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Three-Dimensional Quantitative Assessment of Condylar Displacement and Adaptive Remodeling in Asymmetrical Mandibular Prognathism Patients After Sagittal Split Ramus Osteotomy

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Abstract: This study was performed to evaluate the condylar displacement and associated condylar remodeling in class III patients following mandibular setback surgery via sagittal split ramus osteotomy (SSRO). The sample comprised of 26 condyles of 13 subjects (mean age of 21.2 ± 2.6 y). We evaluated patients with mandibular prognathism and facial asymmetry who had undergone SSRO for mandibular setback at Korea University Hospital between January 2016 and December 2018. Three-dimensional segmentation of the mandibular condyles was done using the initial cone-beam computed tomography scan and scan taken 12 months postoperatively or later. Quantitative assessments of the 3-dimensional condylar displacement from T0 to T1 and bony remodeling of 8 regions of the condylar head were performed. The correlation between the condylar displacement and condylar head remodeling on the deviated (D) and nondeviated (ND) sides was analyzed. Significant correlations between condylar displacement and surface remodeling were observed in both D and ND condyles. The anteroposterior condylar displacement was significantly different between the D and ND sides ($P = 0.007$). There was no significant difference in condylar remodeling between the 2 sides. Condylar displacement and adaptive remodeling after SSRO varied greatly among individuals. Compared with displacement in the ND condyle, displacement in the D condyle has a greater association with condylar remodeling in both D and ND condyles. There is no significant difference in condylar head remodeling between D and ND condyles.

Key Words: class III orthognathic surgery, class III treatment, facial asymmetry, malocclusion

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Long-term stability of mandibular setback surgery in skeletal class III patients is a major concern for oral and maxillofacial surgeons and orthodontists. It has been reported that a sole mandibular setback is one of the least stable surgical procedures, together with the downward movement, and surgical expansion of the maxilla.[1] Most of the skeletal relapse of mandibular setback surgery occurs during the first postsurgical year, mainly attributed to the surgical technique as the major factor for relapse.[1] After osteotomy of the mandible, only the distal segment should be pushed back; however, when the proximal segments are also pushed back, the musculature returns to its original position carrying the chin forward.[2] Other factors associated with postoperative condylar displacement include the amount of mandibular setback, vertical repositioning of the maxilla, rotational movement of the distal segment, tensional balance of the surrounding muscles, fixation method, and osteotomy method [intraoral vertical ramus osteotomy versus sagittal split ramus osteotomy (SSRO)].[3–6]

Changes in the condylar position as a result of orthognathic surgery lead to adaptive remodeling of the condyle in response to changes in the functional loading.[7] Condylar remodeling has been studied mostly in class II patients following mandibular advancement surgery because decrease in mandibular length was observed in many of the patients during long-term retention.[1,8–10] Regarding the condylar changes after orthognathic surgery for class III patients, few studies, which are based on 2-dimensional (D) radiographs or 2D reformatted images of cone-beam computed tomography (CBCT), have been reported. Angular and linear displacement changes in those studies were measured by using reference planes. There are limited volumetric analyses that studied condylar resorption as an outcome of class III orthognathic surgery.[11–13]

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The purpose of this study was to evaluate condylar displacement changes and the associated condylar remodeling in class III patients with facial asymmetry following mandibular setback surgery via SSRO.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board (IRB number-2019AN0011) of Korea University Hospital and all subjects' data was deidentified for this study. The study subjects comprised of patients with mandibular prognathism who had undergone SSRO for mandibular setback at Korea University Hospital, from January 2016 to December 2018. Cone-beam computed tomography was obtained with 3D eXam (KaVo Dental GmbH, Biberach, Germany) (field of view, 17×23 cm; 120 kV and 5 mAs; voxel size, 0.3 mm; pulsed scan time, 17.8 s). Inclusion criteria were as follows: patients with mandibular prognathism and facial asymmetry >3 mm measured at menton; one or both SSRO surgeries; and those who had CBCTs of initial (T0), and at least 12 months postsurgery (T1). Exclusion criteria were as follows: craniofacial syndromes such as cleft lip and palate; previous history of surgery in the jaws; and signs and symptoms related to degenerative joint disease. A total of 26 condyles of 13 patients (10 males, 3 females; mean age of 21.2 ± 2.6 y) were included. The mean menton deviation was 5.1 ± 2.1 mm. G*Power was used to determine the sample size with an α level of 0.05 and power of 0.8.

The amount of menton deviation was measured with reference to the midsagittal reference plane, constructed by the anterior nasal spine, crista galli, and basion. The right and left condyles were classified into deviated (D) side and nondeviated (ND) side as the difference in the amount of setback in the right and the left side may have a significant effect on the condylar displacement.

For 3D quantitative assessment of the condylar displacement after surgery, segmentation of the condyles and the cranial base in the T0 and T1 CBCT images was done using the ITK-SNAP software (open-source, version 3.4.0; http://www.itksnap.org).[14] The condylar models created at T0 and T1 were registered using the cranial base as a reference and were imported to the Slicer software (open-source, version 4.10.2; http://www.slicer.org)[15] for measurement of the translational and rotational changes in the condyles using the Q3DC module of the software. The medial and lateral poles of the condylar head were marked, and the software automatically calculated the linear displacement in the anteroposterior, superior-inferior, and right-left directions, along with the rotations along the coronal (roll), axial (yaw), and sagittal planes (pitch). Positive or negative signs indicated directions of displacement (Supplemental Table 1, Supplemental Digital Content 1, http://links.lww.com/SCS/E277).

For analysis of condylar head remodeling, the condyles were superimposed using the regional superimposition with the superior portion of the mandibular ramus as a reference. After manual approximation of the T0 and T1 condylar models, automated registration was done. Then, simultaneous clipping of the T0 and T1 models above the osteotomy area was done using the Easy clip module of the Slicer software, and computation of point-to-point distances between the 2 models based on the shape correspondence algorithm was done using the SPHARM-PDM[16] module of the software.

Quantitative assessment of the condylar surface remodeling was done in 8 selected regions of interest (ROIs) of the condylar head: anterior I (anterolateral condylar region), anterior II (anteromedial), posterior I (posterolateral), posterior II (posteromedial), superior I (superolateral), superior II (superomedial), medial, and lateral (Fig. 1). Changes were measured in each ROI as signed distances in which positive values indicated bone apposition and negative values indicated bone resorption. Semitransparent overlays, color maps, and vectors were used for visualization and clinical interpretation of the condylar remodeling patterns. Shape correspondence analysis was used for mesh generation with 4002 correspondence points; the magnitude of change was displayed on the condylar surface and vector images (Fig. 2A–C).

Statistical Analysis

The Wilcoxon signed-rank test was used for the comparison of condylar displacement and surface remodeling between D and ND sides. The Spearman correlation analysis was used for association between condylar displacement and surface remodeling. A significance level of P value <0.05 was applied. All analyses were performed using R statistical software, version 3.6.3.

RESULTS

Mean translational and rotational displacement changes of the condyles on the D and ND sides from T0 to T1 are shown in Supplemental Table 2 (Supplemental Digital Content 1, http://links.lww.com/SCS/E277). In the comparison of the D and the ND sides, there was a significant difference in the mean anteroposterior displacement of the condyle ($P = 0.007$) (Supplemental Table 2, Supplemental Digital Content 1, http://links.lww.com/SCS/E277) showing 0.47 mm of posterior movement on the D side, and 0.35 mm of anterior movement on the ND side.

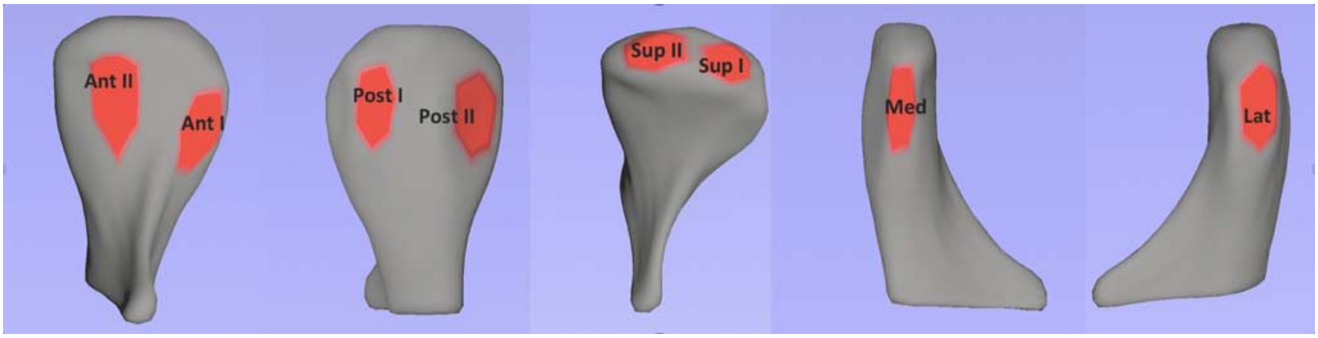

FIGURE 1. The 8 regions of the condylar head for quantitative assessment of surface remodeling: anterolateral (Ant I), anteromedial (Ant II), posterolateral (Post I), posteromedial (Post II), superolateral (Sup I), superomedial (Sup II), lateral (Lat), and medial (Med) regions.

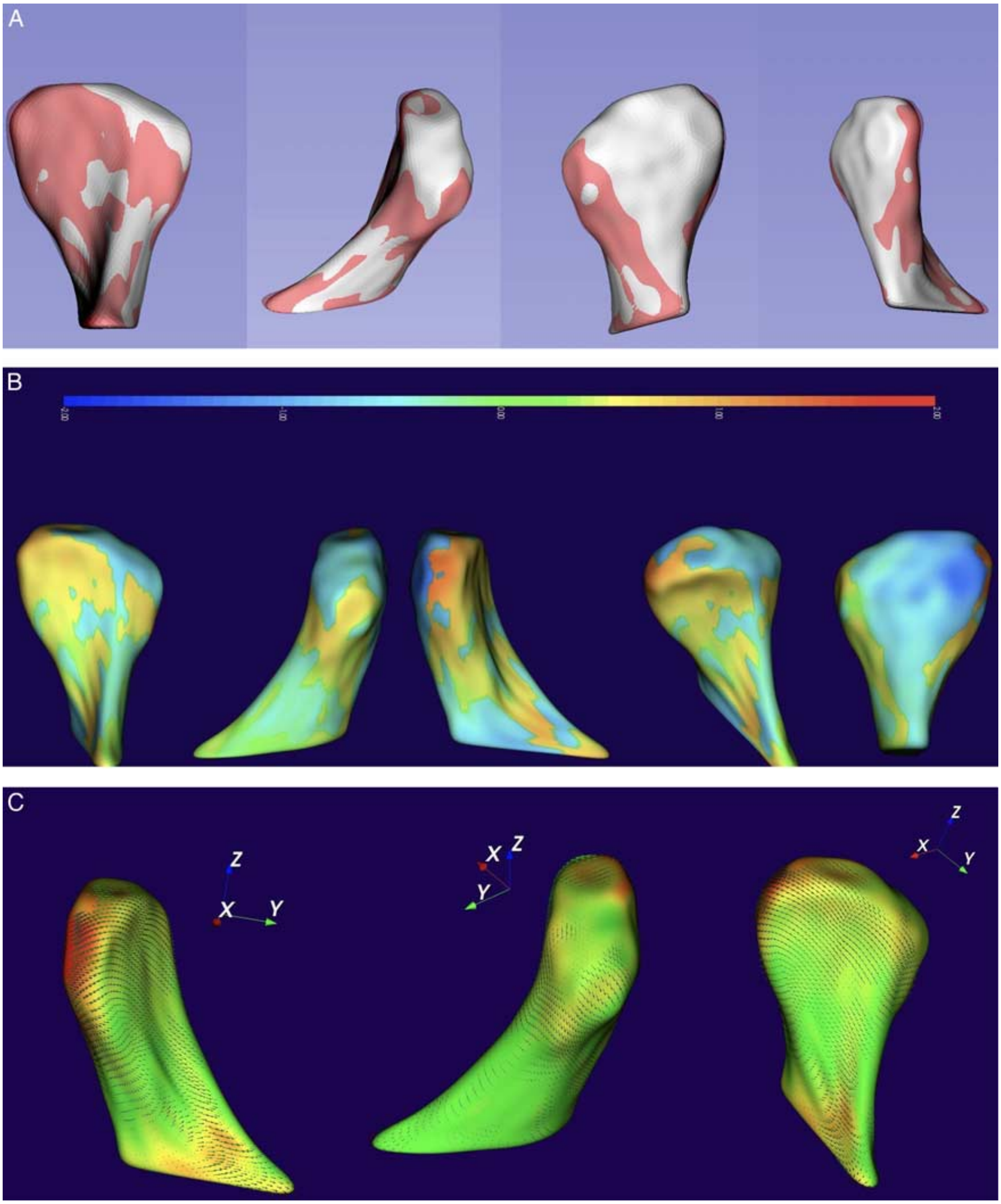

FIGURE 2. Left condyle of a patient who underwent orthognathic surgery. (A) Semitransparent overlay of condylar models at T0 (gray) and T1 (red). (B) Color map of the condylar remodeling changes after surgery (T1). (C) Vector maps indicating amount and direction of condylar remodeling.

The condylar head remodeling that occurred after surgery on the D and ND sides is shown in Supplemental Table 3 (Supplemental Digital Content 1, http://links.lww.com/SCS/E277) and as a box plot in Figure 3. There was no statistical difference in the mean amount of surface remodeling between the D and ND sides. The percentage distribution of different remodeling patterns in each ROI of the condyle on the D and ND sides are displayed in Figure 4. The correlation between the condylar displacement and surface remodeling for the D and ND sides is shown as a heatmap in Figure 5 and as a correlation matrix in Supplemental Table 4 (Supplemental Digital Content 1, http://links.lww.com/SCS/E277).

Anteroposterior condylar displacement on the D side showed a significant positive correlation with the remodeling in the anterior, posterior, and medial of the D side and posterior of the ND side (Supplemental Table 4, Supplemental Digital Content 1, http://links.lww.com/SCS/E277, Fig. 5). Condylar rotation in the axial (yaw) and sagittal (pitch) direction exhibited a positive correlation with the superior, lateral, and medial surfaces of the ND side. Condylar rotation in the

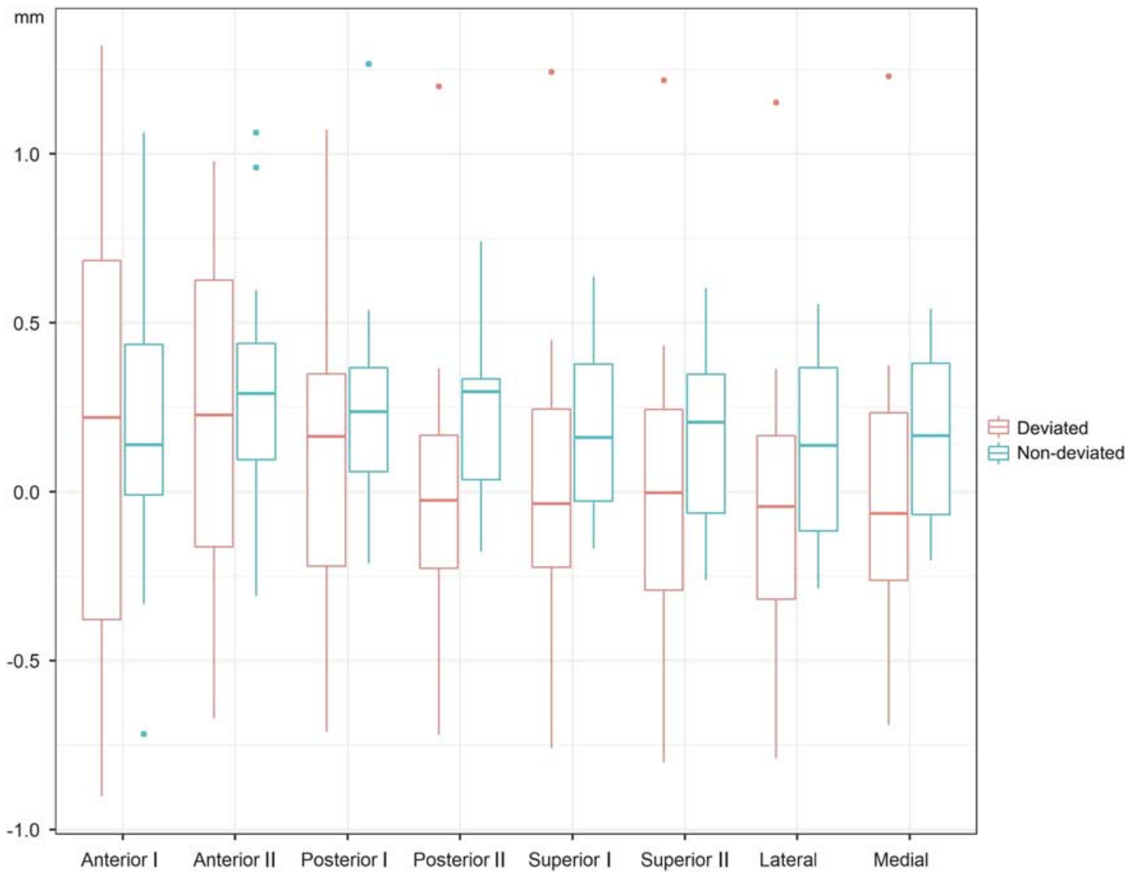

FIGURE 3. Box plot of condylar remodeling following surgery for both deviated and nondeviated sides.

coronal plane (roll) of the D side showed negative correlation with the posterior, superior, lateral, and medial surfaces of the condyle on the same side. Linear displacement of the ND side in the right-left direction showed a significant correlation with the remodeling in the anterior, posterior, superior, lateral, and medial regions of the D side (Supplemental Table 4, Supplemental Digital Content 1, http://links.lww.com/SCS/E277, Fig. 5).

DISCUSSION

Condylar displacement and the resultant changes in the functional loading of the condyles lead to adaptive remodeling of the condyles. Accordingly, we aimed to assess the condylar remodeling changes associated with displacement changes by using a shape correspondence algorithm, which allows analysis of corresponding points rather than the closest point, thus permitting a more accurate understanding of surface changes.[17]

The linear and angular displacement changes showed movements in both directions with a large range, indicating a variety of responses among different individuals. The mean displacement was relatively small ranging from −0.51 to 0.35 mm and 0.47 to 2.50° for linear and angular changes, respectively (Supplemental Table 2, Supplemental Digital Content 1, http://links.lww.com/SCS/E277). However, large standard deviations were observed, especially for rotational changes. Our results were similar to previous reports that have shown a large range of negative and positive values for angular and linear changes of the condyles. Kawamata et al[18] reported greater changes in the angular measurements of the condyles, compared with the linear displacement. Choi et al[19] reported that mandibular setback surgery using SSRO results in lateral displacement of proximal segment and increase in the intergonial width. The mean values indicated increase in intergonial distance and condylar inclinations. However, a large range from negative to positive values were reported in the results. Similar results were reported by Lee and Park,[3] who showed a large range of proximal segment changes in opposite directions.

Rotation in the sagittal plane (pitch) had a change of 2.50 ± 16.37° and 2.33 ± 13.28° for D and ND sides, respectively (Supplemental Table 2, Supplemental Digital Content 1, http://links.lww.com/SCS/E277). Possible reasons for this large range of forward and backward rotation of the ramus could possibly be attributed to patients' vertical characteristics and occlusal changes during postoperative orthodontic treatment. According to a case report of a class III malocclusion patient treated with a surgery-first approach, the sagittal ramus angulation was unchanged immediately after surgery, but a forward rotation was observed after postoperative orthodontics.[20]

Condylar displacement changes between the D and the ND sides showed a significant difference in the linear displacement in the anteroposterior direction. The D side showed a mean backward movement of the condyle, while the ND side showed a mean forward movement of the condyle (Supplemental Table 2, Supplemental Digital Content 1, http://links.lww.com/SCS/E277). This change may be associated with a greater amount of setback in the ND side than the D side. Jakobsone et al[4] reported that there is a greater tendency for relapse with

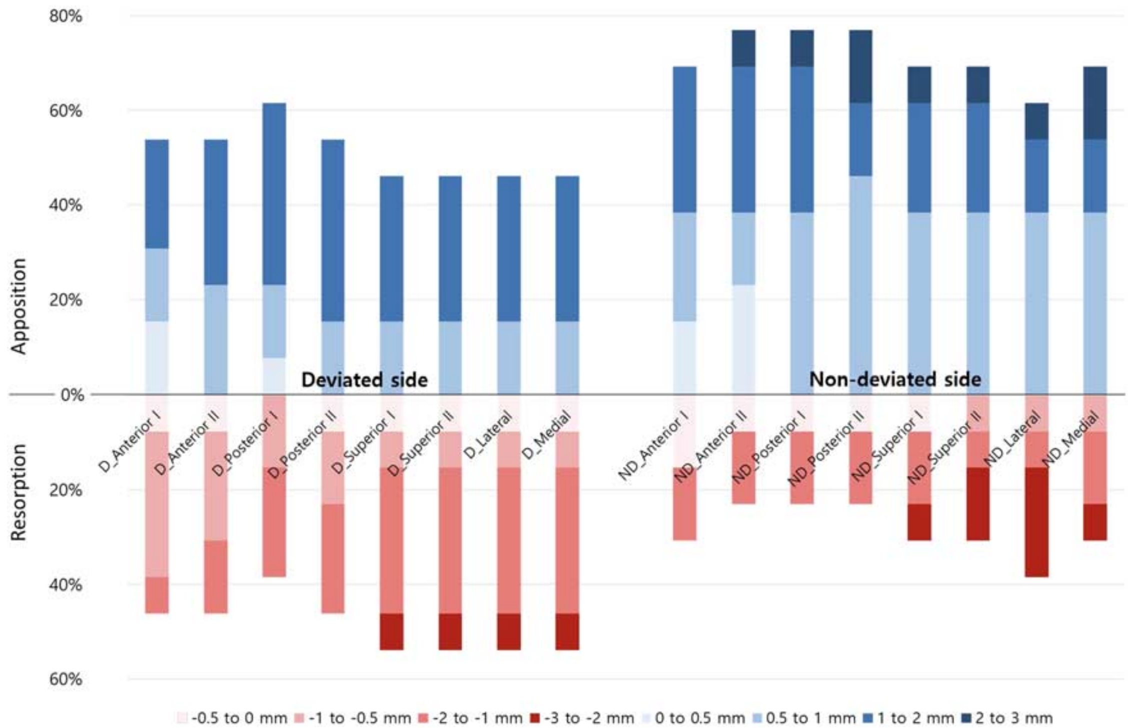

FIGURE 4. Bar graph indicating percentage distribution of patients having condylar resorption or bone apposition after surgery. Anterior I indicates anterolateral region; anterior II, anteromedial region; D, deviated; ND, nondeviated; posterior I, posterolateral region; posterior II, posteromedial region; superior I, superolateral region; superior II, superomedial region.

a greater amount of mandibular setback. In contrast, Lee and Park[3] reported that the positional change of the condyle after SSRO was not correlated with the amount of the setback. However, the association between the condylar displacement and relapse of facial asymmetry was not assessed in this study, warranting a further study.

Mean condylar head remodeling showed a variety of responses, similar to the displacement changes, and there was no significant difference in the mean remodeling changes between the D and ND sides. However, the box plot indicates more resorptive changes on the D side compared with the ND side (Fig. 3). This pattern is also observed in Figure 4 that shows a higher percentage of patients showing condylar resorption on the D side. The difference between the D and ND sides may be associated with the mean backward displacement of the D condyle and mean forward movement of the ND condyle. According to the correlation heatmap shown in Figure 5, the anteroposterior displacements of the D and ND condyles show a positive and negative correlation with the remodeling of the in the D and ND condyles, respectively. However, the correlation was statistically significant only for the D side (Supplemental Table 4, Supplemental Digital Content 1, http://links.lww.com/SCS/E277).

Regarding the association between the condylar displacement and remodeling changes, the displacement changes in the D condyle showed a higher association with condylar remodeling than the ND side. There is usually a greater amount of setback on the ND side, as it has a longer mandibular body. As a result, a yaw of the distal segment occurs, which results in an interference between proximal and the distal segments and may lead to a displacement of the proximal segment.[21,22] Our results showed that yaw of the D condyle showed a significant correlation with the superior, lateral, and medial remodeling of the ND condyle. Yang et al[22] reported that the interference between the proximal and distal segments became larger as the amount of yaw rotation in the distal segment increased and concluded that SSRO with a short lingual osteotomy showed the least displacement of the proximal segment in mandibular prognathism with asymmetry. A previous study on condylar remodeling after SSRO has reported that patients showed variable responses of bone remodeling—resorption, bone formation and no changes in different regions of the condyle.[11] However, most of the patients showed bone resorption in the anterior, superior, and posterior regions of the condyle.[23] In addition, condylar yaw was closely related to changes of condylar surface.[11]

Limitations of this study include a small sample size. High interindividual variability was observed, warranting further studies with a larger sample size, comparison of 1-jaw versus 2-jaw surgeries, surgical technique (SSRO versus intraoral vertical ramus osteotomy), and timing of surgery (conventional approach versus surgery-first approach). The amount of condylar remodeling was small compared with that in mandibular retrognathism patients. However, 3D assessment of condylar remodeling may aid in a better understanding of the long-term postoperative skeletal changes.

CONCLUSIONS

Condylar displacement and surface remodeling after SSRO surgery show a high variability among individuals. One year after surgery, the condyles on the ND side moved anteriorly, while the condyles on the D side moved posteriorly after surgery. Adaptive condylar remodeling showed no significant difference between D and ND condyles in all the studied regions. However, significant correlations were observed between condylar displacement and

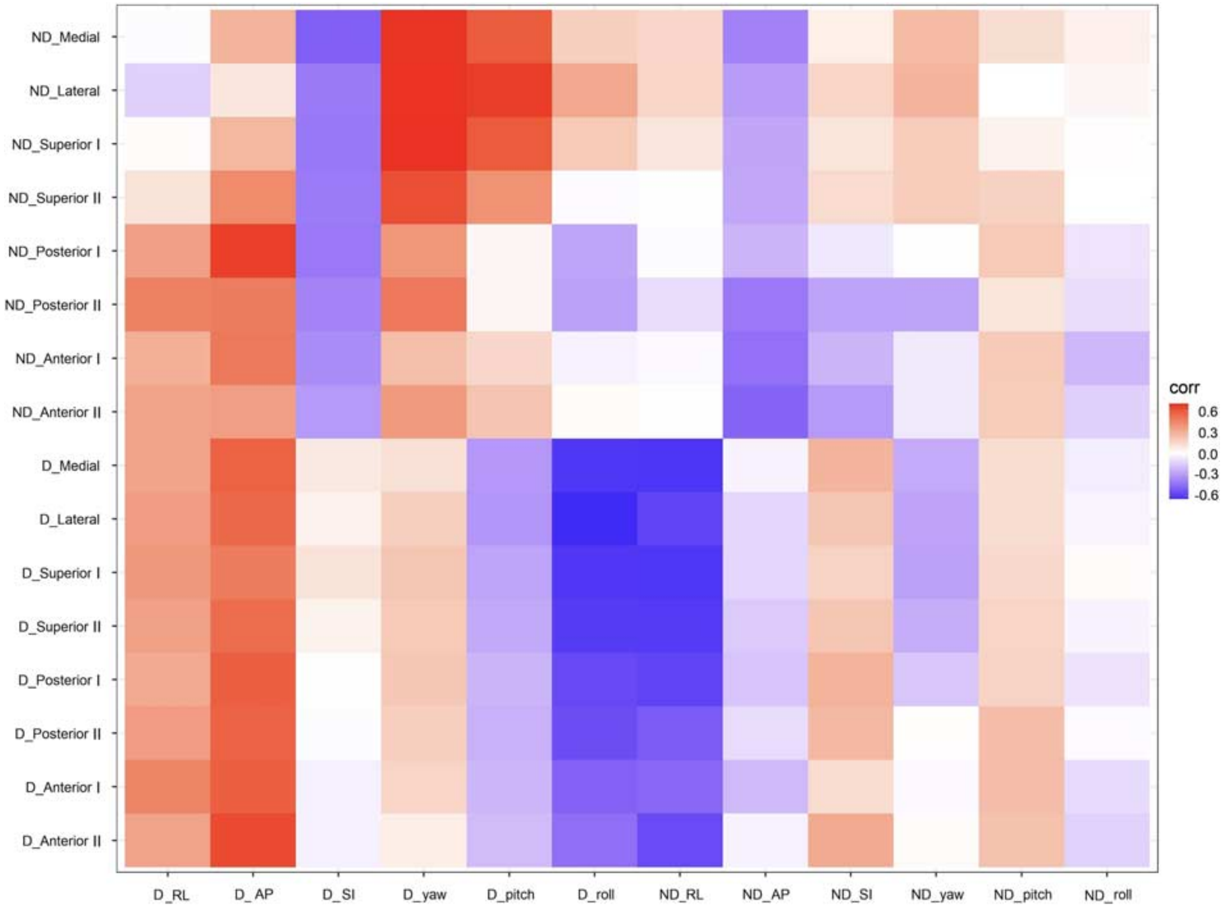

FIGURE 5. Heatmap showing the correlation between the amount of condylar displacement and surface remodeling. Anterior I indicates anterolateral region; anterior II, anteromedial region; AP, anteroposterior; D, deviated; ND, nondeviated; posterior I, posterolateral region; posterior II, posteromedial region; RL, right-left; SI, superior-inferior; superior I, superolateral region; superior II, superomedial region.

remodeling. The displacement in the D condyle had a greater association with the condylar remodeling changes in both D and ND condyles than with the condylar remodeling changes in the ND condyle.

REFERENCES

1. Proffit WR, Turvey TA, Phillips C. The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: an update and extension. *Head Face Med* 2007;3:21
2. Schardt-Sacco D, Turvey TA. Minimizing relapse after sagittal osteotomy for correction of mandibular prognathism. *J Oral Maxillofac Surg* 1997;55:85
3. Lee W, Park JU. Three-dimensional evaluation of positional change of the condyle after mandibular setback by means of bilateral sagittal split ramus osteotomy. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2002;94:305–309
4. Jakobsone G, Stenvik A, Sandvik L, et al. Three-year follow-up of bimaxillary surgery to correct skeletal class III malocclusion: stability and risk factors for relapse. *Am J Orthod Dentofacial Orthop* 2011;139:80–89
5. Blinder D, Peleg O, Yoffe T, et al. Intraoral vertical ramus osteotomy: a simple method to prevent medial trapping of the proximal fragment. *Int J Oral Maxillofac Surg* 2010;39:289–291
6. Kwon TG, Mori Y, Minami K, et al. Stability of simultaneous maxillary and mandibular osteotomy for treatment of class III malocclusion: an analysis of three-dimensional cephalograms. *J Craniomaxillofac Surg* 2000;28:272–277
7. Vandeput AS, Verhelst PJ, Jacobs R, et al. Condylar changes after orthognathic surgery for class III dentofacial deformity: a systematic review. *Int J Oral Maxillofac Surg* 2019;48:193–202
8. Gomes LR, Soares Cevidanes LH, Gomes MR, et al. Three-dimensional quantitative assessment of surgical stability and condylar displacement changes after counterclockwise maxillomandibular advancement surgery: effect of simultaneous articular disc repositioning. *Am J Orthod Dentofacial Orthop* 2018;154:221–233
9. Goncalves JR, Wolford LM, Cassano DS, et al. Temporomandibular joint condylar changes following maxillomandibular advancement and articular disc repositioning. *J Oral Maxillofac Surg* 2013;71:1759
10. Xi T, Schreurs R, van Loon B, et al. 3D analysis of condylar remodelling and skeletal relapse following bilateral sagittal split advancement osteotomies. *J Craniomaxillofac Surg* 2015;43: 462–468
11. An SB, Park SB, Kim YI, et al. Effect of post-orthognathic surgery condylar axis changes on condylar morphology as determined by 3-dimensional surface reconstruction. *Angle Orthod* 2014;84: 316–321
12. Choi BJ, Kim BS, Lim JM, et al. Positional change in mandibular condyle in facial asymmetric patients after orthognathic surgery: cone-beam computed tomography study. *Maxillofac Plast Reconstr Surg* 2018;40:13
13. Hwang HS, Jiang T, Sun L, et al. Condylar head remodeling compensating for condylar head displacement by orthognathic surgery. *J Craniomaxillofac Surg* 2019;47:406–13

14. Yushkevich PA, Piven J, Hazlett HC, et al. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. *Neuroimage* 2006;31: 1116–1128
15. Fedorov A, Beichel R, Kalpathy-Cramer J, et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network. *Magn Reson Imaging* 2012;30:1323–1341
16. Paniagua B, Cevidanes L, Walker D, et al. Clinical application of SPHARM-PDM to quantify temporomandibular joint osteoarthritis. *Comput Med Imaging Graph* 2011;35:345–352
17. Nguyen T, Cevidanes L, Paniagua B, et al. Use of shape correspondence analysis to quantify skeletal changes associated with bone-anchored class III correction. *Angle Orthod* 2014;84:329–336
18. Kawamata A, Fujishita M, Nagahara K, et al. Three-dimensional computed tomography evaluation of postsurgical condylar displacement after mandibular osteotomy. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998;85:371–376
19. Choi HS, Rebellato J, Yoon HJ, et al. Effect of mandibular setback via bilateral sagittal split ramus osteotomy on transverse displacement of the proximal segment. *J Oral Maxillofac Surg* 2005;63:908–916
20. Kim YJ, Gil BG, Ryu JJ. Application of CAD-CAM technology to surgery-first orthognathic approach. *J Korean Dent Assoc* 2018;56:622
21. Yoshida K, Rivera RS, Kaneko M, et al. Minimizing displacement of the proximal segment after bilateral sagittal split ramus osteotomy in asymmetric cases. *J Oral Maxillofac Surg* 2001;59:15–18
22. Yang HJ, Lee WJ, Hwang SJ. Interferences between mandibular proximal and distal segments in orthognathic surgery for patients with asymmetric mandibular prognathism depending on different osteotomy techniques. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2010;110:18–24
23. Ha MH, Kim YI, Park SB, et al. Cone-beam computed tomographic evaluation of the condylar remodeling occurring after mandibular set-back by bilateral sagittal split ramus osteotomy and rigid fixation. *Korean J Orthod* 2013;43:263–270

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