

Integration of 3-dimensional surgical and orthodontic technologies with orthognathic “surgery-first” approach in the management of unilateral condylar hyperplasia

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Recent innovations in technology and techniques in both surgical and orthodontic fields can be integrated, especially when treating subjects with facial asymmetry. In this article, we present a treatment method consisting of 3-dimensional computer-aided surgical and orthodontic planning, which was implemented with the orthognathic surgery-first approach. Virtual surgical planning, fabrication of surgical splints using the computer-aided design/computer-aided manufacturing technique, and prediction of final orthodontic occlusion using virtual planning with robotically assisted customized archwires were integrated for this patient. Excellent esthetic and occlusal outcomes were obtained in a short period of 5.5 months. (*Am J Orthod Dentofacial Orthop* 2015;148:1054-66)

The advent of the digital era has enabled clinicians to use the best available data for evidence-based diagnosis, treatment planning, and execution of treatment. For accurate diagnosis, obtaining precise information from the imaging of the orofacial region in 3 dimensions is absolutely necessary to complement the clinical examination and a thorough medical and

dental history, especially when treating complex malocclusions with orthognathic surgery.¹ Traditionally, 2-dimensional (2D) imaging has been the standard for representing the 3-dimensional (3D) craniofacial region. However, the most common problems with 2D imaging are image distortion, magnification errors, and landmark identification errors.^{2,3} With conventional treatment planning for orthognathic surgery using 2D imaging, treatment outcomes have been reported to be suboptimal, especially in patients requiring correction of pitch, roll, and yaw (ie, facial asymmetry).⁴

With the introduction of 3D cone-beam computed tomography (CBCT), it has become possible to circumvent the above shortcomings. Image distortion and errors in landmark identification have been minimized, and the actual measurements (linear skeletal measurements, overjet, overbite, spacing, and dental arch widths) can be obtained accurately.⁵⁻⁷ Hence, the scope for applying 3D CBCT imaging has widened from image diagnosis to accurate quantification of the dimensions of the orofacial structures.⁵⁻⁷ Additionally, it is now possible to visualize the virtual patient by creating an integral fusion model combining the data from all 3 important tissue groups using a CBCT reconstructed bony volume, digital dental models, and a textured facial soft tissue image.⁸ This model is highly effective in precisely diagnosing the problem in all 3 spatial planes. Furthermore, the fusion model has

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All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.

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Submitted, November 2014; revised and accepted, August 2015.
0889-5406/\$36.00

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<http://dx.doi.org/10.1016/j.ajodo.2015.08.012>



Fig 1. Pretreatment photographs showing facial asymmetry with a skeletal and dental Class III malocclusion, concave profile caused by maxillary deficiency, a slightly prognathic mandible, frontal occlusal plane cant, and noncoincident soft tissue skeletal and dental midlines.

enabled clinicians to accurately plan surgical movements in the virtual environment and generate highly accurate surgical splints using the computer-aided design/computer-aided manufacturing (CAD/CAM) technique⁹ for effective treatment outcomes.¹⁰ It was recently reported that patients with facial asymmetry requiring maxillary and mandibular yaw (rotation around a vertical axis) correction showed excellent positional and orientation accuracies when computer-aided surgical planning was performed.¹¹

In the last decade, significant technologic advancements have been made in computer-aided orthodontic treatment. SureSmile technology (OraMetrix, Richardson, Tex) is a type of computer-assisted orthodontic treatment in which an intraoral dental scanner (OraScanner; OraMetrix) and 3D software generate accurate

and reliable 3D digital models from which virtual treatment plans are obtained through a software interface.¹² The planned treatment can be accurately translated to the patient using robotically assisted archwire bending technology, thus possibly improving the overall treatment efficiency and quality.¹³

In a previous case series, we demonstrated that efficient and effective outcomes can be achieved with 3D virtual surgical planning and digital splints for patients with facial asymmetry.¹⁴ In this study, we integrated the 3D virtual dental planning (SureSmile process) with the 3D virtual surgical planning along with fabrication of digital surgical splints using a CAD/CAM technique. The primary intent of this article is to document how the use of 3D digital technology and the surgery-first approach can significantly reduce the treatment time

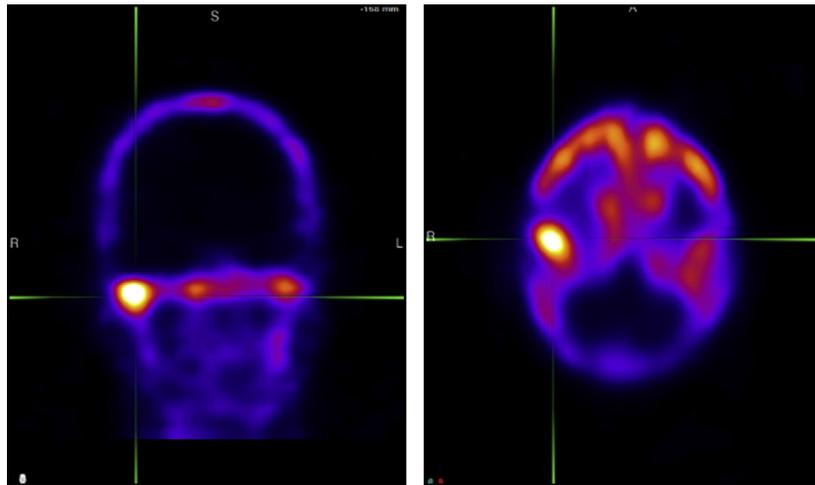


Fig 2. Second Tc-99 scintigraphy examination showing an increased uptake of radioisotope on the right mandibular condyle.

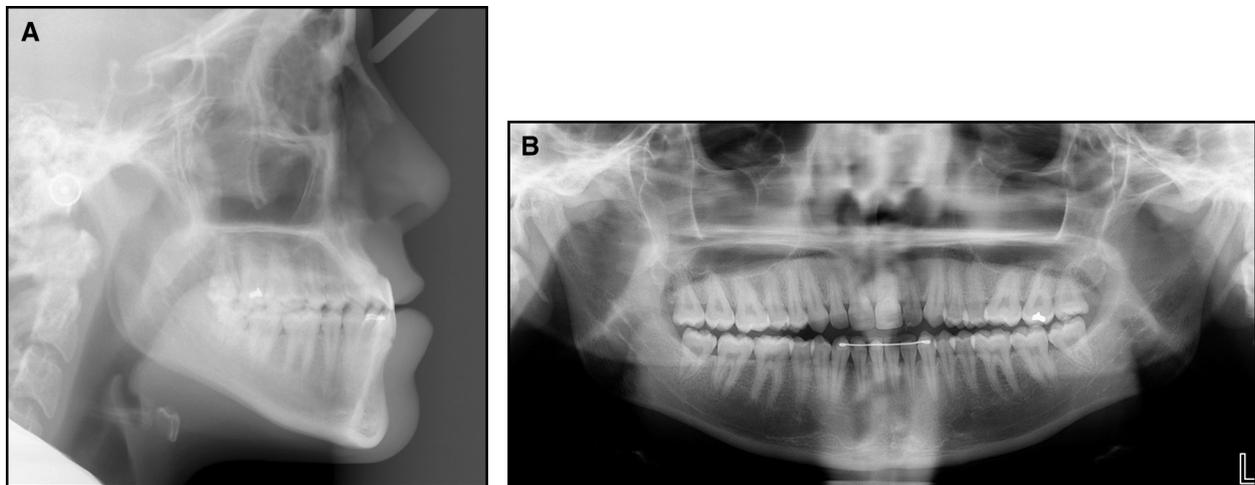


Fig 3. **A**, Pretreatment lateral cephalometric radiograph; **B**, pretreatment panoramic radiograph.

Table. Lateral cephalometric analysis

| Variable | Norm | Pretreatment | Posttreatment | Change |
|--------------------------|------|--------------|---------------|--------|
| SNA (°) | 82 | 81.5 | 85.5 | 4 |
| SNB (°) | 80 | 85 | 85.5 | 0.5 |
| ANB (°) | 2 | -3.5 | 0 | 3.5 |
| SN-GoGn (°) | 32 | 29 | 31 | 2 |
| IMPA (°) | 90 | 82 | 82 | 0 |
| U1-SN (°) | 102 | 119 | 122 | 3 |
| U1-NA (mm) | 4 | 10 | 7 | -3 |
| L1-NB (mm) | 4 | 5 | 4.5 | -0.5 |
| Interincisal angle (°) | 131 | 126 | 122 | -4 |
| Upper lip to E-line (mm) | -4 | -3.8 | -2.2 | 1.6 |
| Lower lip to E-line (mm) | -2 | 1 | -1 | -2 |

in a patient with facial asymmetry caused by unilateral condylar hyperplasia.

CASE REPORT

A 23-year-old Middle Eastern woman reported to the orthodontic clinic at the University of Connecticut with the primary complaint that her jaw was shifting to the left side, and she wanted her bite fixed (Fig 1). Her past dental history showed a consultation with an oral surgeon 4 years previously during which a slight facial asymmetry with the chin point deviated toward the left side was documented. A subsequent clinical examination showed that her facial asymmetry had worsened, with the chin point deviated toward the left side of the facial midline by 4 mm. The patient was referred for a

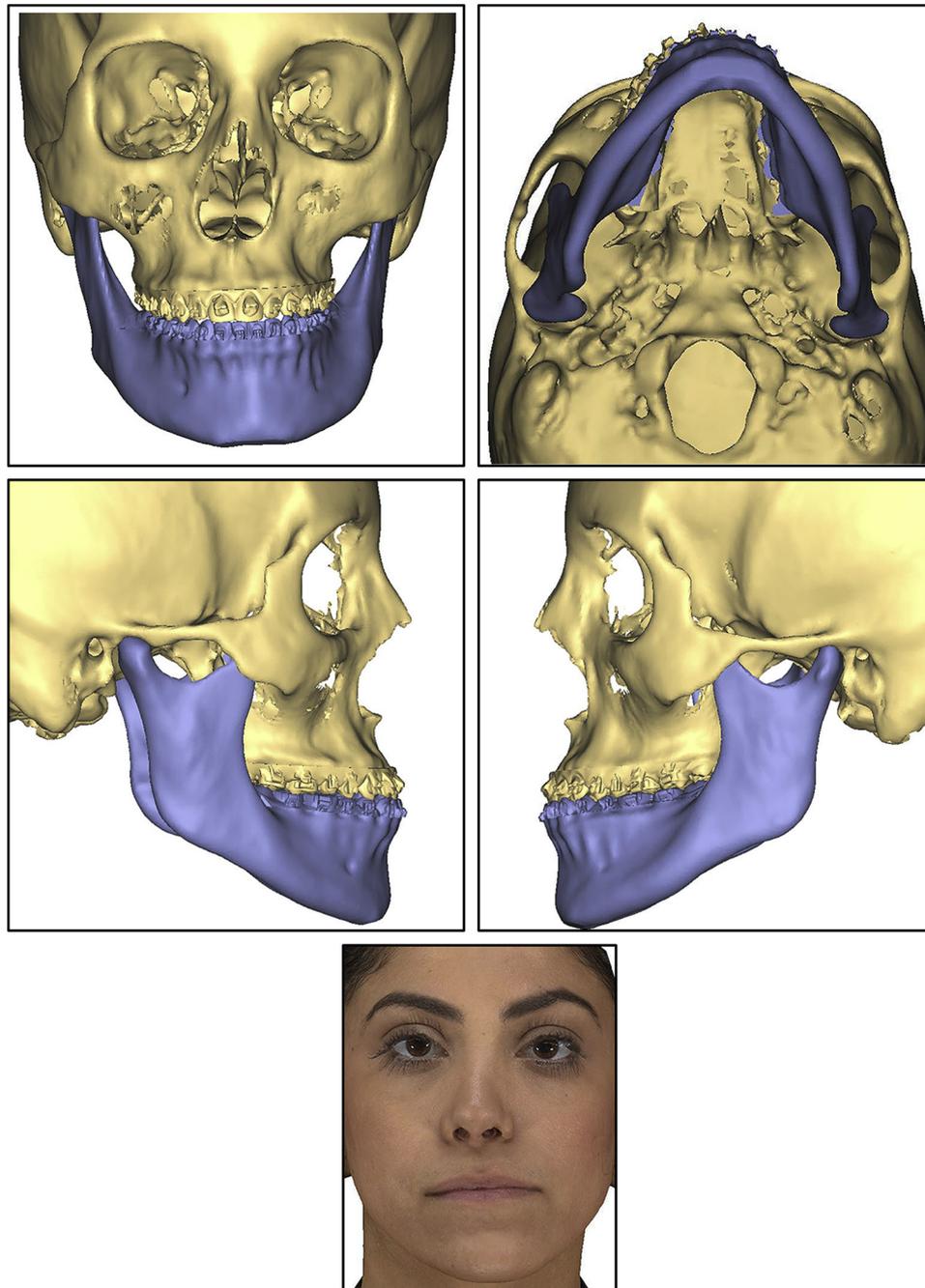


Fig 4. Pretreatment integral fusion model combining the CBCT scan, the dental models, and the 3D photographs.

Technetium (Tc)-99 single photon emission computed tomography scintigraphy examination, and the radiology report suggested right unilateral condylar hyperplasia. Since condylar hyperactivity is expected to subside during the second and third decades of life, the surgeon recommended reevaluating her 9 to

12 months later. However, a second Tc-99 scan taken 9 months later again showed hyperactivity of the right mandibular condyle (Fig 2).

The extraoral examination showed facial asymmetry with the chin point deviated toward the left side of her face by 4 mm. Additionally, a deviated nasal septum

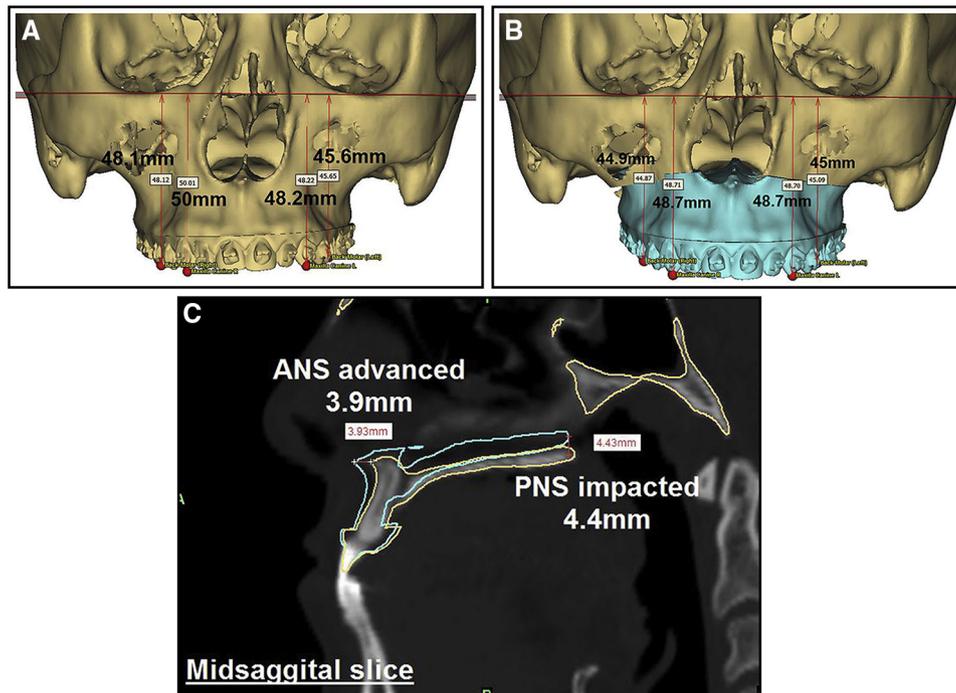


Fig 5. Virtual 3D surgical plan showing the maxillary movements: **A**, preoperative maxillary position; **B** and **C**, LeFort I osteotomy with clockwise rotation of the maxilla with the center of rotation at the maxillary incisal edge. Unilateral maxillary impaction (right side) for the correction of the occlusal cant is seen.

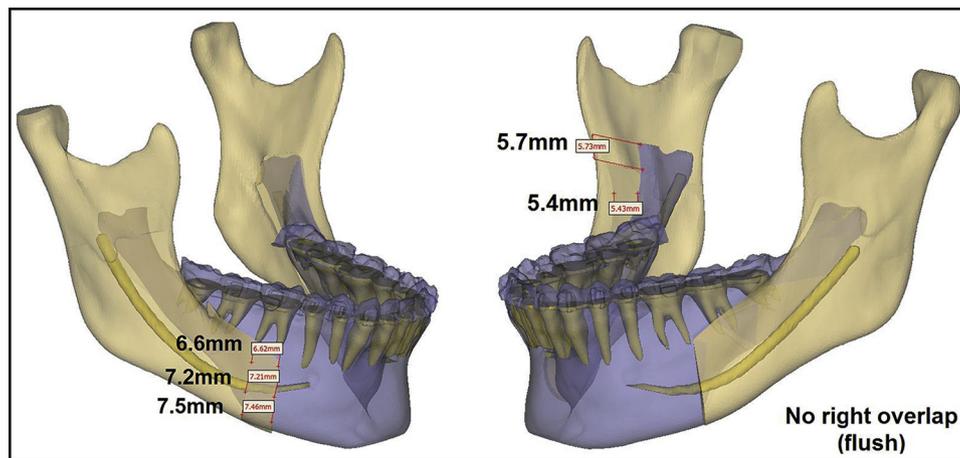


Fig 6. Virtual 3D surgical plan showing the mandibular asymmetric setback with the bilateral sagittal split osteotomy for the correction of the mandibular deformity in the yaw plane. *Yellow* represents the proximal segment of the mandible after the planned bilateral sagittal split osteotomy. *Purple* represents the distal segment of the mandible. With the asymmetric movement of the mandible to the right side, the distal segment overlaps the proximal segment. The magnitude of the overlap is expressed at 3 levels in the corpus of the mandible on the right side. Since the mandible is rotating around the sagittal split osteotomy on the left, no overlap between the proximal and distal segments is observed in the virtual plan.

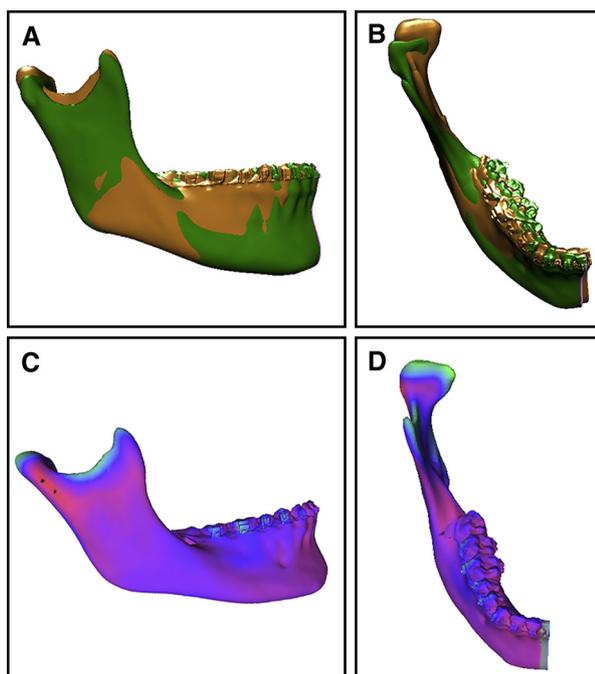


Fig 7. Superimposition of mirrored left normal hemimandible on right side: **A**, lateral view; **B**, superior view; **C** and **D**, 3D color maps demonstrate distance differences between the superimposed surfaces. *Red* illustrates a more positive surface (+3.7 mm) in relation to the left normal hemimandible. *Green* illustrates more negative surface (−7.4 mm) in relation to the left normal hemimandible.

toward the right side further accentuated the facial asymmetry. The extraoral frontal examination at rest showed a noticeable intercommissure cant and a paranasal deficiency, and the soft tissue lower border of the mandible was inferior on the right side compared with the left side (Fig 1). A concave profile caused by a combination of maxillary deficiency and a prognathic mandible was observed (Fig 3, A; Table). Dentally, the patient had a bilateral Class III molar relationship that was more accentuated on the right side with an edge-to-edge bite anteriorly. An occlusal cant was evident, with the left buccal segment more coronal. The mandibular midline was deviated to the left side by 4 mm in reference to the facial midline. She had retroclined mandibular incisors and proclined maxillary incisors, indicating anteroposterior dental compensations for the underlying Class III skeletal relationship. Her smile showed a maxillary cant with a greater gingival display on the right side. The maxillary and mandibular arches were well aligned because she had prior orthodontic treatment. The panoramic x-ray showed different



Fig 8. **A** and **B**, Frontal and profile views before surgery; **C** and **D**, the final outcome of the virtual simulation of the 3D surgical plan.

morphologies of the condyles and ramus lengths between the right and left sides (Fig 3, B).

The main treatment objectives were to prevent further worsening of the asymmetry caused by the active unilateral condylar hyperplasia, improve her facial esthetics and occlusion, and minimize the overall treatment time. Based on the guidelines of Wolford et al,¹⁵ treatment options of either high condylectomy and orthognathic surgery or orthognathic surgery when the hyperactivity of the condyle subsides were offered to the patient. She accepted the high condylectomy and orthognathic surgery–first approach for the correction of her facial asymmetry. The treatment goals consisted of preventing the worsening of facial asymmetry; improving her soft tissue profile; correlating her dental, skeletal, and soft tissue midlines to the facial midline; leveling her frontal occlusal plane; and improving her smile esthetics.

In this patient, both the surgical and orthodontic corrections were planned virtually. For the surgical plan, 3 weeks before the surgery, after indirect bonding of the orthodontic appliances (0.022-in preadjusted

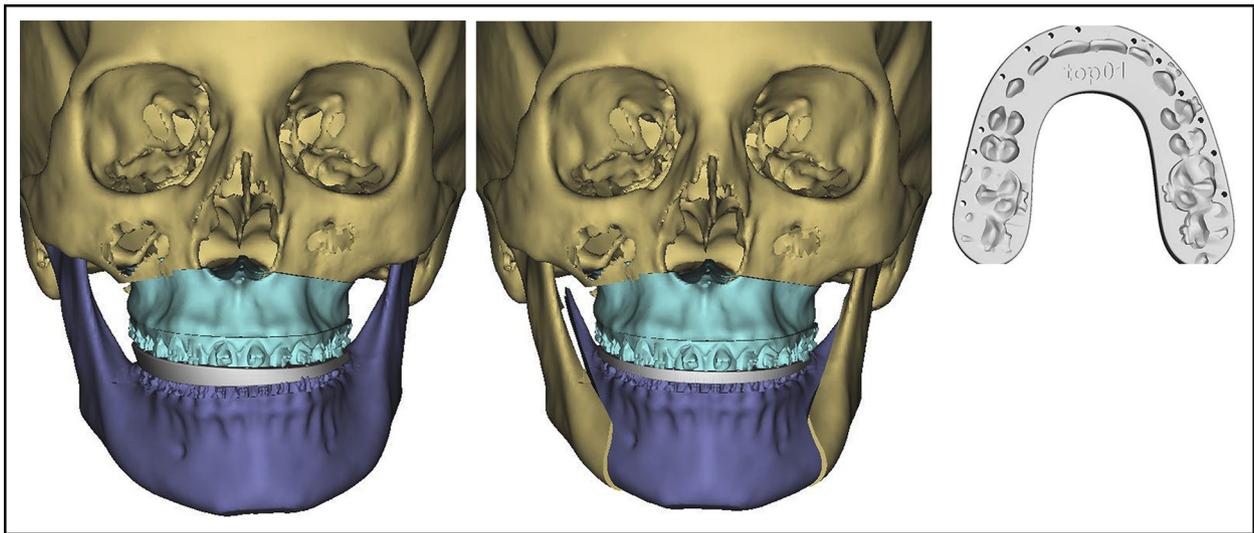


Fig 9. Intermediate and final digital surgical splints.

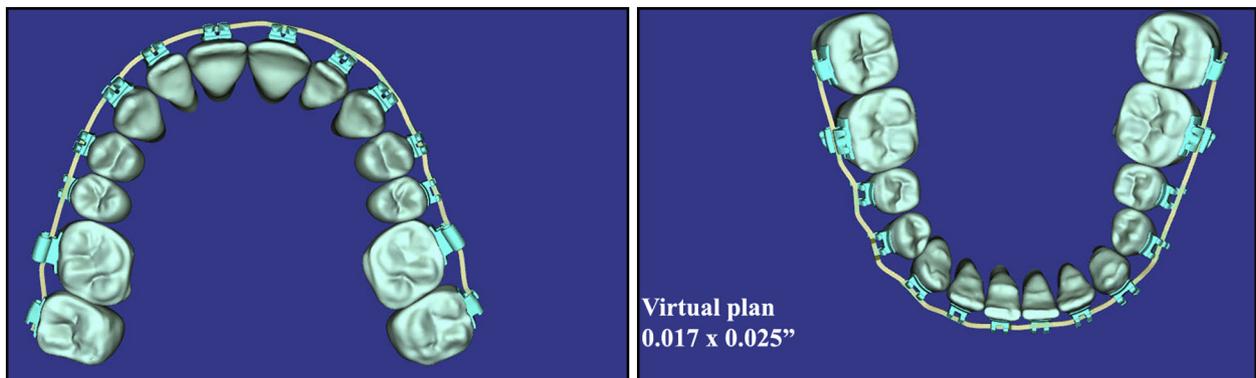


Fig 10. SureSmile virtual plan for 0.017 × 0.025-in archwire.

edgewise brackets), a CBCT scan (exposure time, 14 seconds; field of view, 12-in; voxel size, 1.25 mm) was taken for the construction of a fusion/composite model of the skull as described by Xia et al¹⁶ with Synthes PROPLAN CMF software (Materialise, Plymouth, Mich). The scan was oriented using the interorbital plane as the horizontal reference line. The midline was determined with a line perpendicular to and bisecting the horizontal reference line connecting the left and right orbitales. The patient's 3D photographs (Vectra; Canfield Imaging Systems, Fairfield, NJ) were integrated with the CBCT scan to obtain a textured facial soft tissue image (Fig 4). To achieve the treatment goals, the virtual surgical plan consisted of clockwise rotation of the maxillomandibular complex, a LeFort 1 osteotomy with advancement and asymmetric impaction of the maxilla (Fig 5), and an asymmetric bilateral sagittal split osteotomy for

mandibular setback (Fig 6). A high condylectomy of the right mandibular condyle was planned by mirroring the normal contralateral condyle (Fig 7). Soft tissue simulation was also performed based on the virtual surgical plan (Fig 8) with an algorithm proprietary to the orthognathic surgical planning software company. Then the virtual plan was exported to the CAD/CAM software for digital construction of the surgical splints (Fig 9). The intermediate and final digital splints, made of hybrid epoxy-acrylate polymer, were physically generated using the rapid prototyping additive manufacturing process (SLA-3500 machine; 3D Systems, Rock Hill, SC).

Once the surgical 3D plan was obtained, the orthodontic digital plan was defined based on the skeletal correction objectives. An intraoral dental scan (OraScanner) was obtained at a private orthodontic office with the SureSmile facility. By using the 3D software virtual

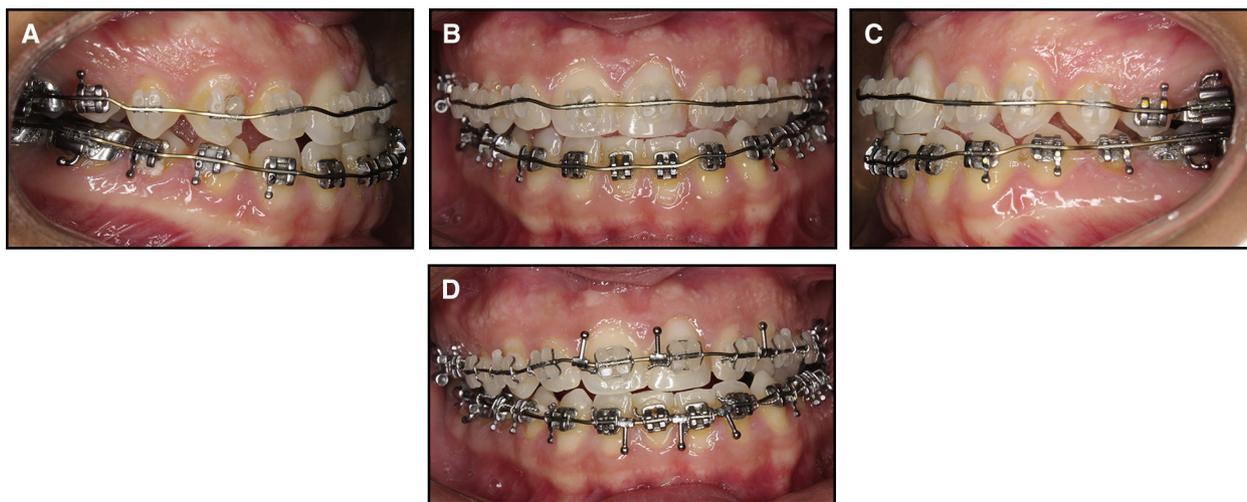


Fig 11. A-C, SureSmile passive 0.017 × 0.025-in nickel-titanium archwires; D, surgical hooks placed on the archwire 1 day before surgery.

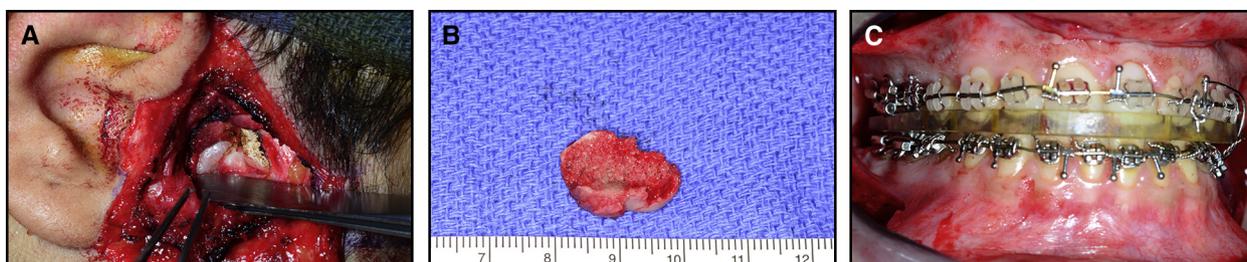


Fig 12. A and B, Removal of the right hyperactive mandibular condyle with a high condylectomy surgical procedure; C, well-fitted final 3D splint printed using the CAD/CAM technique.

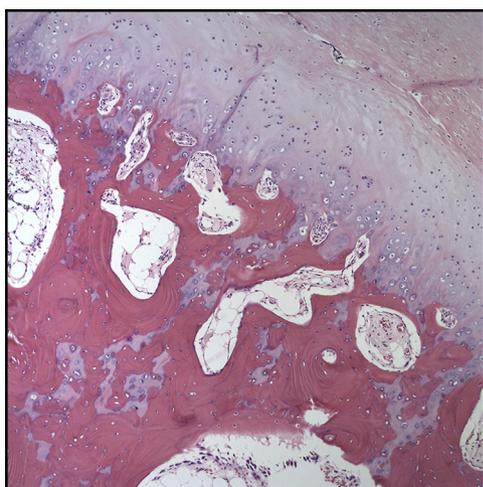


Fig 13. Histopathology section of the right mandibular condyle depicting the chondrocytes progressively undergoing hypertrophy and endochondral ossification toward the cancellous bone that shows persistence of cartilage rests in the thick bony trabeculae.

dentel setup, a simulated outcome was generated. Based on the pretreatment model, maxillary and mandibular 0.017 × 0.025-in nickel-titanium passive presurgical archwires were made contoured to the malaligned teeth. For the first time, a passive presurgical archwire fabricated with SureSmile technology was used in this patient; it ensured no tooth movement and thus proper fit of the surgical splints. Finally, the sequential archwires were fabricated by the SureSmile technology to the predicted orthodontic outcome (Fig 10).

One day before the surgery, the customized SureSmile archwires (0.017 × 0.025-in nickel-titanium) with surgical hooks in the anterior region were placed. These wires were designed to fit passively in the brackets (Fig 11). The planned surgery was transferred to the operating room through the surgical splints. The LeFort I osteotomy was done first, and once all the maxillary movements were achieved, the intermediate splint was used to hold the new maxillary position. The splint was removed when the maxillary position was stabilized with rigid internal fixation. Next, the high condylectomy



Fig 14. Posttreatment photographs showing good esthetic and occlusal outcomes.

and bilateral sagittal split osteotomy procedures were performed, and the final splint was used to achieve the planned mandibular position (Fig 12). The resected condyle was sent for biopsy. The histopathology sections showed that the mandibular condyle was covered with fibrocartilage with a proliferating zone. The chondrocytes were progressively undergoing hypertrophy and endochondral ossification toward the cancellous bone that showed persistence of cartilage rests within thick bony trabeculae. Overall, the morphology was consistent with the clinical and radiologic findings of condylar hyperplasia (Fig 13). The final splint was removed after surgery, and the final occlusion was stabilized with intermaxillary elastics. The maxillary and mandibular third molars were extracted during the surgery.

The patient was seen 2 weeks postsurgery, when the archwires with the surgical hooks were removed. The first set of active SureSmile 0.017 × 0.025-in nickel-

titanium archwires with seating elastics was placed. Four weeks later, 0.019 × 0.025-in nickel-titanium archwires were inserted. The patient was debonded 4.5 months after surgery. The posttreatment evaluations of the photographs (Fig 14) and radiographs (Fig 15) indicate great improvements in facial symmetry and the profile. A Class 1 occlusion with ideal overjet and overbite was obtained. The 2D superimposition of the pretreatment lateral cephalometric radiograph with that at posttreatment reflects the maxillary and mandibular movements (Fig 16). The patient was quite satisfied with the remarkable facial improvement and was grateful for the shortened treatment time. She had rhinoplasty 8 months later to correct her deviated nasal septum. The 11-months posttreatment photographs showed excellent stability of the treatment results and a significant improvement in her nasal profile (Fig 17). The 3D pre-treatment and retention photographs were

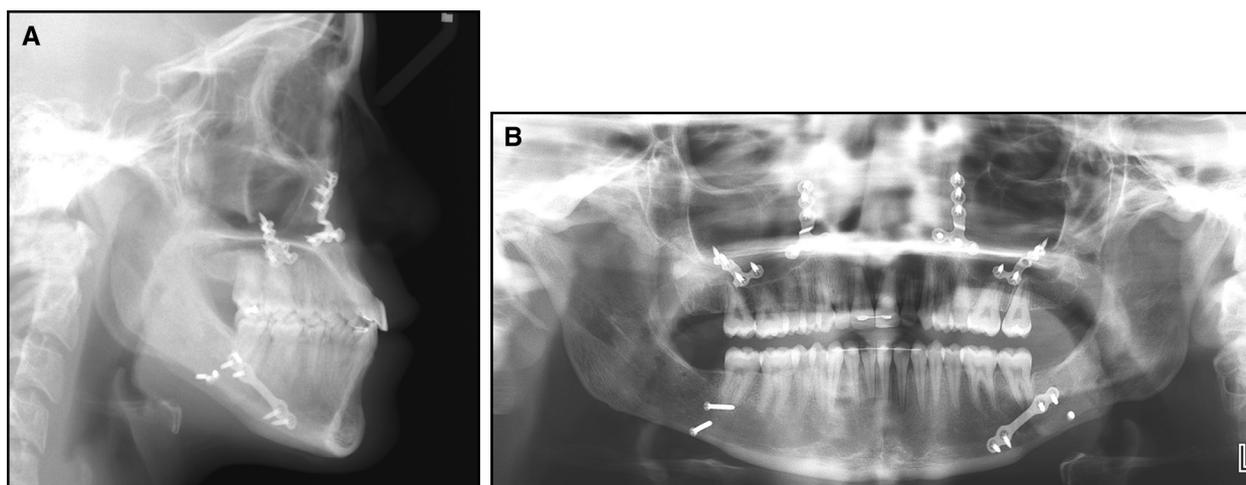


Fig 15. A, Posttreatment lateral cephalometric radiograph; B, posttreatment panoramic radiograph.

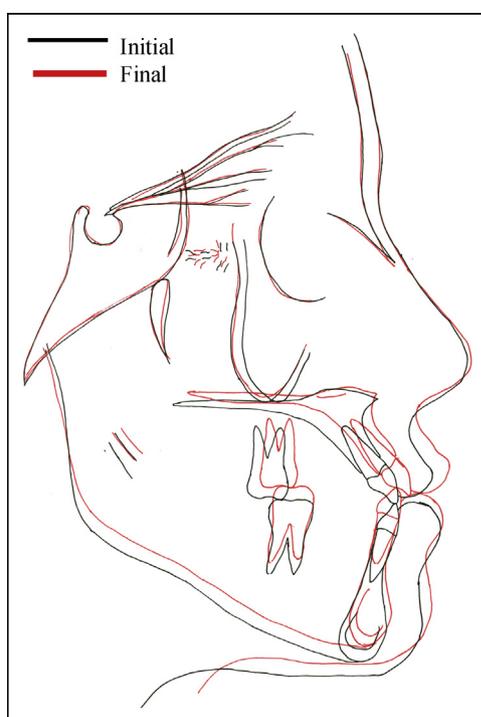


Fig 16. Superimposition of pretreatment and posttreatment lateral cephalograms.

superimposed on the forehead and the nasal root, and [Figure 18](#) shows the soft tissue changes.

DISCUSSION

Unilateral condylar hyperplasia is a self-limiting condition occurring between 10 and 30 years of age with equal distribution between male and female subjects.¹⁷

The unilateral excessive growth of the mandibular condyle may result in significant dental, skeletal, and soft tissue asymmetry. In these patients, bone scanning (Tc-99) is routinely used to evaluate the hyperactivity of the condyles. However, the gold standard for diagnosis of condylar hyperplasia is correlating the clinical findings with the bone scan.¹⁷ This is because the sensitivity of the bone scan depends on the type of scintigraphy study. A recent meta-analysis compared the sensitivity (true positive) and specificity (true negative) of a planar bone scan and the single photon emission computed tomography scanning technique in the diagnosis of unilateral condylar hyperplasia.¹⁸ The sensitivity of the single photon emission computed tomography scan (0.91) was higher than that for the planar bone scan (0.70), whereas the specificity for the 2 techniques was similar (0.9).

Surgical correction of facial asymmetry is complicated because it usually involves all 3 dimensions of space. Conventional planning has significant limitations, since the planned corrections are based on 1 plane or 2 planes of space provided by 2D radiographs, limiting the possibility of fully visualizing the effects of the correction of 1 dimension over the others.¹⁹ Additionally, condylar positional changes and interferences between the proximal and distal segments cannot be predicted.²⁰ However, these shortcomings can be minimized or overcome with 3D virtual surgical planning.¹¹ De Riu et al¹⁹ evaluated the correction of facial asymmetry by comparing the outcomes of conventional and 3D surgical planning. In their randomized clinical trial, they found that the alignment of the maxillary and mandibular dental midlines, the agreement between the mandibular midline and the facial midline, and the



Fig 17. Records at 11 months posttreatment showing excellent stability of the interdisciplinary treatment.

agreement of the mandibular sagittal plane with the midsagittal plane were more accurate in the 3D surgical planning group.

One major advantage with 3D computer-assisted surgical planning is the ability to visualize different combinations of surgical movements to achieve the desired outcome. The accurate prediction of the soft tissue changes after 3D virtual surgery can aid the surgeon and the orthodontist in determining the best treatment option.²¹ Often, in subjects with facial asymmetry, the asymmetry not only is due to the differences in size and shape of the hard tissues, but also is complicated by soft tissue differences between the 2 sides.¹⁴ Hence, visualization of the esthetic changes in the planning stage is of paramount importance to patients with facial asymmetry. Additionally, the surgeon can preview the soft tissue facial outcome and alter the osteotomy cuts and plan for implants or grafting to achieve the desired

outcome.¹⁶ In recent years, several soft tissue simulation software programs have been introduced, but few studies have validated their accuracy with that of the actual surgical outcome.²²

Marchetti et al²³ examined the reliability of soft tissue simulation using SurgiCase-CMF software. They compared the virtual surgical plan with the actual outcome 6 months after surgery. The differences between the simulated plan and the postsurgical plan ranged from 0.50 to 1.15 mm, which were less than the maximum tolerance level of 2 mm. In 91% of virtual plans, the error was less than 2 mm. Similarly, Bianchi et al²¹ found that in 86.8% of simulations, the error was less than 2 mm. Finally, the authors of both studies concluded that the 3D virtual plan with SurgiCase-CMF software could accurately predict the postsurgical facial soft tissue changes. On the contrary, Terzic et al²² reported errors greater than 3 mm in the lower part of

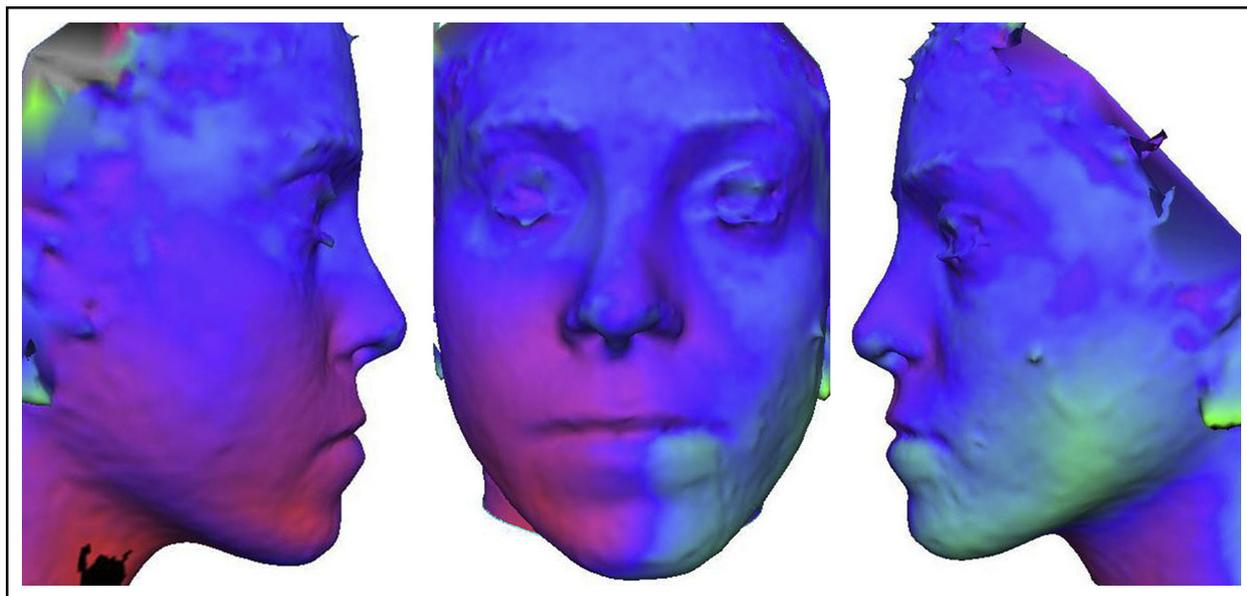


Fig 18. Three-dimensional color map generated by superimposing the pretreatment and 11-month-postoperative 3D photographs. The forehead and the nasal root were used as references. *Blue* indicates areas that have not changed. *Red* (+10 mm) indicates regions that are in front of the preoperative image (ie, the most positive distances), and *green* (–10 mm) shows the most negative distances.

the face in 29.8% of the simulations between the presurgery and postsurgery computed tomography scans. The difficulty in obtaining perfect accuracy may be due to factors such as the behavioral variability of the soft tissues caused by swelling and the patient's muscle tone.²⁴ Also, the patient's head posture and its influence on the soft tissues are unknown.²² Additionally, the posttreatment evaluation was done 6 months after surgery in the study of Terzic et al, whereas Aydemir et al²⁵ showed significant soft tissue changes occurring during the first 3 years after surgery. Also, the software manipulation and the predictions are technique-sensitive and time-consuming and can easily take 3 to 4 hours for just 1 patient, even with experienced personnel.²² However, further long-term studies are necessary to evaluate the soft tissue changes and compare them with the virtual plan as predicted by the software.

Based on these drawbacks with the soft tissue prediction techniques, no definite conclusion could be drawn on the soft tissue prediction because the studies mentioned had limited numbers of subjects and used different prediction software programs. Also, it is questionable whether the simulated plan was achieved by the surgeon. This was evident in our patient as well, although an excellent outcome was obtained. The accuracy of 3D prediction in the soft tissues was questionable, since there was a difference in the virtual prediction and the actual outcome. Additionally, the

photographs at posttreatment and at 11 months in retention showed a slight difference between the right and left sides of the face.

The introduction of the SureSmile process is a significant technologic innovation for providing customized care and minimizing errors from appliance placement.¹² Alford et al²⁶ compared the quality of treatment in subjects who were treated with the SureSmile method with those undergoing conventional fixed orthodontic treatment. SureSmile-aided treatment produced superior rotational correction and interproximal space closure, but the second-order corrections were inferior when compared with the fixed orthodontic treatment group. The American Board of Orthodontics model grading system scores were significantly worse for the SureSmile group. Additionally, the treatment time was significantly reduced by nearly 7 months in patients treated with SureSmile. Similar results were obtained by Saxe et al¹³; the SureSmile patients demonstrated better objective grading system scores by 14.3% compared with the patients who had conventional fixed therapy, along with a 36% decrease in treatment time. However, the major limitation of both studies was that they were retrospective.^{13,26} In the study of Alford et al, the group treated with conventional orthodontic appliances had higher pretreatment discrepancy scores than did the SureSmile group. Thus, well-controlled clinical trials are necessary before making any reasoned

judgment regarding the efficiency and effectiveness of the SureSmile technique when compared with conventional orthodontic treatment.

In the future, we foresee full integration of 3D surgical and orthodontic planning, where manipulation of teeth and jaw movements can be done with the same software.

CONCLUSIONS

Integration of 3D computer-aided orthognathic surgical protocols with 3D digital orthodontic treatment methods (with customized wires in this patient) is possible. An excellent outcome can be achieved with these approaches in conjunction with the surgery-first protocol. Additionally, evidence supports the use of computer-assisted orthognathic surgical planning in the management of facial asymmetry.

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