Int. J. Oral Maxillofac. Surg. 2019; 48: 739–745
https://doi.org/10.1016/j.ijom.2019.01.004, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Research Paper
Orthognathic Surgery

Three-dimensional analysis of condylar changes in surgical correction for open bite patients with skeletal class II and class III malocclusions

J. T. Zupnik[1], M. Ioshida[1], M. Yatabe[1], A. C. O. Ruellas[1], L. R. Gomes[1], S. Aronovich[2], E. Benavides[3], S. P. Edwards[2], B. Paniagua[4], L. H. S. Cevidanes[1]
[1]Department of Orthodontics and Pediatric Dentistry, University of Michigan, Ann Arbor, MI, USA; [2]Department of Oral and Maxillofacial Surgery, University of Michigan, Ann Arbor, MI, USA; [3]Department of Periodontics and Oral Medicine, University of Michigan, Ann Arbor, MI, USA; [4]Kitware Inc., Carrboro, NC, USA

J. T. Zupnik, M. Ioshida, M. Yatabe, A. C. O. Ruellas, L. R. Gomes, S. Aronovich, E. Benavides, S. P. Edwards, B. Paniagua, L. H. S. Cevidanes: Three-dimensional analysis of condylar changes in surgical correction for open bite patients with skeletal class II and class III malocclusions. Int. J. Oral Maxillofac. Surg. 2019; 48: 739–745.

Abstract. The aim of this study was to quantify three-dimensional condylar displacements as a result of two-jaw surgery for open bite correction in patients with skeletal class II and class III malocclusion. Pre-surgical (T1) and post-surgical (T2) cone beam computed tomography scans were taken for 16 patients with skeletal class II (mean age 22.3 ± 9.47 years) and 14 patients with skeletal class III (mean age 25.6 ± 6.27 years). T2 scans were registered to T1 scans at the cranial base. Translational and rotational condylar changes were calculated by x,y,z coordinates of corresponding landmarks. The directions and amounts of condylar displacement were assessed by intra- and inter-class Mann–Whitney U-test or t-test. Class II patients presented significantly greater amounts of lateral ($P = 0.002$) and inferior ($P = 0.038$) translation than class III patients. The magnitudes of condylar translational displacements were small for both groups. Skeletal class III patients had predominantly medial ($P = 0.024$) and superior ($P = 0.047$) condylar translation. Skeletal class II patients presented greater condylar counterclockwise pitch ($P = 0.007$) than class III patients. Two-jaw surgery for the correction of open bite led to different directions and amounts of condylar rotational displacement in patients with skeletal class II compared to class III malocclusion, with greater rotational than translational displacements.

Key words: cone beam computed tomography; mandibular condyles; 3D models; open bite.

Accepted for publication
Available online 1 February 2019

Anterior open bite is considered to be one of the most challenging orthodontic problems to treat, primarily due to its potential for relapse over time[1,2]. This difficulty is largely due to the fact that the etiology of the open bite, as well as the propensity for relapse, is often multifactorial in nature[3].

The etiology of an anterior open bite can vary greatly and can potentially result from oral habits of the lip and tongue, finger sucking, pacifier use, abnormal tongue posture, skeletal abnormalities, and hereditary factors[4]. The prevalence of anterior open bite ranges from 1.5% to 11% in the population, typically decreasing as oral function improves and oral habits subside, and with variations across ethnicities[4,5].

Many treatment protocols have been proposed to correct anterior open bite[6–16]. Treatment options include headgear, orthodontic treatments with and without extractions to camouflage the maxillo-mandibular skeletal vertical discrepancy, temporary anchorage devices and skeletal anchorage, multi-loop edgewise archwires (MEAW), and orthognathic surgery. All of these methods are applied with the purpose of achieving functionally esthetic outcomes that remain stable in the long-term. In non-growing patients, orthognathic surgery can involve a single jaw procedure of the maxilla or mandible, or a combination of both. Bimaxillary procedures should also be considered when there are functional or esthetic concerns, as repositioning of the maxilla helps achieve proper facial height and the mandibular surgery corrects any anteroposterior discrepancies or asymmetries that may exist. Previous studies have attempted to look at which surgical procedures provide the greatest stability[17–24], and the findings have varied: some have found that the overbite remains stable during the follow-up period[17,18,21,22], while others have found significant open bite relapse after surgical treatment[19,20,23,24]. With the different findings seen in terms of relapse, as well as varying opinions on the stability of orthognathic surgery for open bite treatment, further studies to better assess skeletal changes are merited.

One factor often attributed to skeletal relapse of the surgical correction is condylar displacement. Previous studies have shown that displacement of the condyle as a result of surgery can lead to instability of the sagittal split of the mandible[25–27]. Factors that have been associated with condylar displacement during and after surgery include surgeon experience, rotation of the proximal segment, tension on the surrounding musculature, amount of displacement, and the type of fixation used[28]. Various studies of surgical correction in patients with class II or class III skeletal discrepancies have shown that condylar displacement is a frequent occurrence[25,29–32].

A more complete understanding of the amount and direction of condylar movement from a linear and rotational perspective is needed for open bite patients, as it has been stated that control of the proximal segment is the most vital aspect of surgical stability and the prevention of relapse[33].

The advent and increased use of cone beam computed tomography (CBCT) has improved the analysis and assessment of anatomical changes in all dimensions and planes of space. Previous studies have shown that measurements based on CBCT scans are accurate and reliable when compared to lateral cephalograms and dry skull measurements[34,35]. Additionally, validated studies have confirmed the reliability of three-dimensional (3D) CBCT superimpositions for the assessment of changes in the mandibular position after orthognathic surgery[5,36,37].

The aim of this retrospective study was to quantify the condylar changes in all three planes of space as a result of two-jaw surgery for the correction of skeletal open bite malocclusion. The null hypothesis was that condylar changes after two-jaw surgeries are similar in patients with class II and class III malocclusions.

Methods

The study protocol was approved by the University of Michigan Institutional Review Board (IRB). This was a retrospective study including open bite patients who had undergone bimaxillary surgery.

Patient selection

A de-identified list of patients attending the Department of Oral and Maxillofacial Surgery, University of Michigan Hospital, was used to select the study patients. One hundred and twenty-nine patients who had undergone Le Fort I impaction and advancement of the maxilla as well as mandibular advancement (skeletal class II patients) or setback (skeletal class III patients) between January 2008 and March 2014 were selected. All pre-surgical (3 weeks prior to surgery – T1) and post-surgical (6 weeks postoperative, after splint removal – T2) CBCT scans for these patients were obtained.

The inclusion criteria were as follows: (1) presence of anterior open bite, as defined by having a lack of incisal vertical overlap; (2) bimaxillary surgical correction with counterclockwise mandibular rotation; (3) at least one posterior contact between maxillary and mandibular teeth to verify the presence of open bite, as seen on sagittal CBCT cross-sectional slices; (4) either a skeletal class II or class III malocclusion, with respective A-point–nasion–B-point (ANB) angle greater than 4° or smaller than 0°; (5) no craniofacial anomalies or severe asymmetries present, and no history of temporomandibular joint disorders; (6) adequate pre- and post-surgical CBCT image quality. Patients who did not to meet the inclusion criteria were excluded from the study. This study included 16 patients with skeletal class II (mean age 22.3 ± 9.47 years) and 14 patients with skeletal class III (mean age 25.6 ± 6.27 years).

All surgeries were performed by a single surgeon. All patients underwent rigid internal fixation with plates or bicortical screws.

Three-dimensional analysis

All scans were taken in centric relation, using a Picasso Master 3D Vatech CBCT scanner (E-Woo Technology Co. Ltd, Gyeonggi-Do, Korea). Scanning parameters were the following: 20 s, 90 kVp, 3.3 mA, field of view (FOV) of 13 cm, and a voxel size of 0.4 mm^3. ITK-SNAP (open source software, http://www.itksnap.org) and 3D Slicer (open source software, http://www.slicer.org) were used to create 3D surface models. The VAM module of Vectra software (Canfield Scientific, Fairfield, NJ, USA) was used to place anatomical landmarks. These analyses were all performed by a single investigator, trained and calibrated using previously validated methods[37,38]. After the segmentation and registration processes[37], the investigator was blinded during landmark placement as to the specific classification of malocclusion for each patient.

Determination of condylar displacements

Step 1 involved the conversion of individual slices into a single-file format. ITK-SNAP software was used to convert the individual slices of the scan sequence from DICOM format (Digital Imaging and Communications in Medicine) into a single de-identified image format known as GIPL (Guys Image Processing Lab).

Step 2 involved manual approximation. As the orientation of the patient's head was not likely to be the same across the time points, a manual approximation of the T1 and T2 scans in relation to the cranial base was performed using the Transforms tool in 3D Slicer software. The approximated T2 scan was saved as a new file.

Step 3 consisted of the construction of cranial base 3D volumetric label maps (segmentations). All automatic segmentations of the cranial base for T1 and T2 were performed using ITK-SNAP software. The constructed image was then manually checked slice by slice in all planes of space to clean and correct any errors that may have occurred during the automatic segmentation process.

Step 4 was voxel-based registration. T1 and T2 CBCT scans and their corresponding cranial base segmentations were registered in 3D Slicer using a voxel-based protocol. This allowed the cranial base to be used as a reference structure for superimposing the head so that condylar displacements as a result of treatment could be assessed[9].

Step 5 comprised segmentation of the mandible. Using the same methods for the segmentation of the cranial base, 3D volumetric label maps were constructed for the mandible at T1 and T2 registered at the cranial base.

Step 6 involved re-orientation to achieve a common coordinate system. The segmentations were converted to 3D surface models (.stl files) using the Model Maker tool in Slicer. In order to ensure consistency of the measurements for comparison between the sample subjects, all models were plotted on a common coordinate system and re-oriented using the Transform tool in 3D Slicer. The cranial base was used as the reference for sagittal, coronal, and axial orientation. Once T1 had been re-oriented, a matrix file was generated and applied to the T2 surface model of the subject, obtaining proper orientation.

In step 7, landmarks were plotted in Vectra. To measure condylar displacements, the mandibular surface models (T1 and T2) were loaded into the VAM module of the Vectra software (Canfield Scientific). Four corresponding landmarks were placed on all condyles: lateral and medial poles, and superior and anterior surfaces (Fig. 1). Coordinates (x,y,z) for all landmarks were generated and recorded.

Data were collected in step 8. Changes in the coordinates of the four plotted landmarks were evaluated to determine both translational (medial–lateral, anterior–posterior, inferior–superior) and rotational changes (pitch, roll, and yaw) (Fig. 2).

For translational displacements of each condyle, the x,y,z coordinates of the lateral and medial landmarks were averaged to determine the coordinates of the 'geometric center' of each condyle. To calculate translational change from T1 to T2, the corresponding x coordinate (medial–lateral movements) for the geometric center of the T2 condyle was subtracted from the x coordinate of the geometric center of the T1 condyle (T2–T1). This was repeated for the y (anterior–posterior movements) and z (inferior–superior movements) coordinates. For angular rotational changes of each condyle, the T1 and T2 coordinates were entered into a previously established Excel spreadsheet, which was able to automatically generate the angular changes for pitch, roll, and yaw between the two timepoints for right and left condyles. Coordinates for the medial and lateral surface points were used to calculate yaw and roll, while coordinates for the superior and anterior surface points were used to determine pitch.

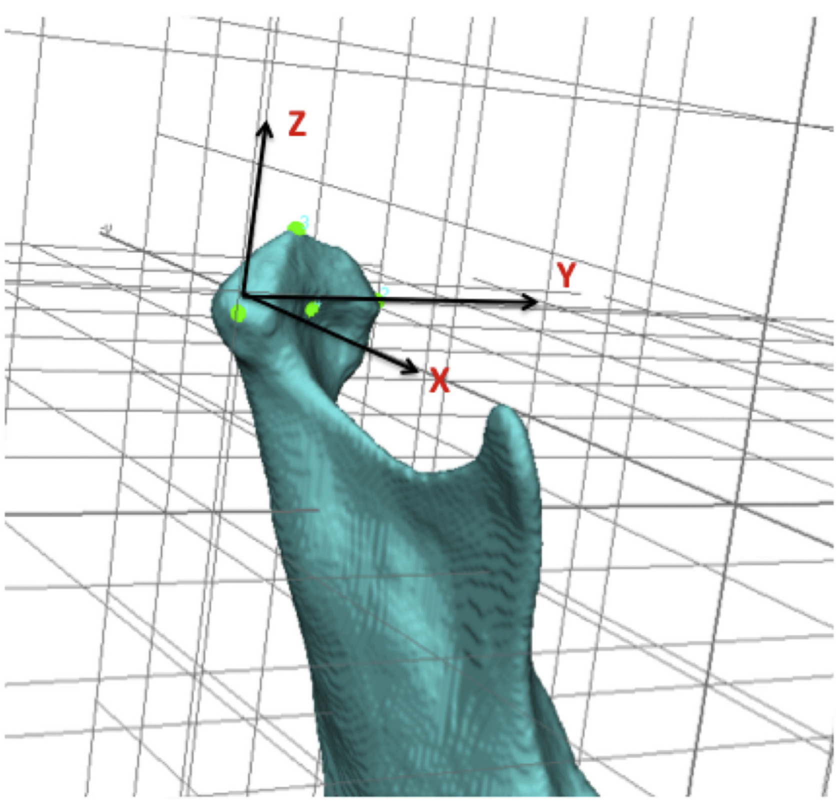

Fig. 1. Three-dimensional mandibular surface model and the landmarks used to measure condylar displacement shown in VAM software.

Statistical analysis

Intra-rater reliability was assessed for the placement of landmarks within the VAM module of Vectra software. The same operator placed landmarks on five randomly selected cases from each group. This was performed three times, each 1 week apart. Intra-class correlation coefficients (ICC) were calculated, and the ICC was above 0.95 in all cases.

Statistical testing of the directions and amounts of condylar displacement was completed using IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA). The sample was assessed for a normal distribution using the Shapiro–Wilk test. No significant differences were found between the right and left sides; therefore, for statistical purposes, data for the two sides were pooled. Intra-group comparisons were performed using the Mann–Whitney U-test or t-test to determine differences in linear or rotational displacements. Inter-group comparisons were performed using the Mann–Whitney U-test. The level of significance was set at $P < 0.05$.

Results

Class II patients had an initial average overjet of 6.38 mm (standard deviation (SD) 2.80) and overbite of −2.94 mm

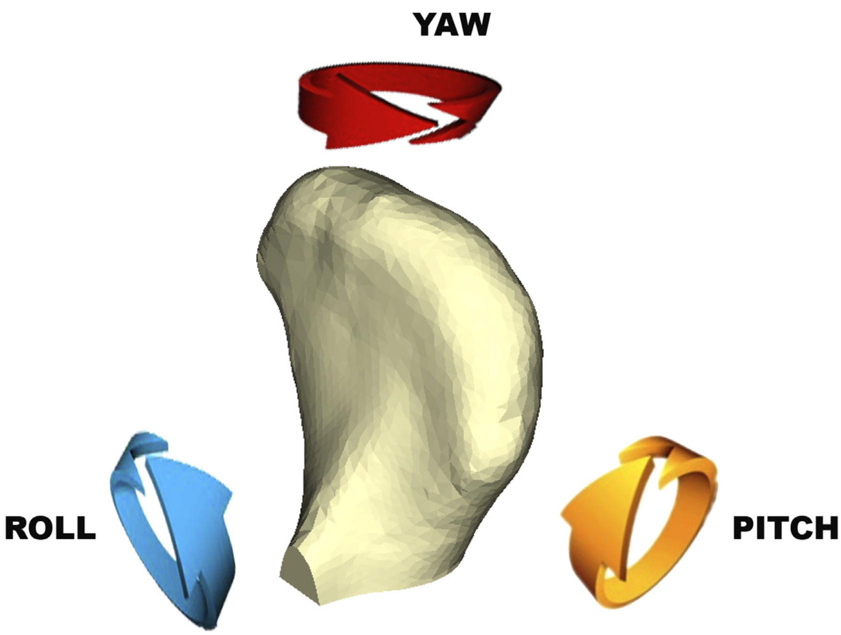

Fig. 2. Illustration of pitch, roll, and yaw rotational movements.

(SD 1.85), while class III patients showed overjet of −5.43 mm (SD 3.28) and overbite of −4.49 mm (SD 2.37). After surgery, class II patients showed an average decrease of 3.63° (SD 2.42) in ANB angle, 3.23 mm (SD 2.88) of overjet, and 3.56 mm (SD 1.76) of overbite. Class III patients showed an average increase of 5.92° (SD 1.73) in ANB angle, 7.71 mm (SD 3.06) of overjet, and 3.77 mm (SD 2.31) of overbite.

Descriptive statistics of the directions and amounts of translational and rotational displacement are displayed in Table 1.

Translational displacements

No statistically significant differences were detected in the intra-group comparisons for class II patients. However, the condyles of class III patients showed statistically significant greater displacement towards medial ($P = 0.024$) and superior ($P = 0.047$) (Table 2). Compared to class III patients, the condyles of class II patients showed statistically significant greater lateral and inferior displacements (Table 2).

Rotational displacements

No statistical analysis could be run for the intra-group comparison of roll in class II patients and roll and yaw in class III patients. Furthermore, inter-group comparisons of roll and yaw could not be run due to the small number of condyles that presented such displacements (Table 1). Overall, statistically similar amounts of yaw, roll, and pitch rotations were found in the intra-group comparisons (Table 2). The condyles in class II patients showed a statistically significant greater counterclockwise pitch rotation compared to class III patients (Table 2).

Discussion

The treatment of anterior open bite is orthodontically challenging. Among the treatment options are headgear[6], orthodontic treatment with and without extractions[7,39], temporary/skeletal anchorage devices[12,14], MEAW[15], and orthognathic surgery[16]. Although not statistically significant, condyles from class II patients showed greater displacement towards lateral, posterior, and superior, while class III patients showed significant greater displacements towards medial and superior (Table 2). This study is novel in measuring linear changes of the condyles in patients with an open-bite class III malocclusion.

In terms of rotational displacements, most condyles in class II patients presented medial roll (90.6%), medial yaw (56.3%), and clockwise pitch (59.4%). These results differ from those of Goncalves et al.[40], who reported that medial roll, lateral yaw, and counterclockwise pitch were the most common rotations after bimaxillary advancement. However, the amount of clockwise pitch was smaller than the counterclockwise rotation (Table 2), which is in accordance with the results of another previous study[29].

In the class III sample, condyles presented a medial roll (89.3%), medial yaw (92.8%), and counterclockwise pitch (57.1%). Medial roll rotation after surgical correction for class III malocclusion has also been reported previously[31,41], but differs from the lateral roll found by Bayat

Table 1. Descriptive table of the number of condyles that showed translational and rotational displacements for Class II and Class III patients.

	Class II (32 total condyles)				Class III (28 total condyles)			
	Right	Left	Total	% of class II condyles	Right	Left	Total	% of class III condyles
Medial	5	6	11	34.4%	9	9	18	64.3%
Lateral	11	10	21	65.6%	5	5	10	35.7%
Anterior	6	8	14	43.8%	6	5	11	39.3%
Posterior	10	8	18	56.3%	8	9	17	60.7%
Inferior	8	7	15	46.9%	4	4	8	28.6%
Superior	8	9	17	53.1%	10	10	20	71.4%
Medial yaw	8	10	18	56.3%	12	14	26	92.9%
Lateral yaw	8	6	14	43.8%	2	0	2	7.1%
Medial roll	13	16	29	90.6%	12	13	25	89.3%
Lateral roll	3	0	3	9.4%	1	2	3	10.7%
CW pitch	11	8	19	59.4%	5	7	12	42.9%
CCW pitch	5	8	13	40.6%	7	9	16	57.1%

CW, clockwise; CCW, counterclockwise.

Table 2. Intra- and inter-group comparison of the amount of translation (in millimeters) and rotation (in degrees); mean (standard deviation) and *P*-values.

Translation

	Medial/lateral			Anterior/posterior			Inferior/superior		
	Medial	Lateral	*P*-value Intra-group	Anterior	Posterior	*P*-value Intra-group	Inferior	Superior	*P*-value Intra-group
Class II	0.88 (0.6)	1.3 (1.3)	0.81	1.02 (1.11)	1.23 (1.32)	0.968	0.58 (0.4)	0.94 (0.8)	0.271
Class III	0.6 (0.47)	0.26 (0.33)	0.024[a,b]	0.5 (0.47)	0.47 (0.32)	0.795[a]	0.30 (0.31)	0.70 (0.79)	0.047[a,b]
P-value inter-group	0.193	0.002[b]		0.218	0.164		0.038[b]	0.298	

Rotation

	Yaw			Roll			Pitch		
	Medial	Lateral	*P*-value Intra-group	Medial	Lateral	*P*-value Intra-group	CW	CCW	*P*-value Intra-group
Class II	7.55 (6.33)	3.05 (3.17)	0.142	5.58 (3.61)	2.5 (3.81)	[c]	3.22 (2.23)	6.07 (5.15)	0.167
Class III	5.41 (3.07)	0.95 (0.78)	[c]	4.63 (2.35)	2.07 (1.77)	0.081	2.30 (1.27)	2.47 (1.79)	0.786
P-value inter-group	0.61	[c]		0.624	[c]		0.312	0.007[a,b]	

CW, clockwise; CCW, counterclockwise.
[a] Independent *t*-test.
[b] Statistically significant.
[c] Not computed.

et al.[42]. The finding of medial yaw is consistent with the previous literature[28,42,43]. The counterclockwise pitch is also in agreement with the literature[28,41]. According to Kim et al.[41], the immediate post-surgical counterclockwise pitch is influenced by the posterior impaction of the maxilla. However, it continues a forward rotation for 3 more months after surgery[41].

The inter-group analysis showed that even though the overall majority of class II condyles showed a clockwise pitch, the amount of counterclockwise pitch was significantly greater in class II patients (6.07 ± 5.15°) than in class III patients (2.47 ± 1.79°) ($P = 0.007$; Table 2), which differs from the findings of Kuehle et al.[44], who reported similar changes in class II and class III after one-jaw surgery (bilateral sagittal split osteotomy) to correct anteroposterior skeletal problems. The asymmetrical rotations observed in this study between the right and left sides were consistent with the patients who had greater amounts of surgical movement.

According to Proffit et al.[45], traditional cephalometric studies assessing changes after treatment typically set the level of clinical significance at ≥2 mm or ≥2°. Thus, although translational displacement of the condyle may be a common occurrence in the surgical correction of open bite, the levels of these movements fall below those of clinical significance established previously in the literature. It has been suggested that if changes are small enough, physiological adaptation of the condylar position may occur, but that this process requires a long time[31]. On the other hand, factors associated with such limited amounts of rotation, as seen in this study, may include the skill and experience of the surgeon, improvements in fixation techniques and pre-surgical planning, intraoperative condylar positioning, and the use of computer-assisted positioning methods. In addition, the present study findings were compared to the outcomes of surgery for the correction of class II and class III malocclusions, most of them without the vertical component. Nevertheless, awareness of such movements and the amounts of such movements could benefit those undertaking future surgeries by minimizing iatrogenic rotations, as well as surgical relapse. Counterclockwise rotation of the condyles is not only considered a risk factor for condylar resorption[46], but also by positioning the condyle more posteriorly and superiorly, it could push the articular disc anteriorly[47] and induce internal derangement or osteoarthrosis[48,49].

The main limitation of this study is the limited sample size. This can be attributed to the fact that not all patients had double-jaw surgery, not all patients had pre- and post-surgical CBCT scans, and there were cases of poor image quality. Furthermore, a large number of patients had to be excluded due to the lack of posterior tooth contact present in the initial CBCT scan.

Considering the greater rotational condylar changes with surgical correction of skeletal open bite compared to translational displacements, studies assessing the relationship to the glenoid fossa, including long-term studies, are necessary to assess the potential clinical significance, as well as the surgical stability.

In conclusion, after mandibular advancement, the majority of condyles were displaced laterally, posteriorly, and superiorly, and showed a rotation pattern of medial yaw, medial roll, and clockwise pitch, even though the amount of counterclockwise rotation was larger. In contrast, after mandibular setback, the majority of the condyles moved medially, posteriorly (but a larger amount of movement towards anterior), and superiorly, and showed a rotation pattern of medial yaw, medial roll, and counterclockwise pitch.

Funding

This grant was supported by NIDCR/NIBIB 024450.

Competing interests

No conflict of interest.

Ethical approval

The protocol was approved by the University of Michigan Institutional Review Board (IRB) HUM00076807 to perform a retrospective study including open bite patients that had been treated with bimaxillary surgery.

Patient consent

Not required.

References

1. Uzdil F, Kayalioglu M, Kendi E, Toroglu MS. A new type of modified Essix Retainer for anterior open bite retention. *Prog Orthod* 2010;**11**:45–52.
2. Salehi P, Pakshir HR, Hoseini SA. Evaluating the stability of open bite treatments and its predictive factors in the retention phase during permanent dentition. *J Dent (Shiraz)* 2015;**16**:22–9.
3. Stojanovic L. Etiological aspects of anterior open bite. *Med Pregl* 2007;**60**:151–5.
4. Cozza P, Baccetti T, Franchi L, Mucedero M, Polimeni A. Sucking habits and facial hyperdivergency as risk factors for anterior open bite in the mixed dentition. *Am J Orthod Dentofacial Orthop* 2005;**128**:517–9.
5. Artese A, Drummond S, Nascimento JMd, Artese F. Criteria for diagnosing and treating anterior open bite with stability. *Dent Press J Orthod* 2011;**16**:136–61.
6. Ngan P, Fields HW. Open bite: a review of etiology and management. *Pediatr Dent* 1997;**19**:91–8.
7. Zuroff JP, Chen SH, Shapiro PA, Little RM, Joondeph DR, Huang GJ. Orthodontic treatment of anterior open-bite malocclusion: stability 10 years postretention. *Am J Orthod Dentofacial Orthop* 2010;**137**. 302.e1–8; discussion 302–303.
8. Lopez-Gavito G, Wallen TR, Little RM, Joondeph DR. Anterior open-bite malocclusion: a longitudinal 10-year postretention evaluation of orthodontically treated patients. *Am J Orthod* 1985;**87**:175–86.
9. Remmers D, Van RW, 't Hullenaar. Bronkhorst EM, Berge SJ, Katsaros C. Treatment results and long-term stability of anterior open bite malocclusion. *Orthod Craniofac Res* 2008;**11**:32–42.
10. de Freitas MR, Beltrao RT, Janson G, Henriques JF, Cancado RH. Long-term stability of anterior open bite extraction treatment in the permanent dentition. *Am J Orthod Dentofacial Orthop* 2004;**125**:78–87.
11. Janson G, Valarelli FP, Henriques JF, de Freitas MR, Cancado RH. Stability of anterior open bite nonextraction treatment in the permanent dentition. *Am J Orthod Dentofacial Orthop* 2003;**124**:265–76. quiz 340.
12. Park YC, Lee HA, Choi NC, Kim DH. Open bite correction by intrusion of posterior teeth with miniscrews. *Angle Orthod* 2008;**78**:699–710.
13. Umemori M, Sugawara J, Mitani H, Nagasaka H, Kawamura H. Skeletal anchorage system for open-bite correction. *Am J Orthod Dentofacial Orthop* 1999;**115**: 166–174.
14. Baek MS, Choi YJ, Yu HS, Lee KJ, Kwak J, Park YC. Long-term stability of anterior open-bite treatment by intrusion of maxillary posterior teeth. *Am J Orthod Dentofacial Orthop* 2010;**138**. 396.e1–396.e9; discussion 396–398.
15. Kim YH. Anterior openbite and its treatment with multiloop edgewise archwire. *Angle Orthod* 1987;**57**:290–321.
16. Solano-Hernández B, Antonarakis GS, Scolozzi P, Kiliaridis S. Combined orthodontic and orthognathic surgical treatment for the correction of skeletal anterior open-bite malocclusion: a systematic review on vertical stability. *J Oral Maxillofac Surg* 2013;**71**:98–109.
17. Proffit WR, Bailey LJ, Phillips C, Turvey TA. Long-term stability of surgical open-bite correction by Le Fort I osteotomy. *Angle Orthod* 2000;**70**:112–7.
18. McCance AM, Moss JP, James DR. Stability of surgical correction of patients with skeletal III and skeletal II anterior open bite, with increased maxillary mandibular planes angle. *Eur J Orthod* 1992;**14**:198–206.
19. Denison TF, Kokich VG, Shapiro PA. Stability of maxillary surgery in openbite versus nonopenbite malocclusions. *Angle Orthod* 1989;**59**:5–10.
20. Fischer K, von Konow L, Brattstrom V. Open bite: stability after bimaxillary surgery — 2-year treatment outcomes in 58 patients. *Eur J Orthod* 2000;**22**:711–8.
21. Espeland L, Dowling PA, Mobarak KA, Stenvik A. Three-year stability of open-bite correction by 1-piece maxillary osteotomy. *Am J Orthod Dentofacial Orthop* 2008;**134**:60–6.
22. Fontes AM, Joondeph DR, Bloomquist DS, Greenlee GM, Wallen TR, Huang GJ. Long-term stability of anterior open-bite closure with bilateral sagittal split osteotomy. *Am J Orthod Dentofacial Orthop* 2012;**142**:792–800.
23. Joss CU, Thuer UW. Stability of hard tissue profile after mandibular setback in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2008;**30**:352–8.
24. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg* 2009;**67**:301–13.
25. Will LA, Joondeph DR, Hohl TH, West RA. Condylar position following mandibular advancement: its relationship to relapse. *J Oral Maxillofac Surg* 1984;**42**:578–88.
26. Epker BN, Wessberg GA. Mechanisms of early skeletal release following surgical advancement of the mandible. *Br J Oral Surg* 1982;**20**:175–82.
27. Van Sickels JE, Tiner B, Keeling SD, Clark GM, Bays R, Rugh J. Condylar position with rigid fixation versus wire osteosynthesis of a sagittal split advancement. *J Oral Maxillofac Surg* 1999;**57**:31–4.
28. Kim YJ, Oh KM, Hong JS, Lee JH, Kim HM, Reyes M, Cevidanes LH, Park YH. Do patients treated with bimaxillary surgery have more stable condylar positions than those who have undergone single-jaw surgery? *J Oral Maxillofac Surg* 2012;**70**:2143–52.
29. Alder ME, Deahl ST, Matteson SR, Van Sickels JE, Tiner BD, Rugh JD. Short-term changes of condylar position after sagittal split osteotomy for mandibular advancement. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999;**87**:159–65.
30. Chen S, Lei J, Wang X, Fu KY, Farzad P, Yi B. Short- and long-term changes of condylar position after bilateral sagittal split ramus osteotomy for mandibular advancement in combination with Le Fort I osteotomy evaluated by cone-beam computed tomography. *J Oral Maxillofac Surg* 2013;**71**:1956–66.
31. Kim YI, Cho BH, Jung YH, Son WS, Park SB. Cone-beam computerized tomography evaluation of condylar changes and stability following two-jaw surgery: Le Fort I osteotomy and mandibular setback surgery with rigid fixation. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011;**111**:681–7.
32. Zafar H, Choi DS, Jang I, Cha BK, Park YW. Positional change of the condyle after orthodontic-orthognathic surgical treatment: is there a relationship to skeletal relapse? *J Korean Assoc Oral Maxillofac Surg* 2014;**40**:160–8.
33. Schendel SA, Epker BN. Results after mandibular advancement surgery: an analysis of 87 cases. *J Oral Surg* 1980;**38**:265–82.
34. Berco M, Rigali Jr PH, Miner RM, DeLuca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. *Am J Orthod Dentofacial Orthop* 2009;**136**. 17.e1–9; discussion 17–18.
35. Hassan B, van der Stelt P, Sanderink G. Accuracy of three-dimensional measurements obtained from cone beam computed tomography surface-rendered images for cephalometric analysis: influence of patient scanning position. *Eur J Orthod* 2009;**31**:129–34.
36. Cevidanes LH, Bailey LJ, Tucker Jr GR, Styner MA, Mol A, Phillips CL, Proffit WR, Turvey T. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. *Dentomaxillofac Radiol* 2005;**34**:369–75.
37. Schilling J, Gomes LC, Benavides E, Nguyen T, Paniagua B, Styner M, Boen V, Gonçalves JR, Cevidanes LH. Regional 3D superimposition to assess temporomandibular joint condylar morphology. *Dentomaxillofac Radiol* 2014;**43**:20130273.
38. Ruellas AC, Tonello C, Gomes LR, Yatabe MS, Macron L, Lopinto J, Goncalves JR, Garib Carreira DG, Alonso N, Souki BQ, Coqueiro Rda S, Cevidanes LH. Common 3-dimensional coordinate system for assessment of directional changes. *Am J Orthod Dentofacial Orthop* 2016;**149**:645–56.
39. Janson G, Valarelli FP, Beltrao RT, de Freitas MR, Henriques JF. Stability of anterior open-bite extraction and nonextraction treatment in the permanent dentition. *Am J Orthod Dentofacial Orthop* 2006;**129**:768–74.

40. Goncalves JR, Wolford LM, Cassano DS, da Porciuncula G, Paniagua B, Cevidanes LH. Temporomandibular joint condylar changes following maxillomandibular advancement and articular disc repositioning. *J Oral Maxillofac Surg* 2013;**71**. 1759.e1–15.
41. Kim YJ, Lee Y, Chun YS, Kang N, Kim SJ, Kim M. Condylar positional changes up to 12 months after bimaxillary surgery for skeletal class III malocclusions. *J Oral Maxillofac Surg* 2014;**72**:145–56.
42. Bayat M, Badri A, Momen-Heravi F, Garajei A, Asgarian A. Transverse displacement and angulation of the proximal segment after mandibular setback by means of bilateral intraoral vertico-sagittal ramus osteotomy. *J Oral Maxillofac Surg* 2011;**69**:906–10.
43. Han YS, Jung YE, Song IS, Lee SJ, Seo BM. Three-dimensional computed tomographic assessment of temporomandibular joint stability after orthognathic surgery. *J Oral Maxillofac Surg* 2016;**74**:1454–62.
44. Kuehle R, Berger M, Saure D, Hoffmann J, Seeberger R. High oblique sagittal split osteotomy of the mandible: assessment of the positions of the mandibular condyles after orthognathic surgery based on cone-beam tomography. *Br J Oral Maxillofac Surg* 2016;**54**:638–42.
45. Proffit WR, Phillips C, Turvey TA. Stability after mandibular setback: mandible-only versus 2-jaw surgery. *J Oral Maxillofac Surg* 2012;**70**:e408–14.
46. Hwang SJ, Haers PE, Zimmermann A, Oechslin C, Seifert B, Sailer HF. Surgical risk factors for condylar resorption after orthognathic surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000;**89**:542–52.
47. Ren YF, Isberg A, Westesson PL. Condyle position in the temporomandibular joint. Comparison between asymptomatic volunteers with normal disk position and patients with disk displacement. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995;**80**:101–7.
48. Ellis 3rd E, Hinton RJ. Histologic examination of the temporomandibular joint after mandibular advancement with and without rigid fixation: an experimental investigation in adult *Macaca mulatta*. *J Oral Maxillofac Surg* 1991;**49**:1316–27.
49. Katzberg RW, Keith DA, Ten Eick WR, Guralnick WC. Internal derangements of the temporomandibular joint: an assessment of condylar position in centric occlusion. *J Prosthet Dent* 1983;**49**:250–4.

Address:
Marilia Yatabe
Clinical Assistant Professor
Department of Orthodontics and Pediatric Dentistry
University of Michigan. 1011 North University Avenue
Ann Arbor
MI
United States 48109
Tel.: +1 734 964 1080
E-mail: msyatabe@umich.edu