Three-Dimensional Cephalometric Analysis: The Changes in Condylar Position Pre- and Post-Orthognathic Surgery With Skeletal Class III Malocclusion

Aabhinav Shrestha, MDS; Shao Hua Song, MDS; Han Nyein Aung, MDS; Jirayus Sangwanakul, BDS; and Nuo Zhou, PhD

Abstract: The study includes 21 adult patients with skeletal class III malocclusion who underwent orthognathic surgery and had computed tomography images recorded presurgery (T0) up to 6 months after the surgery (T1). The computed tomography images were analyzed three-dimensionally using the Proplan CMF 3.0 software. Different skeletal and dental parameters were used in analyzing the cephalometric analysis of the patients. The change in the condylar axis angle was evaluated on 3 planes: axial, coronal, and sagittal. The anteroposterior position of the condyle in relation to the glenoid fossa was evaluated in the sagittal plane. SNB, ANB, and Y-axis were statistically significant (P < 0.01). Significant differences on the condylar axis angle were found between the groups on the sagittal plane (P < 0.05) whereas no significant differences were noted on the axial and the coronal plane. In the anteroposterior condylar position related to the glenoid fossa, the condyle exhibited different displacement on different condyles. The right condyle exhibited more of the posterior displacement whereas the left condyle exhibited more of anterior displacement of the condyle in relation to the glenoid fossa. Numerous studies have done regarding the changes after postsurgery using the two-dimensional cephalometric analysis.

Key Words: 3D Cephalometry, condyle, orthognathic surgery, skeletal class III malocclusion (J Craniofac Surg 2021;32: 546–551)

Traditionally skeletal and soft tissue changes following the orthognathic surgery have been assessed in 2 dimensions by superimposing the pre and the postoperative cephalographs on the stable structures of the face such as the anterior cranial base or by comparing the linear and the angular cephalometric measurement. Quantifying the surgical changes using three dimensional images follows the same method as traditional 2 dimensional analysis with the addition of the third dimension (the depth) which augments the amount of information obtained from the facial image. Recent advancement in imaging technology and computerized 3D computed tomography (CT) images has simplified the process of 3D planning by incorporating a computer assisted surgical procedure which has improved in the precision of the orthognathic surgery. Skeletal class III malocclusion is considered as one of the easiest to identify but most difficult to treat, that is the reason it is also called as complex and intractable orthodontic disorders. It exhibits the maxillary retrusion, mandibular protrusion or a combination of both with a concave facial profile. Facial asymmetry has been detected in 40% of patients with skeletal class III malocclusion. Asymmetrical surgical movement of the jaw can change the postoperative position of the mandibular condyle.

The prevalence of skeletal class III malocclusion is relatively high in the Chinese population than other ethnic group. Prevalence of class III malocclusion in Caucasians ranges from 0.8% to 4.0% and rises up to 12% to 13% in Chinese and Japanese populations. It not only affects the oral function such as chewing and deglutition but also affects the overall facial esthetics and tends to get worse as the age increases. Several distinct cephalometric features have been reported in class III patients, such as a short anterior cranial base length, acute cranial base angle, a short and retrusive maxilla,
These complex cases require careful treatment planning, an integrated approach and patient cooperation. A poor facial appearance is often the patient’s chief complaint, but it may be accompanied by functional problems, temporomandibular disorders, or psychosocial handicaps. Maxillary advancement, mandibular setback and bimaxillary osteotomy are the 3 basic options to correct the deformity. Patient undergoing orthognathic surgery shows a considerable amount of changes both in the hard tissues and soft tissues. The maxilla and mandible are reoriented during the orthognathic surgery. The soft tissues are also changed with respect to the hard tissue 3 dimensionally. Generally the facial esthetics are improved after the surgery but these changes are judged mainly by the changes in the soft tissues as well.

The optimum position of the condyle in dentistry has always been a controversial issue. There are various studies which define the optimum position of the mandibular condyle for prosthetic rehabilitation. In a radiographic study, Rickerts reported that most of the patients with temporomandibular joint (TMJ) disorders was concentric. Ikeda et al in limited cone beam computed tomography assessed symptoms free subjects who had no disk displacements as verified by magnetic resonance imaging, and showed that the ratio of the position of the condyle to the glenoid fossa (anterior space to posterior space) was 1.0 to 1.9 to 1.6.

During the orthognathic surgery, proper condylar positioning is one of the most important factors in postoperative stability. Changes mostly occur in the position of the mandibular condyle, the articular disc and the paradiscal tissues. If there is an inappropriate condylar placement of the TMJ, it can result in many postoperative complications which may further result in idiopathic condylar resorption, different functional disorders and in a long time may result in post-operative relapse. Knowing the condylar movement after the orthognathic surgery can help prevent postoperative instabilities. There are different factors contributing to the change in condylar position during orthognathic surgery. These factors mainly include the posture of the patient during surgery, the orientation of the muscles of mastication, the use of muscle relaxants, improper rigid fixation, faulty fixation methods, intracapsular bleeding of the TMJ, and edema formation of the TMJ, internal derangement or a combination of all these factors.

**AIM OF THE STUDY**

The purpose of this study is to evaluate the pre and postsurgical cephalometric findings, investigate the condylar axis angle on different planes and the changes in the anteroposterior position of the mandibular condyle of severe skeletal class III malocclusion by three-dimensional approach.

**MATERIAL AND METHODS**

**Inclusion Criteria**

1. Skeletal class III malocclusion (ANB angle < -3°).
2. Age of the patient >18 years old.
3. Complete case history with pre and post treatment CT data, photographs, lateral and frontal cephalogram, orthopantomogram.
4. Informed consent signed by the patient and the family members to take part in the clinical research.

**Exclusion Criteria**

1. Patient with congenital abnormalities such as cleft lip and palate and any other associated syndromes.
2. Patient suffering from systemic diseases (Diabetes, Hypertension, Pulmonary Disorders, Bronchial Asthma, Allergies).
3. No any history of trauma to the jaw.
4. No any history of temporomandibular disorders.

**Clinical Data**

A retrospective study was performed in adult patients aged 18 to 35 years (Mean: 24 years) with skeletal class III malocclusion (Mean ANB: -4.05°) who had undergone orthognathic surgery from the study period from March of 2014 to April of 2017.

**Computed Tomography Assessment**

For all the subjects, we obtained CT to assess the craniofacial structures, the cephalometrics, the position of the mandibular condyle, skeletal and occlusal changes before surgery (T0) and 6 months after surgery (T1) (Figs. 1–4). These CT images were taken on Phillips 256-slice helical CT system (Phillips company, Netherlands) from 923 hospital (formerly called 303 Hospital of Nanning). Patients were trained to be in a centric relation before obtaining the CT images and the clinician confirmed the mandibular position before acquiring the CT images. DICOM images of the coronal, axial, and sagittal views were generated and analyzed in the Proplan CMF 3.0 software. The axes of the coordinates in a 3D image (0, 0, 0) represented the Nasion. Four landmark points (PoL, PoR, OrR, OrL) based on the FH plane were indicated to set the natural head position (Supplementary Digital Content, Table 1, http://links.lww.com/SCS/B674).

**Cephalometry Wizard**

The Cephalometry wizard were used to indicate the anatomical landmarks to perform a Cephalometric analysis. The analyses used were Condyle Points, Downs, Frankfurt, Steiner and Tweeds.

**Measurement of Skeletal Changes**

In this study, reference planes and points were determined (Supplementary Digital Content, Table 2, http://links.lww.com/SCS/B675). Three different planes constructed are FH plane, mid sagittal reference plane and coronal plane.

**Measurement of Condylar Axis Changes**

To evaluate changes in the condylar axis, the angular measurement on 3 different planes were obtained according to the reference planes (Supplementary Digital Content, Table 3, http://links.lww.com/SCS/B676).

**Measurement of the Antero-Posterior Condylar Position in the Glenoid Fossa**

The spaces between the mandibular condyle and the glenoid fossa were used on the sagittal multiplanar reconstruction image, which was parallel to the mid sagittal reference plane passing through the center of the condyle. Anterior and the posterior space was measured on the sagittal plane with a value 4 times enlarged multiplanar reconstruction image. The lines tangent to the most prominent anterior and the posterior aspects of the mandibular condyle were drawn from the most superior aspect of the glenoid fossa on the reference plane. Anterior and posterior distances were measured from the most prominent anterior and posterior points of the condyle to the glenoid fossa. These values were transferred to the Pullinger formula:

\[
\text{Posterior space} - \text{Anterior space} \times 100
\]

**Posterior space + Anterior space**

This equation determined the percentage of anterior or posterior displacement of the condyle, with concentricity as a reference. A
score of $-12$ approximately to $+12$ indicated concentricity, with less than $-12$ indicating a posterior position, and more than $+12$ indicating an anterior position (Supplementary Digital Content, Table 4, http://links.lww.com/SCS/B677).

**Statistical Analysis**

Error of method: The reliability of obtaining measurement on CT images was computed using Dahlberg formula\(^2\) for the determination of the standard error was applied for the double determination, and the standard errors were expressed in degrees and millimeters. The formula is:

\[ S_e = \sqrt{\frac{\sum d^2}{2n}} \]

\( S_e \) is the standard deviation of the differences of each of the replicates from the mean, \( n \) is the number of CT measurements, and \( d \) is the difference between the primary and the secondary data. The standard error of the angular measurement was found to be 0.41°.

Comparison of the presurgery and the postsurgery groups were done by comparing the means of these groups. Paired \( t \)-test were done to analyze the statistical differences among these groups. Data were statistically analyzed using IBM SPSS version 23.0 for windows.

**RESULTS**

Among the 21 patients, 19 patients underwent bilateral split sagittal ramus osteotomy (BSSRO) 1 patient underwent intraoral vertical ramus osteotomy and 1 patient underwent unilateral sagittal split ramus osteotomy. Out of the 19 patients undergoing BSSRO, 8 patients underwent BSSRO followed by Genioplasty whereas, 11 patients underwent only BSSRO. Out of 21 patients, 16 patients were found to have the deviation of the mandible either to the right or left with asymmetrical facial proportion.

After the surgery no patient had any evidence of wound infection, bone instability, malunion or long-term malocclusion. Significant differences were observed between the pre and the postsurgery groups in different skeletal parameters. There was a remarkable improvement in the skeletal facial profile after orthognathic surgery. Significant changes were observed in both SNB and ANB ($P < 0.01$) suggesting that these values improved significantly close to the normal values (Supplementary Digital Content, Table 5, http://links.lww.com/SCS/B678). Significant differences were observed on the growth axis or the \( Y \)-axis (both right and the left) ($P < 0.01$) achieving the mean value of the skeletal class I growth axis pattern. However, no significant differences were observed in SNA as no any surgical procedure were performed on the maxilla.

The distribution of the different condylar axis angle is shown in Figures 5D and 6A to C. After the careful evaluation of the condylar axis on the 3 planes there was significant differences between the pre and the postsurgical group on the sagittal plane ($P < 0.05$). However, no significant differences were noted on the axial and the coronal plane (Supplementary Digital Content, Table 6, http:// links.lww.com/SCS/B679). There was a decrease in the axial and the coronal condylar axis angle suggesting that there was an inward rotation of the condyle. However, the change is found to be statistically not significant. Whereas in the sagittal view the angle is increased suggesting that there was an anterior displacement of the condyle.

Both anteroposterior condylar position related to the glenoid fossa were changed from the presurgery and the postsurgery groups (Supplementary Digital Content, Table 7, http://links.lww.com/SCS/B680). The condyle exhibited different displacement on different condyles (Fig. 6D). The right condyle exhibited more of the posterior displacement whereas the left condyle exhibited more of...
an anterior displacement of the condyle in relation to the glenoid fossa.

**DISCUSSION**

Patient undergoing orthognathic surgery shows a considerable amount of changes in the hard and the soft tissues. The facial esthetics are improved significantly in the case of mandibular prognathism. Jung et al reported that after the surgery mandibular prognathism was significantly corrected and 3D evaluation shows a significant differences in the hard tissues as well as the soft tissues.25 Wang et al in 2009 reported that in their study between pre surgery and postsurgery cephalometric analysis except N-S-Ar, N-S-Ba, N-S-Gn, Nba-Ptn and Y axis, other discrepancies all had statistical differences (P < 0.05).26 Our study also showed that most of the cephalometric analysis except SNA were found to be statistically significant. Three dimensional cephalometric analyses showed that SNB angle changed from (90° ± 8°) to (87° ± 4.6°) (P < 0.01) indicating that the backward displacement of point B improved significantly close to the normal. Similarly, ANB angle was improved from (−3.83 ± 1.85°) to (2.21 ± 1.37°) indicating that the relationship of the mandible to the maxilla improved significantly (P < 0.01) to the skeletal class I facial type. Most of the surgeries were performed on the lower jaw rather than the upper jaw, so least changes were expected in the upper jaw.

Orthognathic surgery is likely to cause changes in the postsurgical condylar position and has been reported to have potential for idiopathic condylar resorption, functional disorder, and postsurgical relapse. Although there have been many studies on changes in condylar position after the orthognathic surgery, most have investigated the changes within a 6 month period of time after surgery and investigations were record with the help of 2 dimensional radiography and among them also very few cases have been reported amongst the patient with skeletal class III malocclusion.28–30

Wang et al in 2016 reported that fusing of the CBCT and 3D images used as a new method in evaluating the soft and the hard tissue changes after orthognathic surgery was feasible and accurate.31 The virtual 3D composite craniofacial models permitted concurrent assessment of hard and soft tissues during the diagnosis and treatment planning.

Many studies have reported that condylar axis rotation after surgery, and the effects of sagittal split ramus osteotomy (SSRO) / transoral vertical ramus ostetomy and rigid fixation/non rigid fixation. Ueki et al in 2007 assessed the change in the condylar long axis and the skeletal stability following SSRO and introral vertical ramus osteotomy for mandibular prognathia.29 Frey et al in 2008 suggested that all the symptoms after SSRO tend to decline over time and the amount of advancement and mandibular rotation should not be considered as risk factors for the development of temporomandibular disorders in patients without preexisting conditions.30

There are few studies concerning the anteroposterior position of the condyle related to glenoid fossa using 3D computed tomography. Published studies on postoperative changes of the mandibular condyle have mostly been performed using the traditional two-dimensional radiography with limited findings. Recent efforts to overcome such limitations include the use of three-dimensional cone beam volumetric imaging. The cone beam volumetric imaging is found very useful for measuring and assessing the complex anatomical structures such as the TMJ.32 Numerous studies have been conducted to evaluate the result of various different surgical techniques and postsurgical therapies to minimize relapse. Considering the horizontal condylar axis changes after the mandibular orthognathic surgery influences the stability, Ueki et al in 2005 reported that when rigid fixation is used, improper positioning of the proximal segment can cause various different problems including TMJ dysfunction.33 They reported that immediately after the surgery the SSRO group consistently showed a trend towards an increased angle of the condylar long axis, which showed a tendency to decrease slightly with time.

Kawamata et al in 1998 evaluated the pre surgical and the postsurgical condylar position using a jaw bone based model based on the pre and the postsurgical CT images of patients with mandibular prognathism.34 They found that the condyle moved backward whereas in our study we found that there is an increase in the sagittal condylar axis suggesting the forward movement of the condyle (P < 0.05). Kim et al in 2013 reported that both the axial condylar angles rotated inward after SSRO and tend to turn outward even when its rotation was small, however the amount of outward rotation was not statistically significant.35 In our case we found out that there was a decrease in the axial and the coronal axis angle suggesting there was an inward rotation of the condyle. In a different study done by Kim et al in 2010, changes of the condylar axis in the coronal and the sagittal views showed statistically significant differences that tend to decrease.36 Moreover such
condylar position changes during the postsurgical maintenance period were shown to be similar to the findings of Ghang et al in 2013.34

Freihofer et al in 1975 showed that condyles appeared to be positioned anteriorly in the glenoid fossa.35 Similarly, Will et al in 1984 found that both condyles were positioned posteriorly in patients who underwent SSRO to advance the mandible.36 However, Hackney et al in 1989 found no correlation between the amount of mandibular advancement and changes in the condylar position or mandibular shape.37 Hu et al in 2000, suggested that posterior displacement and forward rotation of the condyle after mandibular setback resulted from the tension of the temporalis and masseter muscle.38 Lee and Park in 2002 reported that the mandibular condyle was located more anteriorly after the mandibular setback and was related to overcorrection.39

Following Pullinger method for the assessment of the anteroposterior condylar position in the glenoid fossa, the condyle was categorized into 3 groups: anterior, concentric, and posterior position.40 Many studies showed that condylar position was changed after the orthognathic surgery or that there was no change.41–43 Alhammadi et al in 2016 investigated the 3D changes in the anteroposterior position of the mandibular condyle as well as the joint space parameters following the maxillary first premolar extraction in skeletal class II patients using the Pullinger method and found that there was a statistically significant posterior position of the condyle with relation to the vertical plane.44 However in ours the right condyle exhibited more of a posterior displacement and left condyle exhibited more of an anterior displacement. This may be due to the reason as the patients included in our study most of them had a lower face deviation either to the right or left and also the surgical procedure performed are also different so different displacement of the condyle was expected. Wang in 2016 conducted a similar study as ours using Proplan CMF 1.2 to analyze the changes in the facial symmetry and TMJ structures at different periods of after intraoral condylectomy combined with orthognathic surgery and concluded that the condylar axis angle on horizontal plane gradually grew and the condyle moved slowly upward on both sides. They also assessed the anteroposterior position of the condyle by using the Pullinger method and the result obtained were as similar to ours.45

CONCLUSION

The results of this study suggest that with increasing in the advancement of the imaging technology 3D analysis helps the surgeon in visualizing the hard and the soft tissues way better than the traditional approach. This study shows that after orthognathic surgery there was a remarkable improvement in the facial profile of skeletal class III malocclusion. This study also suggest that the condyle tend to move in a certain direction after surgery and this movement can influence the treatment outcome of the patient on a long run. However, care should be taken not to change the axis of rotation of the mandibular condyle to prevent from the treatment relapse and to avoid different tempororo mandibular disorders. Although this study yielded significant results over a period of 6 months after surgery, it was performed in a very limited number of patients. Further research on changes in the condylar position is needed with a longer observation period, considering various factors such as occlusion and the fixation method. For more accurate comparison, the relationship between the mandibular condyle and the articular disk should be recorded by magnetic resonance imaging.

REFERENCES

1. Proffit WR, Fields HW, Sarver DM. Contemporary Orthodontics. St. Louis, MO: Mosby; 2007

2. Steiner CC. The use of cephalometry as an aid in planning and assessing orthodontic treatment. Am J Orthod 1960;46:721

3. Cividanes LH, Styner MA, Proffit WR. Image analysis and superimposition of 3-dimensional cone-beam computed tomography models. Am J Orthod Dentofacial Orthop 2006;129:611–618

4. Smith JD, Thomas PM, Proffit R. A comparison of current prediction imaging programs. Am J Orthod Dentofacial Orthop 2004;125:527

5. Tucker MR, Farrell BB. Correction of dentofacial deformities. In: Hupp JR, Tucker MR, Ellis E, eds. Contemporary Oral and Maxillofacial Surgery. Philadelphia, PA: Elsevier Health Sciences; 2016:520–563

6. Lew KK, Foong WC. Horizontal skeletal typing in an ethnic Chinese population with true class III malocclusion. Br J Orthod 1993;20:19–23

7. Vig KD, Ellis E 3rd. Diagnosis and treatment planning for the surgical orthodontic patient. J Dent Clin North Am 1990;34:361–384

8. Sinclair PM. Orthodontic considerations in adult surgical orthodontic cases. J Dent Clin North Am 1988;32:509–528

9. Baik HS, Kim KH, Park Y. Distribution and trend in malocclusion patients. J Kor J Orthod 1995;25:87–100

10. Lin JJ. Prevalence of malocclusion in Chinese children age 9-15. J Clin Dent 1985;5:57–65

11. Kim EJ, Ki EJ, Cheon HM, et al. 3-Dimensional analysis for class III malocclusion patients with facial asymmetry. J Korean Assoc Oral Maxillofac Surg 2013;39:168–174

12. Phillips C, Proffit WR. Psychosocial aspects of dentofacial deformity and its treatment. In: Proffit WR, White Jr R, Sarver DM, eds. Contemporary Treatment of Dentofacial Deformity. St. Louis, MO: Mosby; 2003:69

13. Bailey LJ, Sarver DM, Turvey TA, et al. Class III problems. In: Proffit WR, White Jr R, Sarver DM, eds. Contemporary Treatment of Dentofacial Deformity. St. Louis, MO: Mosby; 2003:507

14. Taub PI, Patel PK, Buchanan SR, et al. Ferraro’s Fundamentals of Maxillofacial Surgery. Second ed. Springer; 2015

15. Naimi FB, Gill DS. Orthognathic Surgery: Principles, Planning and Practice.Wiley Blackwell; 2010

16. Kim YI, Jung YH. The assessment of the short-and long-term changes in the condylar position following sagittal split ramus osteotomy (SSRO) with rigid fixation. J Oral Rehabil 2010;37:262–270

17. Ellis ER. Condylar positioning devices for orthognathic surgery: are they necessary? J Oral Maxillofac Surg 1994;52:536

18. Ricketts RM. Occlusion – the medium of dentistry. J Prosthodont 1969;21:39–60

19. Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Dentofacial Orthop 2009;135:495–501

20. Kim YI, Jung YH. Condylar position after bimaxillary surgery. J Oral Maxillofac Surg 2013;2013:1–12

21. Ueki K, Degeliyurt K, Hashiba Y, et al. Horizontal changes in the condylar head after sagittal split ramus osteotomy with plate fixation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:656–661

22. Ueki K, Nakagawa K, Marukawa K, et al. Changes in condylar long axis and skeletal stability after bilateral sagittal split ramus osteotomy with poly-L-lactic acid or titanium plate fixation. J Int Oral Maxillofac Surg 2005;34:627–634

23. Fang B, Shen GF, Yang C, et al. Changes in condylar and joint disc positions after bilateral sagittal split ramus osteotomy for correction of mandibular prognathism. J Int J Oral Maxillofac Surg 2009;38:726–730

24. Pullinger A, Hollender L. Variation in condyle–fossa relationships according to different methods of evaluation in tomograms. J Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;129:725–731

25. Kim HY. Statistical notes for clinical researchers: Evaluation of measurement error 1: using intraclass correlation coefficients. Restor Dent Endod 2013;38:98–102

26. Yu-Jin Jung, Myung-Jin Kim, Seung-Hak Baek. Hard and soft tissue changes after correction of mandibular prognathism and facial asymmetry by mandibular setback surgery: Three-dimensional analysis using computed tomography. J Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107:763–771

27. Wang XX, Zhang J, Zhang WJ, et al. A stability study of hard tissue changes in patients with skeletal class III malocclusion after orthodontic-orthognathic treatments. J Hua Xi Kou Qiang Yi Xue Za Zhi 2009;27:60–63
28. Yosano A, Katakura A, Takaki T, et al. Influence of mandibular fixation method on stability of the maxillary occlusal plane after occlusal plane alteration. J Bull Tokyo Dent Coll 2009;50:71–82
29. Ueki K, Marukawa K, Shimada M, et al. Condylar and disc positions after sagittal split ramus osteotomy with and without Le Fort I osteotomy. J Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:342–348
30. Frey DR, Hatch JP, Van Sickels JE, et al. Effects of surgical mandibular advancement and rotation on signs and symptoms of temporomandibular disorder: a 2-year follow-up study. J Am J Orthod Dentofacial Orthop 2008;133:490.e1–490.e8
31. Wang Zhe, Zhu Liu-ning, Zhou Lin, et al. Feasibility of integrating 3D photos and cone-beam computed tomography images used to evaluate changes of soft and hard tissue after orthognathic surgery. J Peking Univ (Health Sci) 2016;48:544–549
32. Pannarato G, Garagiola U, Carletti V, et al. Change in condylar and mandibular morphology in juvenile idiopathic arthritis: cone beam volumetric imaging. J Minerva Stomatol 2010;59:519–534
33. Kawamata A, Fujishita M, Nagahara K, et al. Three-dimensional computed tomography evaluation of postsurgical condylar displacement after mandibular osteotomy. J Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85:371–376
34. Ghang MH, Kim HM, You JY, et al. Three-dimensional mandibular change after sagittal split ramus osteotomy with a semirigid sliding plate system for fixation of a mandibular setback surgery. J Oral Surg Oral Med Oral Pathol Oral Radiol 2013;115:157–166
35. Freihofer HPM, Petresevic D. Late results after advancing the mandible by sagittal splitting of the rami. J Maxillofac Surg 1975;3:250–257
36. Will LA, Joondeph DR, Hohl TH, et al. Condylar position following mandibular advancement: its relationship to relapse. J Oral Maxillofac Surg 1984;42:578–588
37. Hackney FL, Van Sickels JE, Nummikoski PV. Condylar displacement and temporomandibular joint dysfunction following bilateral sagittal split osteotomy and rigid fixation. J Oral Maxillofac Surg 1989;47:223–227
38. Hu J, Wang D, Zou S. Effects of mandibular setback on the temporomandibular joint: A comparison of oblique and sagittal split ramus osteotomy. J Oral Maxillofac Surg 2000;58:375–380
39. Lee W, Park JU. Three-dimensional evaluation of positional change of the condyle after mandibular setback by means of bilateral sagittal split ramus osteotomy. J Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002;94:305–309
40. Fujimura N, Nagura H. New appliance for repositioning the proximal segment during rigid fixation of the sagittal split ramus osteotomy. J Oral Maxillofac Surg 1991;49:1026–1027
41. Jung JR, Choi GH, Park YJ, et al. The evaluation of positional change of the mandibular condyle after bilateral sagittal split ramus osteotomy using three dimensional computed tomography in skeletal Class III patients. J Korean Oral Maxillofac Surg 2009;35:316
42. Lee SK, Kim KW, Kim CH. Postoperative positional change of condyle after bilateral sagittal split ramus osteotomy associated with mandibular asymmetry. J Korean Assoc Oral Maxillofac Surg 2004;30:359
43. Kim JW, Lee DH, Lee SY, et al. 3D CT evaluation of condyle head position, mandibular width, and mandibular angle after mandibular setback surgery. J Korean Assoc Oral Maxillofac Surg 2009;35:229
44. Alhammadi MS, Fayed MS, Labib A. Three-dimensional assessment of condylar position and joint spaces after maxillary first premolar extraction in skeletal Class II malocclusion. J Orthod Craniofac Res 2017;20:71–78
45. Wang XX. Imaging analysis of temporomandibular joint anatomy changes after intraoral condylectomy combined with orthognathic surgery. J Chin J Stomatol 2016;51:350–356