Can cone-beam computed tomography superimposition help orthodontists better understand relapse in surgical patients?

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This case report describes the interdisciplinary treatment of a 19-year-old Brazilian man with a Class I malocclusion, a hyperdivergent profile, an anterior open bite, and signs of temporomandibular joint internal derangement. The treatment plan included evaluation with a temporomandibular joint specialist and a rheumatologist, orthodontic appliances, and maxillomandibular surgical advancement with counterclockwise rotation. Cone-beam computed tomography images were taken before and after surgery at different times and superimposed at the cranial base to assess the changes after orthognathic surgery and to monitor quantitatively the internal derangement of the temporomandibular joints and surgical relapse. Our protocol can improve the orthodontist's understanding of surgical instability, demonstrate the clinical value of cone-beam computed tomography analysis beyond the multiplanar reconstruction, and guide patient management for the best outcome possible. (Am J Orthod Dentofacial Orthop 2014;146:641-54)

Maxillomandibular advancement has been associated with condylar changes particularly for patients with previous temporomandibular joint (TMJ) internal derangement.[1-3] Postsurgical condylar changes lead to skeletal and occlusal instability that can compromise surgical and orthodontic achievements.[3] Orthodontists notice changes in occlusion progressively, and usually they are the professionals who will manage the instability after orthognathic surgery, at which time the surgical team is no longer seeing the patient frequently. The clinician must be able to identify any etiologic factors involved in the instability with the adequate knowledge and technology that each case requires to prevent or intercept postsurgical complications. Orthodontic treatments that require surgical intervention should include cone-bean computed tomography (CBCT) to properly monitor bone segments and TMJ stability. Recent advances in 3-dimensional (3D) image assessments have allowed researchers and clinicians to see beyond cross-sectional images and switch from subjective conclusions to quantitative facts that can make significant differences for optimal patient care.[4-7]

This case report describes the relevance of a quantitative CBCT image analysis protocol (with freeware software only) and its clinical application used to minimize occlusal and skeletal disharmonies during postsurgical orthodontics and concomitant condylar osteoarthritic changes.

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ETIOLOGY AND DIAGNOSIS

The patient was a 19-year-old Brazilian man. His medical history was noncontributory, and the extraoral examination showed a hyperdivergent facial profile, increased lower third of the face, labial incompetence, and increased nasolabial angle with the maxilla and mandible posteriorly positioned in the sagittal view. Intraorally, he had an anterior open bite, a deep curve of Spee in the maxillary arch, maxillary posterior teeth with excessive lingual crown inclinations, maxillary and mandibular midlines shifted 1 mm to the left, no significant transversal cant,

Fig 1. Pretreatment photographs: hyperdivergent facial profile, anterior open bite, no significant transversal cant, proclined maxillary and mandibular incisors, and Class I malocclusion.

proclined maxillary and mandibular incisors, and a Class I malocclusion (Figs 1 and 2).

The panoramic radiograph showed signs of left condylar remodeling, vertically positioned maxillary and mandibular third molars, and a mandibular arch fixed retainer (canine to canine) from previous treatment (Fig 3). The lateral cephalometric radiograph showed a narrow symphysis, proclined and protrusive maxillary and mandibular incisors, a long soft palate, decreased retroglossal and retropalatal airway spaces, and an increased mandibular occlusal plane angle (Fig 4). Previous treatment relapses causing open bite and poor facial esthetics were the main concerns for a new orthodontic treatment.

The physical examination of the patient showed signs of TMJ internal derangement that suggested further investigation with a magnetic resonance imaging (MRI) evaluation. Slight articular disc displacements with reduction were observed on the right and left TMJs with both discs' morphology preserved (Fig 5). The left fast spin echo weighted MRI immediately after surgery showed a level 1 hypersignal on the upper and lower TMJ compartments (Fig 5, *C*).[8-10]

TREATMENT OBJECTIVES

The treatment objectives were to (1) improve facial appearance, (2) achieve normal overbite and overjet, (3) improve chin projection, (4) obtain lip competence, and (5) reduce the proclination of the maxillary and mandibular incisors.

TREATMENT ALTERNATIVES

Intrusion of the maxillary and mandibular posterior teeth with temporary anchorage devices is an alternative for the treatment of anterior open bite in adults. Although the technique is not new, the immediate results are not predictable, and long-term results have yet to be published. Additionally, facial improvement would be restricted to mandibular counterclockwise rotation with

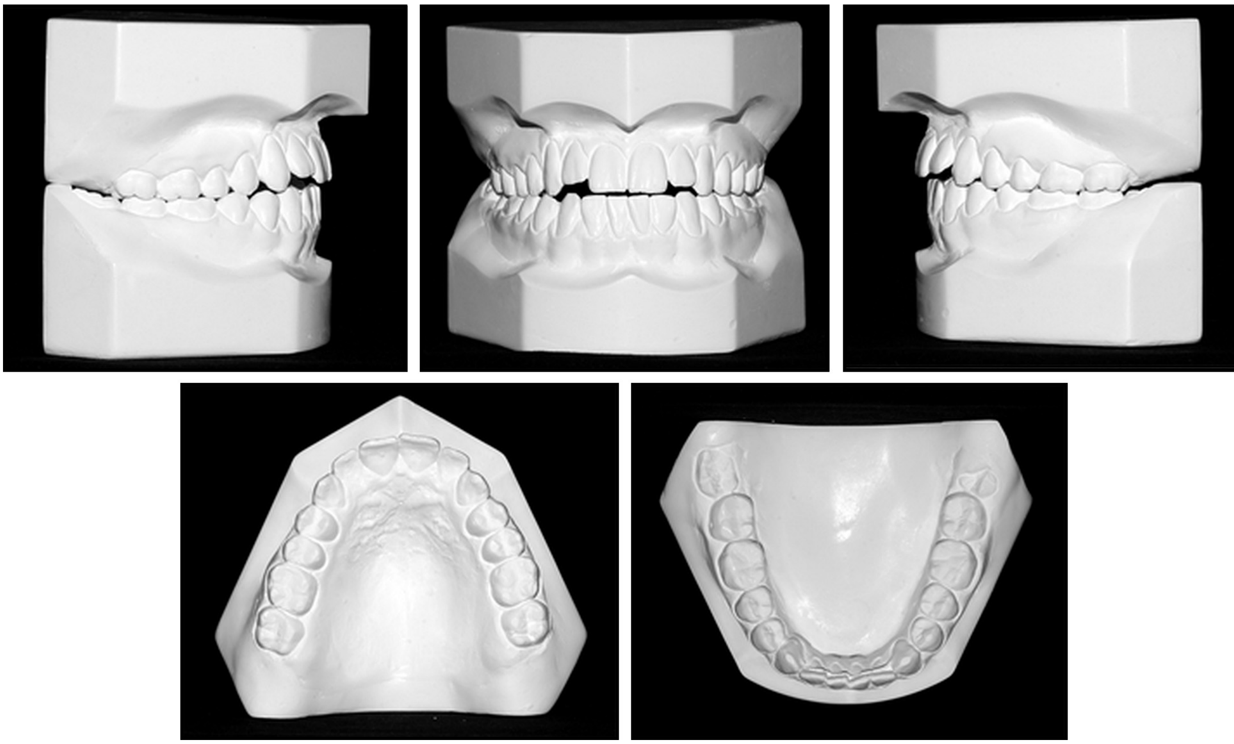

Fig 2. Pretreatment dental models.

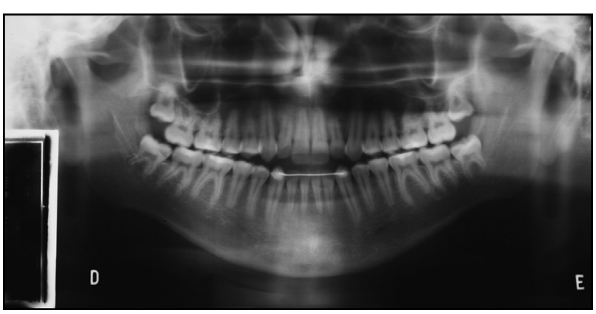

Fig 3. Pretreatment panoramic radiograph: signs of left condyle remodeling, maxillary and mandibular third molars vertically positioned, and mandibular fixed retainer (canine to canine) in place from previous treatment.

no significant effect on the nasolabial angle and a minimal impact on the facial profile. For a surgical approach, 2 alternatives included (1) maxillary posterior impaction associated with chin advancement and vertical reduction, and (2) maxillomandibular counterclockwise rotation and advancement with vertical chin reduction. Maxillary posterior impaction would provide limited facial improvement because counterclockwise rotation of the mandible would be tied to the maxillary occlusal plane angle. This planning would be similar to orthodontic camouflage without the surgery.

Fig 4. Pretreatment lateral cephalometric radiograph: narrow symphysis, proclined and protrusive maxillary and mandibular incisors, long soft palate, decreased retroglossal and retropalatal airway spaces, and increased mandibular occlusal plane angle.

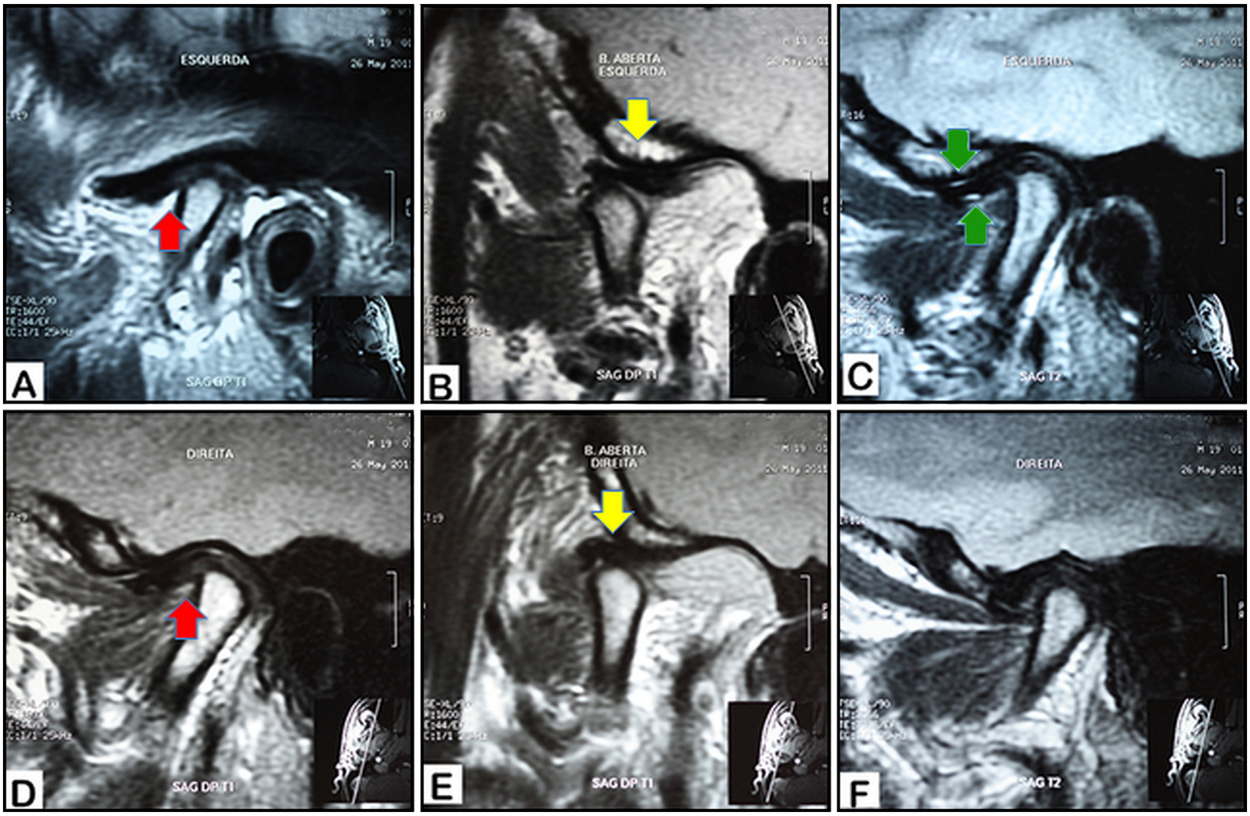

Fig 5. Pretreatment sagittal oblique TMJ: **A-C,** left and **D-F,** right fast spin echo MRI. T2-weighted closed-mouth position proton density shows left and right articular discs with normal morphology and slight anterior displacements with lack of contact between the condylar head and the intermediate zone (*red arrows* in **A** and **D**). Open-mouth positions depict adequate disc reduction (*yellow arrows* in **B** and **E**). Left T2-weighted closed-mouth position (*green arrows* in **C**) depicts line of hypersignal (level 1) on the upper and lower TMJ compartments. Right T2-weighted closed-mouth position depicts no intracapsular hyper signal (**F**).

Maxillomandibular counterclockwise rotation and advancement would better address the patient's facial esthetic expectations but would increase TMJ loading and the risk for condylar resorption and osteoarthritis.[3,11]

All treatment options were discussed with the patient and his parents, and they decided on a combined orthodontic and surgical treatment plan including double-jaw surgery.

TREATMENT PROGRESS

Before the surgery, Roth prescription 0.018-in slot brackets were placed on the maxillary and mandibular dentitions. Leveling and alignment were achieved in 3 segments (UR3-7, U2-2, and UL3-7) in the maxillary arch with this progression of archwires: 0.014-in nickel-titanium, 0.016 × 0.22-in nickel-titanium, 0.016 × 0.022-in stainless steel, and 0.017 × 0.025-in stainless steel. The same archwire progression was used with a continuous arch form in the mandibular arch.

Before surgery, the patient was advised to avoid potential deleterious habits (ie, clenching) to the TMJs and was referred to a nonsurgical TMJ specialist. A comprehensive screening by a rheumatologist showed no autoimmune disease involvement. The following medications were prescribed before surgery to control possible condylar resorption: vitamins C, D, and E; calcium; and omega-3 fatty acid.[12] The surgery and initial recovery period were uneventful.

The immediate presurgical CBCT image (T1) was obtained 1 week before surgery, consisting of 3-piece LeFort 1 maxillary osteotomies, bilateral sagittal split ramus osteotomies with careful and passive proximal and distal segment repositioning, genioplasty, and

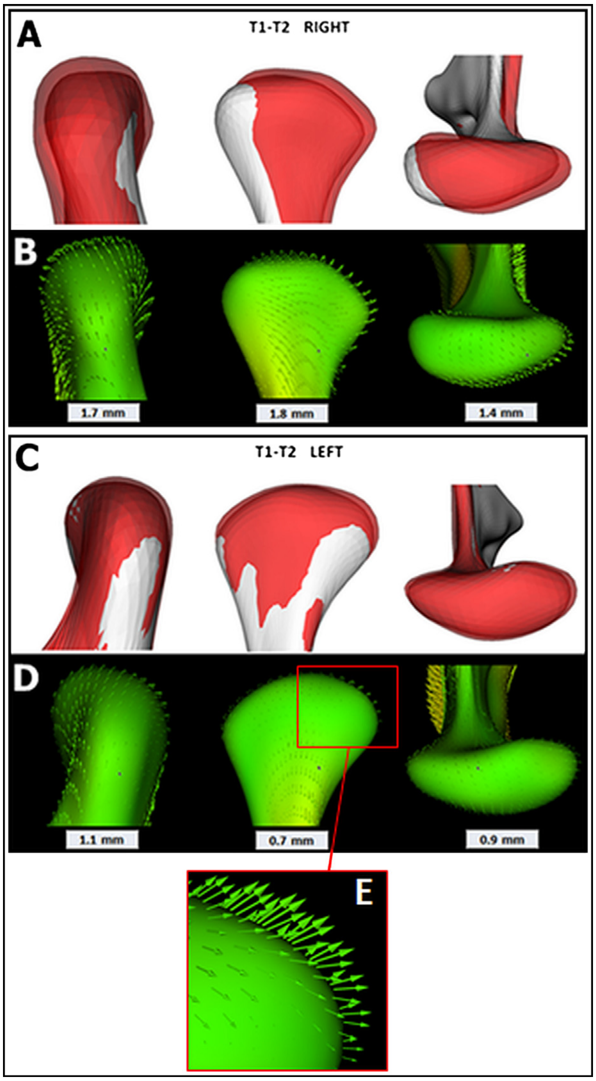

Fig 6. Changes in the condyles in the lateral, posterior, and superior views as a result of surgery: **A** and **C,** semitransparencies of the right and left condyles. Changes due to surgery are observed by the different position of the condyle from presurgical (T1, *white*) to immediately postsurgical (T2, *red*). **B** and **D,** Condyle model of T1 (*solid image*) and vectors showing the directions and quantitative changes to T2. **E,** Close-up image in the condyle area showing the vectors.

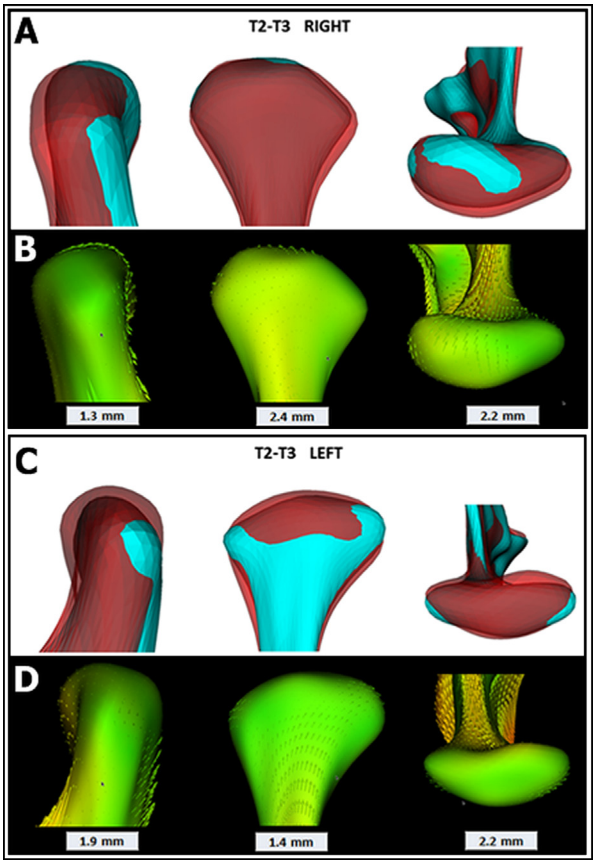

Fig 7. Changes in the condyles in the lateral, posterior, and superior views from immediately postsurgery to the 1-year follow-up: **A** and **C,** condylar changes from immediately postsurgical (T2, *red*) to the 1-year follow-up (T3, *light blue*); **B** and **D,** condyle model of T2 (*solid image*) and vectors showing the direction and quantitative changes to T3.

methylmethacrylate implants on both zygomatic and infraorbital rims to improve the anteroposterior projection of the region. Immediately after surgery (T2), a bilateral Class I occlusion, normal overbite, and normal overjet had been achieved, and a new CBCT image was acquired. The palatal splint was removed 8 weeks after surgery, and postsurgical orthodontic treatment was resumed. After surgery, the patient was maintained with clonazepam (0.5 mg daily) for 1 year to control the bruxism that could affect bone healing and increase TMJ loading.[13]

The maxillary sectioned arch was changed to a continuous arch 0.017 × 0.025-in copper-nickel-titanium and then to a continuous 0.017 × 0.025-in stainless steel archwire. Four months after surgery, the occlusion showed progressive shifting toward a slight canine Class II occlusion on the left side that remained 1 year after surgery (T3) as shown in a new CBCT image. Segmentations of all CBCT images were completed using open-source software ITK-snap (http://www.itksnap.org).[7] Surgical and postsurgical 3D cranial base registrations were obtained with an automated rigid voxel-wise method for accurate assessment of condylar changes that were computed using SPHARM-PDM toolbox (freeware: http://www.nitrc.

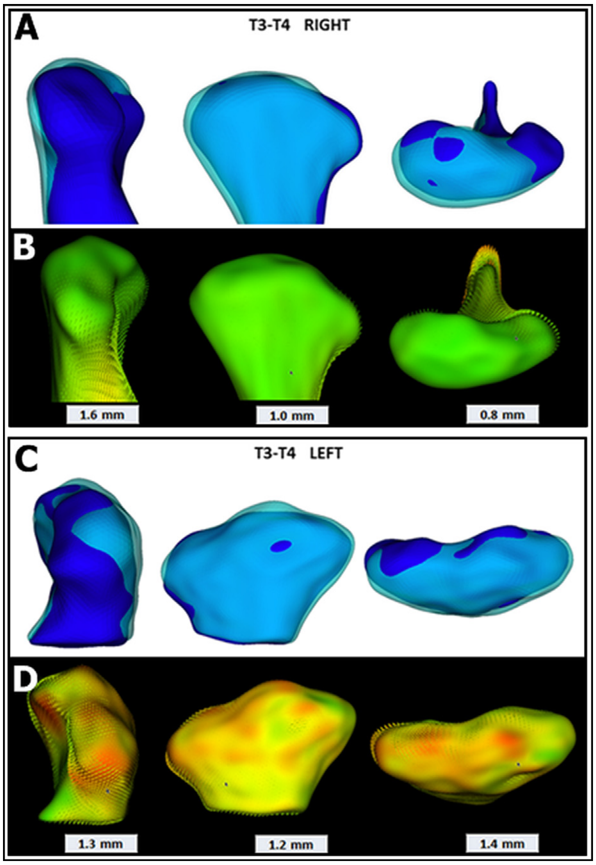

Fig 8. Changes in the condyles in the lateral, posterior, and superior views from the 1-year follow-up to the 2-year follow-up: **A** and **C,** condylar changes from 1 year of follow-up (T3, *light blue*) to 2 years of follow-up (T4, *dark blue*); **B** and **D**, condyle model of T3 (*solid image*) and vectors showing the directions and quantitative changes to T4.

org/projects/spharm-pdm).[4,6] This method establishes correspondent surfaces based on their morphology; it is a precise tool for longitudinal measurement of 3D surface structures.[14-18] Right and left condylar changes are shown as semitransparent overlays, displacement or remodeling direction vectors, and quantifications of surgical (T2-T1) and 1-year postsurgical (T3-T2) intervals (Figs 6 and 7). During surgery, the predominant condyle displacement directions were posteriorly, superiorly, and laterally in both the right (1.7, 1.8, and 1.4 mm) and left (1.1, 0.7, and 0.9 mm) TMJs, respectively (Fig 6). One year after surgery, the predominant right condyle was displaced anteriorly (2.4 mm), superiorly (2.2 mm), and medially (1.3 mm), whereas the left condyle moved posteriorly (1.4 mm), inferiorly (2.2 mm), and medially (1.9 mm) (Fig 7). The left condyle was significantly smaller at 1 year after surgery. At this point, the possibility of other systemic medications was discussed with the patient and his parents to control the left condylar resorption: the disease-modifying antirheumatic drug (etanercept), a TNF-inhibitor, piroxicam, celecoxib, and doxycycline.[12] All of these options were refused because of the potential side effects of long-term usage.

Because of the overall right and left condylar changes observed and left Class II canine tendency, it was decided to maintain the Class II mechanics with intermaxillary elastics to decrease condylar loading and allow possible TMJ adaptation. Debonding was postponed for another year. A new CBCT image was acquired 2 years after surgery (T4). Condylar changes were once again monitored and quantified between 1 and 2 years after surgery (Fig 8). The predominant directions of condyle displacement and remodeling were anterior, inferior, and lateral in both the right (1.0, 0.8, and 1.6 mm) and left (1.1, 1.4, and 1.3 mm) condyles, respectively. The 2-year follow-up showed a slight left condyle overall dimensional decrease relative to the 1-year follow-up assessment (Fig 8).

At the 2-year follow-up, the patient had no complaints, and the occlusion seemed to be stable within 3 months without intermaxillary Class II elastics. The patient and his parents agreed to debonding after we showed them our TMJ concerns and consequent occlusion limitations. The importance of close follow-up was emphasized because of the possibility for further condylar changes and consequent relapse. A mandibular fixed bar retainer (canine to canine) was bonded, and a maxillary removable retainer was constructed (Fig 9).

TREATMENT RESULTS

The patient's overall facial esthetics was improved in both profile and the frontal view. Overbite and overjet were within normal limits, and a Class I relationship was achieved with the exception of the left canine, which remained with a slight Class II sagittal relationship. The mandibular midline was slightly shifted to the left; this could be explained by the remodeling direction of the left condyle. All anterior teeth had significant gingival dehiscences that were already present from the first treatment because vertical elastics were used to correct the open bite. Increased dehiscence with the second treatment was related to the orthodontic compensation of skeletal instability. The left canine area showed a 1-mm open-bite tendency even though the mandibular left canine was 1 to 2 mm more superior than the right one (Figs 9-12). The superimpositions of the T1 and T3 cephalometric tracings showed significant counterclockwise rotation of the occlusal plane angle, maxillary advancement, mandibular

Fig 9. Posttreatment facial and intraoral photographs.

advancement, and vertical reduction and advancement of the chin. The regional superimposition on the palatal bone showed uprighting of the maxillary incisors obtained with the 3-piece maxillary osteotomies and the anterior segment clockwise rotation. The mandibular plane superimposition showed significant mandibular incisor extrusion at the 1-year follow-up (Fig 13, *A* and *B*). Overall postsurgical changes observed 2 years after surgery showed significant soft-tissue swelling resolution, slight maxillary incisor uprighting, and distal translation of the mandibular molars (Figs 14 and 15).

The posttreatment MRI (2 years after surgery) showed right and left TMJ articular disc displacements without reduction. The right condyle and the articular disc are depicted with normal morphology. The left condyle and the articular disc experienced significant degeneration. No signs of joint effusion were observed on the right or left weighted MRI at T2 (Fig 16).

DISCUSSION

This case presentation shows a reliable quantitative method to monitor condylar changes after orthognathic surgery and its relevance to postsurgical orthodontic difficulties. Once restricted to the academic environment, the construction of 3D surface models from CBCT scan measurements of bony changes has progressively become an essential tool in the orthodontic office. Although this technique is not user-friendly, all software used for image processing, visualization, and analysis that we used was open source and free. It is important for research studies to bridge the gaps between academic research and the private orthodontic office so that new protocols become clinical applications as soon as they are validated in the specialized literature. Commercial companies usually decrease this time gap, but private investment involvement results in a significant increase in costs to the final users. Furthermore, commercial software programs are not open source and

Fig 10. Posttreatment dental models.

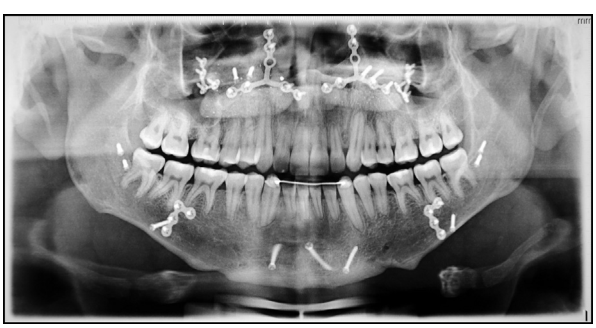

Fig 11. Posttreatment panoramic radiograph.

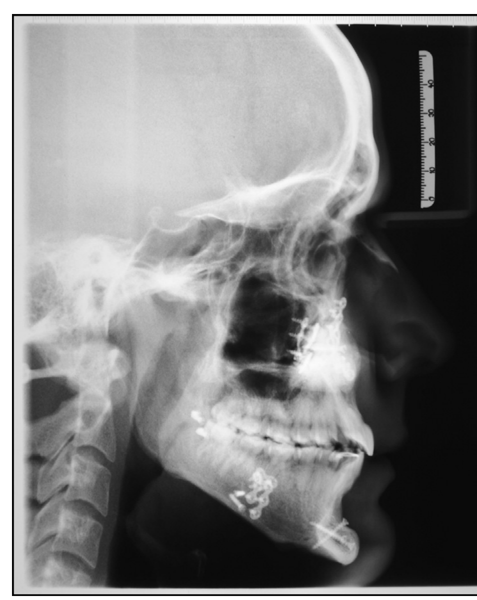

Fig 12. Posttreatment lateral cephalometric radiograph.

present restrictions that impede interaction with each other. Orthodontics has changed since the introduction of CBCT; from improved diagnosis to complex CAD-CAM technology, the specialty took a fast track with the 3D possibilities. The protocol presented here allows clinicians to quantitatively monitor surgical and postsurgical changes that affect the TMJs, basal bone, and teeth for the ultimately desired good occlusion and facial harmony. The semitransparencies (Figs 6, 7 and 8, *A* and *C*) are helpful for visualizing the changes; however, one cannot appreciate the magnitude of the changes. For quantification, the same method that has been used in a recent study[19] and described by Paniagua et al[18] was used in this study. Briefly, the method involves the use of a software program (SPHARM-PDM) to show the distance between corresponding areas at 2 times (one area represented by solid mesh and the other area by vectors in Figs 6, 7, and 8, *B* and *D*). Both directionality

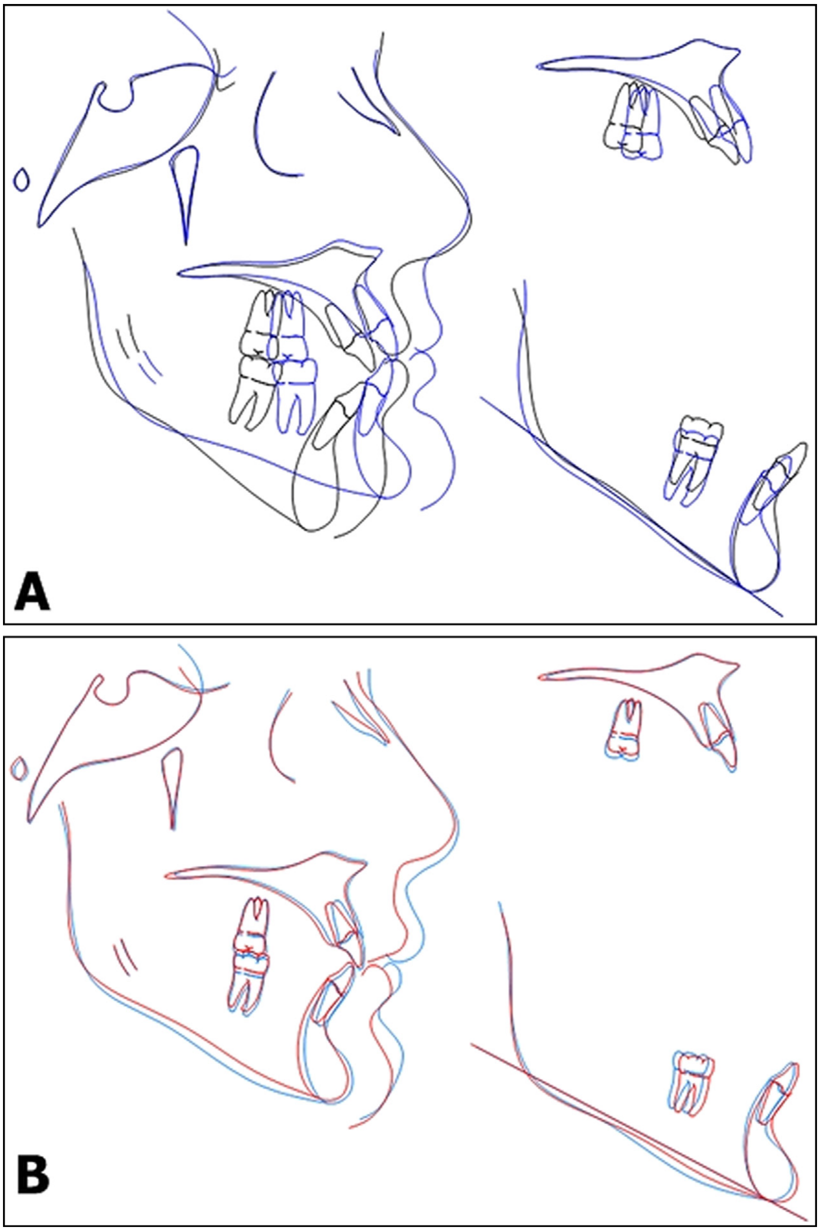

Fig 13. Overall and regional superimpositions of cephalometric tracings: **A,** immediately presurgical (T1, *black line*) and 1 year after surgery (T3, *blue line*); **B,** immediately postsurgical (T2, *light blue line*) and 2 years posttreatment (T4, *red line*).

and magnitude of change are represented by vectors on the graphic (Fig 6, *E*).

In this patient, a Class I anterior open bite was treated with a surgical and orthodontic approach followed by condylar resorption and subsequent spatial changes, particularly on the left side. This phenomenon affected the occlusion in all 3 planes of space. Detailed monitoring of condylar changes with 3D surface modeling and quantification from CBCT images offered additional information to guide the orthodontists in regard to appropriate timing for debonding and mechanics while accomplishing acceptable skeletal and dental outcomes (Table). The left condyle dimensional reduction was evident on the semitransparent overlays, and the positional changes and remodeling directions were depicted on the vector maps at 1 year (Fig 7) and 2 years (Fig 8) after surgery. Patients with hyperdivergent Class II anterior open bite are frequently treated with a combined

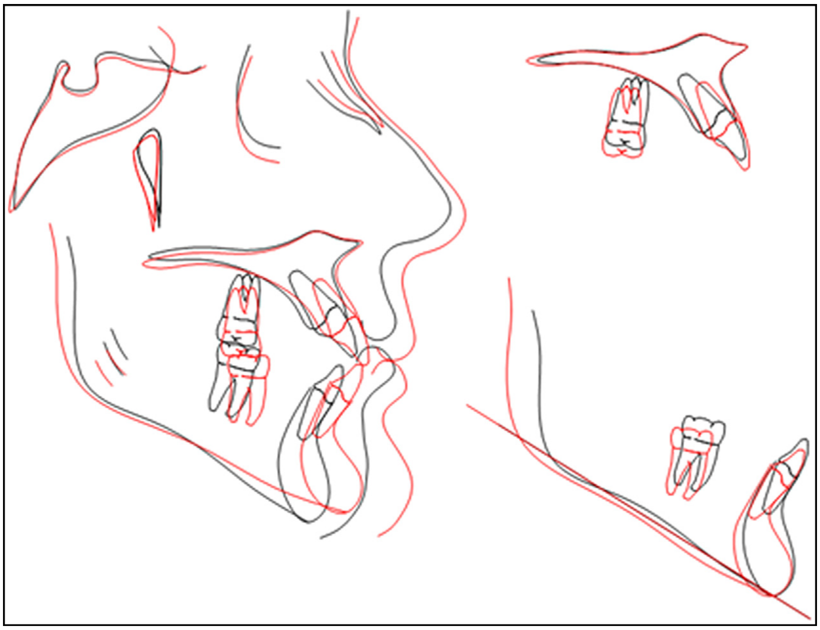

Fig 14. Overall and regional superimpositions of the initial and final cephalometric tracings: initial presurgical (*black line*) and 2 years posttreatment (T4, *red line*).

Table. Cephalometric analysis

Variable	*Norm*	*Initial*	*Pretreatment (T1)*	*Posttreatment (T2)*	*Surgical change (T2-T1)*	*1 year postsurgical (T3)*	*1-year follow-up (T3-T2)*	*2 years postsurgical (T4)*	*2-year follow-up (T4-T3)*
SNA (°)	82	82.1	81.3	85.4	4.1	86.3	0.9	83.4	−2.9
SNB (°)	80	81.4	78.9	81.9	3.0	82.8	0.9	81.9	−0.9
ANB (°)	2	0.7	2.5	3.5	1.0	3.5	0	1.4	−2.1
Sn.GoMe (°)	32	39.9	42.1	32.8	−9.3	31.5	−1.3	35.2	3.7
FMA (°)	25	35.6	34.5	23.0	−11.5	23.3	0.3	24.7	1.4
IMPA (°)	90	86.2	88.7	90.8	2.1	91.5	0.7	92.9	1.5
U1-NA (°)	22	36.4	31.3	22.2	−9.1	24.7	2.5	21.4	−3.3
U1-NA (mm)	4	8.4	6.6	4.0	−2.6	4.7	0.7	5.3	0.6
L1-NB (°)	25	27.5	29.7	25.5	−4.2	25.8	0.3	30	4.2
L1-NB (mm)	4	6.1	7.7	6.0	−1.7	6.7	0.7	5.6	−1.1

orthodontic and surgical approach when facial esthetics is the main concern. It is beyond the scope of this article to review all the controversy related to condylar resorption; rather, the goal is to review essential facts from the literature that might contribute to appropriate patient management. Previous studies have shown that mandibular advancement with or without maxillary impaction is usually a predictable surgical procedure for patients with normal or low mandibular plane angles requiring not more than 10 mm of mandibular advancement and limited to the 1-year follow-up.[20-22] Limited occlusal instability after combined orthodontic and surgical treatment may be related to condylar changes in patients with a hyperdivergent facial type. These patients are more susceptible to TMJ internal derangements than are patients with other facial patterns, regardless of the surgical and orthodontic treatment.[23-32]

In addition to the obvious clinical similarities (decrease of condylar volume, aggravation after large mandibular advancement, previous anterior open bite), we did not use the terminology suggested by Handelman and Greene[33] (progressive/idiopathic condylar resorption) because they emphasized the massive female prevalence among affected patients and the hormone-mediated phenomenon related to adolescents and young women.

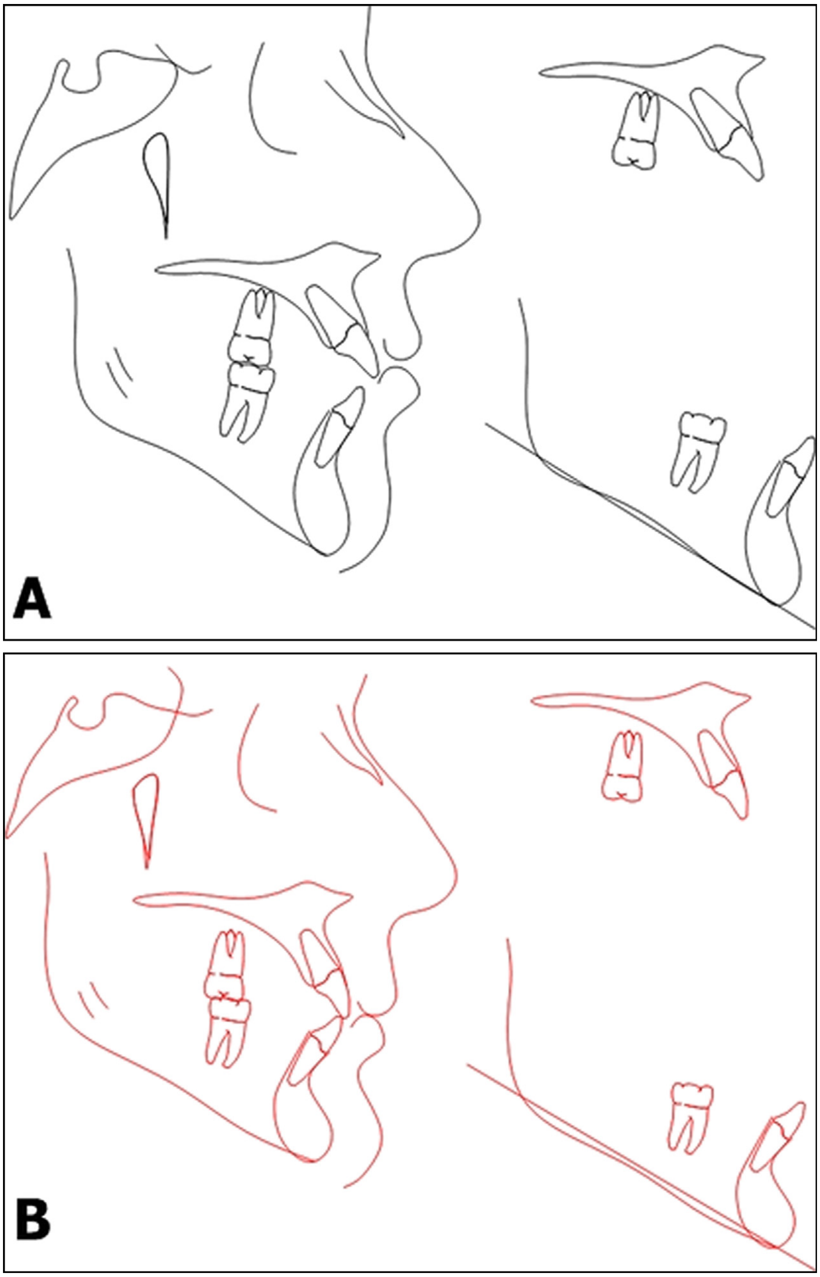

Fig 15. **A,** Initial cephalometric tracing; **B,** final cephalometric tracing.

Condylar changes during surgery are expected with large mandibular advancements.[20,21,34] Among the etiologic factors, patients with previous TMJ internal derangement are particularly susceptible to condylar resorption.[2,35-38] Other studies disagree with this finding, emphasizing the lack of correlation between asymptomatic volunteers with internal derangements and condylar resorption.[13]

Condylar torque might be related to condylar resorption, although we found in the literature pertaining to TMJ only hypotheses without a clinical trial or a longitudinal case series to support them.[13,39] If we consider condylar torque as TMJ loading, condylar torque has been demonstrated to be deleterious to any kind of joint and has been found to be the primary cause of articular degeneration.[11]

Due to the incongruent morphology of the TMJ articular surfaces, the intra-articular disc in position controls the stress applied to the TMJ.[40,41] The biochemical cascade of events followed by additional loading in the

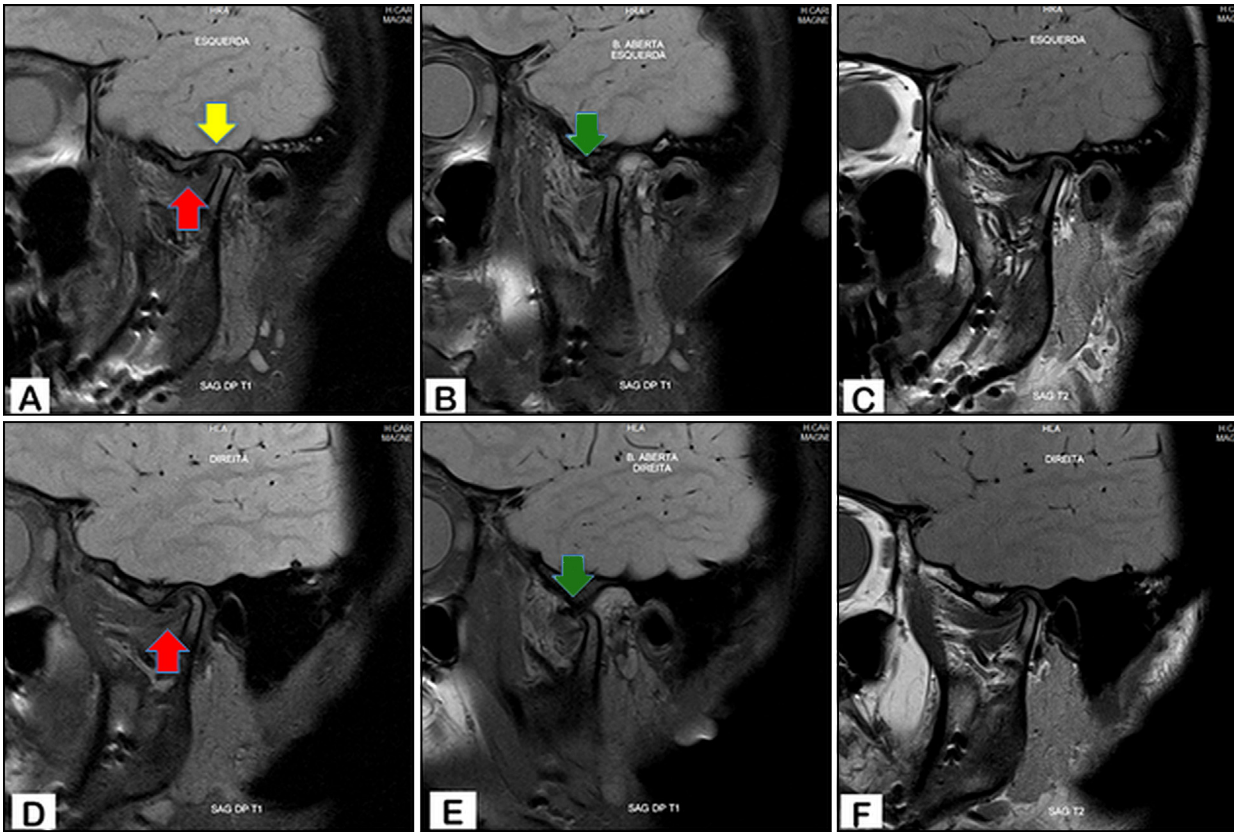

Fig 16. **A-C,** Posttreatment (2 years after surgery) sagittal oblique TMJ left and **D-F,** right turbo spin echo MRI. T2-weighted closed-mouth position proton density shows the left and right articular discs in frank anterior displacements (*red arrows*) and left condyle and disc with degenerative features (*yellow arrow*). Open-mouth positions depict no disc reduction on the right (**E**) or left (**B**) sides (*green arrows*). Left T2-weighted closed-mouth position (**C** and **F**) shows no intracapsular hypersignal.

joints and the mechanical damage to the articular surface have been described in detail.[42] Interestingly in this patient, neither the disc position nor the condylar torque during surgery seemed to be a predictable risk factor for the postsurgical condylar resorption experienced. Both TMJs initially had similar articular disc dislocations with reduction, and the condylar displacements of the right condyle (1.7, 1.8, and 1.4 mm) were actually greater than those of the left condyle (1.1, 0.7, and 0.9 mm) quantified at the lateral pole, the posterior surface, and the top of the condyle, respectively. If disc displacement or the amount of torque during surgery was a good indicator for condylar resorption, why did the right condyle experience noticeably less resorption than the left one?

According to the amount of TMJ hypersignal observed on the T2-weighted MRI, effusion is classified in 4 increasing levels (0, 1, 2, and 3).[10] Perhaps the slight hypersignal (level 1) that was observed only on the upper and lower compartments of the left TMJ (Fig 5, *C*) on the T2-weighted MRI could be a risk indicator for osteoarthritis, joint degeneration, and consequently condylar resorption.[8,9,43,44] Joint effusion has been found in younger patients more often than osteoarthritis, inflammatory cytokines, and, in particular, interleukin-1β, interleukin-6, interleukin-8, tumor necrosis factor-α, and cytokine receptors.[8,10,36,44] Level 1 TMJ joint hypersignal has not been considered as joint effusion because a line of joint effusion has been demonstrated in asymptomatic volunteers; however, more recent studies showed level 1 hypersignal on T2-weighted MRI to be significantly related to the previously mentioned cytokines and cytokine receptors.[8-10] Kaneyama et al[8] reported that level 1 TMJ hypersignal showed the strongest correlation with cytokine receptors when compared with levels 0, 2, and 3.

Presurgical and postsurgical medications and vitamin therapy have been suggested to control condylar resorption: vitamin D (bone density), vitamin C and omega-3 fatty acid (antioxidants), klonapin (antibruxism), and simvastatin (autoimmune inhibitor).[12,13] We used these medications in this patient before surgery and for 1 year after surgery. Although all medications have side effects, these seemed worth the risk in the view of the family and the staff. The same interpretation was not addressed to other medications recommended to control condylar resorption, particularly tumor necrosis factor-α and RANKL blockers, which are related to increased risks of infections and other autoimmune diseases.[45] The patient and his parents did not accept tetracycline on a long-term basis because it has been suggested to interfere with condylar resorption.[12,13] In our subjective experience comparing this patient with similar ones we have treated, the medications and vitamins prescribed did not affect the outcomes significantly. That is in contrast with the orthodontic mechanics, which were significant in the control of the postsurgical condylar changes and occlusal effects.

It is important to emphasize that the protocol we used does not allow differentiation from remodeling because of the condylar spatial changes, since the mandible is a movable bone and the cranial base was the reference for longitudinal superimpositions. A regional superimposition method to access TMJ osteoarthritis is under development and will be available shortly. CBCT superimposition clearly guided the postsurgical orthodontic treatment to the best possible result.

CONCLUSIONS

CBCT modeling and 3D superimpositions associated with TMJ MRI can improve the orthodontist's understanding of surgical instability and guide patient management for the best outcome possible.

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