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Three-dimensional effect of pitch, roll, and yaw rotations on maxillomandibular complex movement

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ABSTRACT

Objectives: The purpose of this study was to evaluate the 3-dimensional (3D) effect of pitch, roll, and yaw rotations on maxillomandibular complex (MMC) movements in skeletal Class III surgical patients using 3D cone-beam computed tomography (CBCT) data and mathematical calculations.
Materials and methods: Preoperative CBCT data of 152 skeletal Class III surgical patients was obtained. The subjects were divided into four groups: group 1, non-extraction with a normal/short face; group 2, non-extraction with a long face; group 3, extraction with a normal/short face; and group 4, extraction with a long face. The maxillary and mandibular landmarks were digitized on the reconstructed 3D models, and the movements of their standardized coordinates by pitch, roll, and yaw rotations were calculated using a transformation matrix.
Results: The rotations resulted in significantly different amounts of MMC movement among the groups, which generally increased from groups 1 to 4. While roll rotation greatly affected the lateral movement of the menton and the vertical movement of the gonion, yaw rotation primarily affected the lateral and anteroposterior movement of the gonion. Combined pitch and roll rotations were required for unilateral impaction of the maxillary first molar.
Conclusion: The 3D surgical treatment objectives (STO) method was valuable for accurate prediction of MMC movements by pitch, roll, and yaw rotations, which are frequently required in orthognathic surgery patients.

1. Introduction

Orthognathic surgery combined with orthodontic treatment is the treatment of choice in adult skeletal Class III patients in whom the skeletal discrepancy is too severe to be managed by camouflage orthodontic treatment alone (Proffit W. et al., 2013). While only 5% of skeletal Class II patients are surgical candidates, up to 33% of skeletal Class III patients require surgical-orthodontic treatment (Proffit W. R. and White, 1990). Although these patients certainly benefit from orthognathic surgery, they inevitably suffer greater risks including morbidity, pain, and postoperative complications (Iannetti et al., 2013; Kang, 2014). Therefore, meticulous treatment planning, including accurate prediction of the surgical outcome, is mandatory.

Traditional approaches to predict the outcome of orthognathic surgery or establish the surgical treatment objectives (STO) have used 2-dimensional (2D) radiography such as lateral cephalograms, posteroanterior (PA) cephalograms, and submentovertex radiography. However, 2D radiography has inherent errors such as internal orientation error, external orientation error, geometric error, and association error (Quintero et al., 1999). The validity of 2D radiography for STO is even more questionable in patients with facial asymmetry due to the considerable internal orientation error caused by head position in PA cephalograms (Yoon et al., 2002; Koh et al., 2003). Moreover, differential impaction in the left and right maxilla cannot be properly evaluated in 2D images. Considering that 40–80% of skeletal Class III patients show noticeable facial asymmetry (Severt and Proffit, 1997; Willems et al., 2001; Haraguchi et al., 2002; Chew, 2006), traditional 2D radiography is not a valid tool for establishing accurate STO in the majority of those patients. Three-dimensional (3D) computed tomography (CT)

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has gained wide acceptance in diagnosis for orthognathic surgery patients (Donatsky et al., 2009; Aboul-Hosn Centenero and Hernandez-Alfaro, 2012), but little is known concerning its use in 3D STO.

During orthognathic surgery, Le Fort I down fracture and mandibular osteotomy are employed to free the maxillomandibular complex (MMC), which acts as a rigid body with six degrees of freedom in 3D space. Movement in the MMC includes translations in anteroposterior, lateral, and vertical directions, and rotations around the *x*-, *y*-, and *z*-axes, the so-called pitch, roll, and yaw rotations (Dorafshar et al., 2014). In order to reposition the MMC into the proper position as determined by STO, complex translational and rotational movements of the MMC are required, especially in patients with facial asymmetry. Translational movements are readily comprehensible because all of the coordinates move in the same direction and at the same magnitude. In contrast, 3D rotational movements create complicated and differential motions according to their locations in the MMC, which are hardly recognizable without proper mathematical calculations. Therefore, the purpose of this study was to evaluate the 3D effect of the pitch, roll, and yaw rotations on MMC movements in skeletal Class III surgical patients using 3D CT data and mathematical calculations.

2. Materials and methods

2.1. Study population

This study using a retrospective cohort was approved by the Yonsei Dental Hospital Institutional Review Board (IRB No.14-0018). Patients who visited the Yonsei University Dental Hospital (Seoul, South Korea) between 2012 and 2014 were selected based on the following criteria: (1) adult patients diagnosed with skeletal Class III (age > 18 years, ANB angle < 0°), (2) patients who underwent orthognathic surgery with pre-surgical orthodontic treatment to finish the leveling and alignment, and resolve the transverse discrepancy for stable surgical occlusion, (3) patients who underwent cone-beam computed tomography (CBCT) within 3 months preoperatively, (4) no missing permanent teeth except for maxillary premolars extracted during preoperative orthodontic treatment, and (5) patients who did not have a craniofacial deformity syndrome. The 152 patients meeting the criteria were included in this study and divided into four subgroups according to whether the maxillary premolars were extracted during the preoperative orthodontic treatment and based on the lower anterior facial height (LAFH) as follows: group 1 ($n = 55$), non-extraction with a normal/short face (ANS-Me < 80 mm); group 2 ($n = 41$), non-extraction with a long face (ANS-Me > 80 mm); group 3 ($n = 31$), extraction with a normal/short face; and group 4 ($n = 25$), extraction with a long face. Table 1 summarizes the patient characteristics.

Table 1
Patient characteristics.

Variable	Mean	SD	Minimum	Maximum
Group 1 ($n = 55$)				
Age (y)	21.4	4.4	18.0	42.0
ANB (°)	−3.30	2.30	−9.91	−0.01
SN-MP (°)	32.95	7.21	13.57	49.72
LAFH (mm)	75.62	4.44	53.32	79.83
Group 2 ($n = 41$)				
Age (y)	21.7	2.8	18.0	28.0
ANB (°)	−2.66	1.87	−7.96	−0.62
SN-MP (°)	38.70	5.32	27.35	49.71
LAFH (mm)	84.88	3.76	80.16	96.07
Group 3 ($n = 31$)				
Age (y)	21.6	4.0	18.0	30.0
ANB (°)	−2.91	2.25	−9.76	−0.31
SN-MP (°)	35.47	6.07	18.60	47.59
LAFH (mm)	74.55	3.68	70.06	79.53
Group 4 ($n = 25$)				
Age (y)	21.9	2.88	18.0	29.0
ANB (°)	−2.01	1.48	−4.74	−0.01
SN-MP (°)	38.65	6.11	28.54	50.95
LAFH (mm)	84.65	4.27	80.13	93.77

SN-MP: sella-nasion to mandibular plane angle; LAFH: lower anterior facial height (anterior nasal spine to menton).

2.2. CBCT assessment

CBCT (Alphard3030; Asahi Roentgen Inc., Kyoto, Japan) was performed on the maxillofacial region for 17 s at a field of view of 20 cm × 17.9 cm, 80 kVp, and 5 mA. Patients were seated in an upright position with occlusion in maximum intercuspation. The CBCT data were converted into digital imaging and communication in medicine (DICOM) files at a 0.39 cm slice thickness and reconstructed into 3D images using the InVivoDental software program (version 5.2; Anatomage, San Jose, CA, USA).

The reconstructed 3D images were reoriented using the nasion-basion-ANS as the midsagittal reference plane and the FH plane, defined as the horizontal plane passing through the right orbitale and porion, and perpendicular to the midsagittal plane. Landmarks were digitized and verified on the axial, coronal, and sagittal slices, and their coordinates were calculated with the zero point (0, 0, 0) at the nasion (Fig. 1). The landmarks and their respective coordinates are described in Tables 2 and 3.

2.3. Standardization of coordinates

Because the purpose of this study was to evaluate the effect of pitch, roll, and yaw rotations, and not the detailed anatomical characteristics of skeletal Class III orthognathic patients, the landmark coordinates in all patients were converted into a symmetric standardized model with surgical occlusion to simplify the mathematical calculation (Table 4). This standardization procedure consisted of the following three steps. The first step was to make the symmetric model. For the *x*-coordinates, the coordinates of the midsagittal landmarks (U1-tip, U1-apex, ANS, PNS, LIE, B, Pog, Me) were fixed to 0, and those of the bilateral landmarks (UL6, UR6, LL6, LR6, Go-L, Go-R) were averaged based on the absolute values. For the *y*- and *z*-coordinates, the coordinates of the midsagittal and bilateral landmarks were averaged. The second step was to translate all coordinates by re-designating the zero point (0, 0, 0) at the standardized coordinates of the U1-tip (U1-tip′), which served as the center of rotation. The final step was to establish surgical occlusion by translating and rotating the mandibular coordinates in order to exclude the effect of varying negative overjet among the patients. This was performed by first translating the mandibular coordinates to set the zero point at LIE; rotation was then performed around the *x*-axis to parallel the maxillary and mandibular occlusal planes (connecting the U1-tip′, UL6′, and UR6′ to the LIE, LL6′, and LR6′, respectively), and finally, translation was performed to set LIE at (0, 2, −2), which established the 2 mm overjet and overbite. The translation and rotation of coordinates was performed using a transformation matrix, which is explained in the following section. After the standardization, the maxillary incisor inclination, occlusal plane angle, arch length, and arch width were calculated, which are described in Table 2.

2.4. Mathematical calculation of the pitch, roll, and yaw rotations

Three-dimensional movement of a group of coordinates can be calculated using translation and rotation matrixes. For *n*