible in the y axis direction. The recommended points for the coronal plane might be sella, clinoidale (Lt/Rt), ANS, PNS, and Rh. These were found to be the most reproducible points in Part I.[20]

CONCLUSIONS

The landmarks for orthodontic cephalometry were selected in the 3D CT images, and their reproducibility was investigated for the construction of a 3D coordinate system in head and neck images. There was no significant difference in the reproducibility of the horizontal plane except for the S-Cl plane. The FH planes were more reproducible than the other planes on the basis of the mean and SD of the angle of intersection. There was no significant difference in the reproducibility of FH plane constructed with 3 out of 4 points ($p < 0.05$). The angle of intersection made by 2 FH planes composed of both Po and one Or showed an error less than 1°. This is the same when 2 FH planes were composed of both Or and one Po. But the former cases showed significantly smaller error ($p < 0.05$). The reproducibility of the midsagittal plane was favorable with an error range of 0.61 to 1.93° except for 5 cases (FMS-Nc, Na-Rh, Na-ANS, Rh-ANS, and FR-PNS). It could be inferred that reproducibility of the plane is determined by the spatial relationship of the points that construct the plane, in addition to the reproducibility of the points themselves. The 3D coordinate system can be established by three planes which were the plane constructed by both Po and right Or as a horizontal plane, the plane perpendicular to the horizontal plane, including the midpoint of the Foramen Spinosum and Nc as a midsagittal plane, and the plane simultaneously perpendicular to the horizontal and midsagittal planes, including point clinoidale, or sella, or PNS as a coronal plane.

- 국문초록 -

3차원 두부영상의 기준좌표계 설정을 위한 연구: II부 수평기준면과 정중시상면의 재현성

박재우 · 김남국 · 장영일

본 연구는 삼차원 두부 영상을 위치시키기 위한 좌표계를 구성하는 방법에 대해 제안하기 위해, CT data에서 기존의 두부방사선 계측사진에서 쓰이는 점들을 선정하고, 이를 바탕으로 수평, 수직평면의 안정성을 조사하였다. 서울대학교 치과병원에 내원한 환자 18명의 CT자료를 채득하였으며, 모든 환자는 서울대학교 병원 진단방사선과에서 촬영하였다 (Somatom Plus 4: Siemens, Erlangen, Germany). V works for surgery 4.0 (Cybermed Inc., Seoul, Korea)을 이용하여 3차원 좌표축을 선정하고, 계측점을 선택하였다. 좌표축을 동일하게 설정하기 위해 7개의 점(reference point)을 4•4•2 pixel size의 voxel로 따로 표시하였다. 계측점을 선정한 후, V surgery (Cybermed Inc., Seoul, Korea)에서 각 점의 좌표값을 추출하였다. 각각의 점들은 2회 반복 선정한 후 점들을 조합하여 수평, 수직평면의 재현성을 평가한 결과 다음과 같은 결론을 얻었다. 수평 기준면의 재현도는 S-Cl평면을 제외하고는 통계적으로 유의한 차이를 보이지 않았으나, 사잇각은 FH평면이 가장 작게 나타났다. FH평면은 Po과 Or중 어느 3점을 선택하더라도, 통계적으로 유사한 재현도를 보였다. FH1과 FH2의 사잇각과 FH3과 FH4의 사잇각은 1° 이하의 적은 오차를 보이며, FH3와 FH4의 사잇각이 통계적으로 더 작은 차이를 보였다. 정중시상면의 재현도는 FMS-Nc, Na-Rh, Na-ANS, Rh-ANS, FR-PNS를 기준으로 설정한 경우를 제외하면, 0.61 ~ 1.93°의 양호한 값을 보였다. 이상의

결과에 의하면 공간에서 정의되는 평면의 재현도는 평면을 정의하는 점 자체의 식별오차뿐 아니라, 각 점의 위치관계에도 영향을 받는 것을 알 수 있었다. 따라서, 안정적인 3차원 기준 좌표계를 구성하려면 양측 Po과 편측 Or으로 구성되는 평면을 수평기준면으로, 수평면에 수직이고, Foramen Spinosum의 중점과 Nc를 포함하는 평면을 수직기준면으로, 수평면과 수직면에 수직이고, clinoidale나 sella, PNS를 지나는 평면을 전두면으로 설정하는 것이 바람직할 것으로 생각된다.

(**주요 단어**: 3차원 계측점, 재현도, 수평기준면, 정중시상면)

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COMMENTARY

Similar to methods of superimposition of craniofacial structures in lateral cephalometric analysis, this article introduces and describes a system for registration of 3-dimensional craniofacial image data sets. In the 2-dimensional realm, superimposition systems have allowed for many advances in our understanding of growth and development, treatment changes and enhanced our knowledge of orthodontic biomechanics and orthodontics in general. Superimposition is an invaluable tool for orthodontic analysis and research. In recent years, 3-dimensional craniofacial imaging devices have been developed[1] featuring relatively low radiation dose[2] and improved resolution[3] and, as a result, have been rapidly adopted by orthodontists for diagnosis and treatment planning as well as for research.[4] Sophisticated software programs and systems allow for visualization and reformatting of the data volumes for orthodontic applications.[5] The availability of 3-dimensional image information without the projection and anatomic superimposition associated with traditional imaging has created opportunities to rediscover much of what is understood about craniofacial growth and development and orthodontic treatment. An invaluable tool is accurate registration (like superimposition in 2-dimensional data) of the 3-dimensional information as established in this article. The reference coordinate system described sets the stage for a number of studies using

CBCT and CT image data and new approaches to the analysis of patient imaging data.

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