Three-dimensional treatment planning for maxillary and mandibular segmental surgery for an adult Class III: *Where old meets new*

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ABSTRACT

Class III open bite malocclusion can be among the most difficult case types to obtain an excellent occlusal, skeletal, and facial outcome. Treatment options include growth modification, extraction for orthodontic camouflage, and orthognathic surgery. For the most severely affected and non-growing patients, orthognathic surgery is often the most predictable and, in some situations, the only viable way of achieving an optimal result. The risks and benefits of surgical treatment options can occasionally be difficult to assess particularly for providers with limited experience. Two-dimensional surgical predictions can assist but do not permit the third dimension to be visualized. New techniques of computer-aided surgical simulation can enable the surgeon, orthodontist, and patient to better visualize and understand the treatment approach and enable them to make the most effective and efficient treatment related decisions. This case merges knowledge of the full spectrum of historical surgical techniques with the new approach of computer-aided surgical simulation (CASS) to perform complex segmental maxillary and mandibular surgery to obtain an excellent functional and esthetic result. (*Angle Orthod.* 2019;89:138–148)

KEY WORDS: Orthognathic surgery; Computer aided surgical simulation; Mandibular subapical

INTRODUCTION

Class III malocclusion affects approximately 5% of the population with severe Class III (3 mm or greater) affecting 0.5% of the population.[1,2] Historically, an excellent result could be obtained for many of the less severe patients (AB-OP $\leq$ 6, ANB>$-$5) with an orthodontic-only approach.[3] However, more severe skeletal base discrepancy patients (AB-OP > 6 mm) often require a combined surgical orthodontic approach.[4,5] The Class III malocclusion was originally thought to be caused by excessive mandibular growth.[6] More recently, diagnosis and treatment planning paradigms have shifted to indicate a greater role for maxillary deficiency alone or combined with mandibular growth excess.[6]

Based on the perceived deficiencies of previous treatment methods, several new treatment approaches have emerged for severe skeletal discrepancies, including temporary anchorage devices (TADs), skeletal anchorage system (SAS), surgery first, and Bollard plates.[7–9] Each approach has its risks and limitations and there appears to be a progression of treatment approaches based on the severity of the malocclusion. TADs are currently being used in less severe skeletal discrepancies as a more efficient and more effective way of achieving an orthodontic-only camouflage result.[10] SAS with its bone plates in addition to the bone screws appears to provide a greater level of dental camouflage along with a mildly favorable skeletal effect.[8] Finally, Bollard plates have been used effectively in severe skeletal malocclusions, though the magnitude and location of the skeletal effect is quite variable.[9,11] Some patients demonstrate greater maxillary protraction, whereas other patients experience greater mandibular retrusion even when treated at the same developmental stage and with the same treatment protocol. A surgery-first approach has been purported to be more efficient by performing the

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surgery either first or very early in the combined treatment approach rather than at the midpoint of the combined treatment approach.[12,13]

Historically, two-dimensional (2D) lateral cephalometric prediction tracings were performed to both plan for and attempt to determine the most optimal treatment approach.[14] This 2D approach was particularly effective in assisting the surgical orthodontic team when multiple treatment approaches were being considered.[15,16] As technology improved, computers were used to enhance the efficiency of the process, including linking a profile photograph to the lateral cephalometric radiograph.[17,18] With subsequent technological advancements in imaging such as cone-beam computed technology (CBCT), digital models, three-dimensional (3D) printing, and increased computing power to merge all of the datasets, true 3D treatment planning has become possible.[19] Xia and Gateno as well as other investigators have reported the use of computer-aided surgical simulation (CASS) to be an accurate and effective way of predicting treatment for the surgeon and the patient.[20–22]

One form of treatment that is often overlooked in traditional orthognathic surgery is segmentation of the maxilla, mandible, or both. Broadly classified, mandibular segmental procedures include both the mandibular body ostectomy[23] and the mandibular anterior subapical approach,[24] both of which were among the earliest forms of care including use prior to the advent of the LeFort I osteotomy.[25]

This case illustrates a patient effectively and efficiently treated with orthodontics, segmented LeFort I, mandibular anterior subapical combined with bilateral sagittal split setback. The treatment approach was able to be visualized accurately in advance using multiple 3D platforms.

History and Diagnosis

NK, a 29.7-year-old Korean female, presented to the University of Michigan dentofacial deformities clinic. (Figures 1 through 3). Full clinical exams were performed by specialists in oral and maxillofacial surgery, orthodontics, and orofacial pain. Extraoral sagittal examination revealed a concave profile with pronounced maxillary hypoplasia and mandibular hyperplasia. From the frontal view, she demonstrated both maxillary and mandibular asymmetry and maxillomandibular cants with the patient's left side more inferiorly positioned. The mandibular skeletal midline was 4 mm to her right. Intraoral examination revealed severe Class III molar malocclusion (10 mm right and 15 mm left) bilaterally. She exhibited a nearly Class I left and Class II half cusp right canine relationship. There was significant spacing (5.5 mm bilaterally) in

the maxillary arch between the canine and first premolar. In the mandibular arch, first premolars had been previously extracted with space remaining both mesial and distal to the mandibular canines and mild spacing in the mandibular incisor region. Transversely, the patient exhibited a unilateral right posterior cross bite. Attempts were made to determine if she had a centric relation to centric occlusion (C_r - C_o) shift but none was detected.

Cephalometrically, NK demonstrated proclination of the maxillary teeth, maxillary hypoplasia, mandibular hyperplasia, mandibular body and chin asymmetry, and retroclined mandibular incisors. The full cephalometrics for orthognathic surgery (COGS) analysis is in Table 1 and the tracing is in Figure 3.

During the initial clinical exam, the patient reported that she had undergone treatment "for several years" and recently requested removal of her orthodontic appliances "because the other provider said they could not fix my bite any better than this." The earlier treatment was reportedly initiated with a planned orthodontic camouflage treatment approach consisting of mandibular first premolar extraction. The patient reported that during treatment, because the reverse overjet was unable to be corrected, the provider started making spaces in the maxillary arch to enhance the attempt to obtain positive horizontal overlap of the incisors. The patient was dissatisfied with the treatment result and wished to pursue an alternate treatment approach.

Attempts were made to obtain the records from the previous provider's office but the attempt was unsuccessful. Examination of the previous start, progress, and finish records would have enabled the team to better understand what portion of the malocclusion was due to the previous orthodontic care and what portion resulted from the initial skeletal imbalance.

Treatment Objectives

The treatment goals were as follows:

(1) Establish ideal overbite and overjet with Class I canine relationships bilaterally.
(2) Correct the facial dysmorphology resulting from both the original malocclusion and the previous orthodontic camouflage treatment.
(3) Level, align, and consolidate the maxillary and mandibular spacing into three segments in each arch.
(4) Correct the sagittal maxillary hypoplasia, vertical maxillary excess, asymmetry, and cant, and reduce the interdental spacing via a three-piece segmental LeFort I osteotomy.
(5) Correct the mandibular hyperplasia, cant, and asymmetry, and reduce the interdental spacing via

Figure 1. Pretreatment photographs: Significant Class III dental and skeletal malocclusion, posterior crossbite but positive overjet due to previous camouflage treatment.

(a) mandibular anterior subapical surgery; and

  (b) bilateral sagittal split osteotomy (BSSO) to setback the mandible following the autorotation.

(6) Complete interdental space closure, arch coordination, and occlusal finishing with a combined TAD

Figure 2. Pretreatment panoramic radiograph demonstrating previous extraction of mandibular first premolars, creation of space in the maxillary arch.

and conventional orthodontic approach during the postsurgical period.

The patient understood the rationale for the approach, consented to care, and was eager to complete the correction of her malocclusion.

Treatment Alternatives

Because of the severe nature of her skeletal malocclusion and the failed previous orthodontic-only treatment attempt, only combined surgical orthodontic approaches were presented to the patient. Due to the patient's age and maturational status, it was determined that Bollard plates might produce small skeletal changes but would be unable to resolve the skeletal asymmetry and cant. An alternate surgical orthodontic approach was considered using the typical presurgical orthodontic decompensation followed by conventional two-jaw surgery (single-piece LeFort I advancement with surgical mandibular setback) followed by postsurgical finishing. The potential advantage of the more
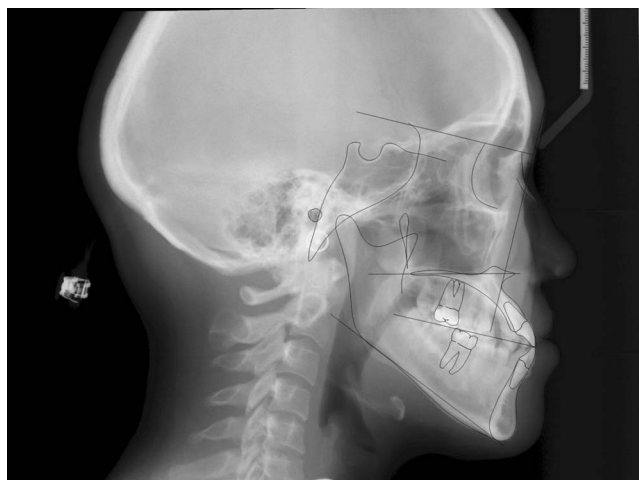
Figure 3. Pretreatment lateral cephalometric radiograph and tracing demonstrates the Class III skeletal and dental malocclusion with skeletal asymmetry.

common surgical approach was familiarity with the typical osteotomy cuts, avoiding the interdental osteotomies and thus minimizing the risk of dental or neurovascular trauma. However, the patient had already taken significant time with the first treatment approach, and the segmented surgery provided the opportunity to accomplish some of the space closure more efficiently than with a conventional presurgical orthodontic approach.

Treatment Progress

Following obtaining informed consent, spacers were placed and the patient returned a week later for 0.022″ × 0.028″ bands for first and second molars and bonded brackets for the remainder of the dental arches. Initial nickel-titanium arch wires were placed to resolve the rotations and initiate arch coordination. Progressively more rigid stainless steel wires were used to obtain ideal arch coordination and the arches were leveled in three segments using steps in the arch wire to maintain the vertical discrepancy. Because the maxillary canines were already present within the anterior segment, they were maintained rather than moving them distally into the posterior segment. The mandibular left canine was closer to the anterior segment and the mandibular right canine was nearly centered in the previous extraction space. For symmetry, arch coordination, easier biomechanical decompensation of the mandibular incisors, and to facilitate a larger surgical segment, the mandibular canines were placed within the anterior segment with open coil springs between the mandibular second premolars and canines bilaterally. Once the dentition was aligned and the individual segments were leveled, presurgical records were

obtained (Figures 4 through 6). To facilitate the CASS approach, a CBCT was obtained. Periapical radiographs of the planned interdental osteotomy sites were also taken to assure proper root angulation to minimize potential surgical trauma. Progress models were analyzed to assure the fit and coordination of the individual segments and then scanned so they could be merged with the CBCT to perform CASS. Immediately prior to surgery, segmental maxillary and mandibular arch wires were placed with surgical hooks crimped and tack-welded to the arch wire to facilitate the intermaxillary fixation (Figure 4).

Surgical Planning

Oral and maxillofacial surgery (OMFS) submitted the CBCT and 3D scan of the presurgical dental models. The digital datasets were merged and the maxillary and mandibular segmental surgical plan was created using the Virtual Surgical Planning software (VSP, Medical Modeling Inc., Golden, CO). The precise 3D movements of each segment as well as the net jaw base were determined (Figure 7 and Table 2).

To address the vertical discrepancy and to level the frontal and functional occlusal plane cants, differential impaction of the maxillary anterior and posterior segments was planned. To address the maxillary "yaw" or rotational asymmetry, differential advancement of the segments was planned to effectively rotate and center it with respect to the midsagittal reference plane. To facilitate maxillary space closure, the posterior maxillary segments were advanced nearly into contact with the anterior maxillary segment and then the entire maxilla was advanced to the final position. In summary, the maxilla was impacted, advanced, and rotated.

To complete the skeletal and occlusal correction, a combined mandibular anterior subapical and BSSO were performed. The subapical was accomplished with a horizontal osteotomy well below the mandibular incisor and canine roots. After visualizing the mental nerve, the vertical portion of the subapical osteotomy was performed bilaterally in the interdental spaces. The mandibular subapical segment was set posteriorly in near approximation with the posterior mandible and rigidly fixed with two "L" plates laterally and a three-hole "straight" plate medially. The BSSO procedure was performed in standard fashion to accomplish the simultaneous autorotation and asymmetric setback.

Following approval of the two-jaw segmented surgical plan by orthodontics and surgery, and acceptance by the patient, interim and final surgical splints were fabricated via 3D rapid prototyping printing.

Table 1. Pretreatment, Progress, and Posttreatment Lateral Cephalometric Measures Using the Cephalometrics for Orthognathic Surgery (COGS) Analysis[a]

Measure	Female Norm (Mean ± SD)	Pre-Tx	Pre-Sx	Final
Cranial base				
Ar-PtM (//HP)	32.8 ± 1.9	29.1	29.1	28.7
PTM-N (//HP)	50.9 ± 3.0	54.0	54.0	54.6
Horizontal (skeletal)				
N-A-Pg angle	2.6 ± 5.1	−9.0	−9.0	−7.4
N-A (//HP)	−2.0 ± 3.7	−2.4	−2.4	−1.9
N-B (//HP)	−6.9 ± 4.3	5.1	5.1	−0.9
N-Pg (//HP)	−6.5 ± 5.1	5.4	5.4	1.2
Vertical (skeletal, dental)				
N-ANS (⊥ HP)	50 ± 2.4	55.8	55.8	53.5
ANS-Gn (⊥ HP)	61.3 ± 3.3	77.1	77.1	75.9
PNS-N (⊥ HP)	50.6 ± 2.2	59.3	59.3	54.8
MP-HP (angle)	24.2 ± 5.0	33.5	33.5	36.6
1-NF (⊥ NF)	27.5 ± 1.7	33.6	33.6	33.8
6-NF (⊥ NF)	23 ± 1.3	23.3	23.7	23.3
6-MP (⊥ MP)	32.1 ± 1.9	31.4	30.5	31.9
1-MP (⊥ MP)	40.8 ± 1.8	41.2	41.2	37.9
Maxilla, mandible				
PNS-ANS (//HP)	52.6 ± 3.5	47.8	47.8	46.4
Ar-Go (linear)	46.8 ± 2.5	49.4	49.4	44.4
Go-Pg (linear)	74.2 ± 5.8	84.8	84.8	84.7
B-Pg (//MP)	7.2 ± 1.9	8.6	8.6	10.1
Ar-Go-Gn (angle)	122 ± 6.9	138.5	138.5	138.4
Dental				
OP upper-HP (angle)	7.1 ± 2.5	8.0	6.7	16.2
1-NF (angle)	112.5 ± 5.3	123.0	123.0	111.2
1-MP (angle)	95.9 ± 5.7	82.2	82.2	77.3
A-B (//OP)	−0.4 ± 2.5	14.2	13.2	16.1
Soft tissue analysis				
Facial convexity angle: G-Sn-Pg′	12.0 ± 4	−1.5	−2.4	5.6
Maxillary projection: G-Sn	6.0 ± 3.0	4.1	5.7	6.3
Mandibular projection: G–Pg′	0 ± 4	8.9	12.5	4.9
Vertical height ratio: G-Sn/Sn-Me	1	1	1.1	1
Lower face throat angle: Sn-Gn′-C	100 ± 7	93.1	93.1	95.8
Lower vertical height-depth ratio: Sn-Gn′/C-Gn′	1.2	1.2	1.1	1.2
Lip position and form				
Nasolabial angle: Cm-Sn-Ls	102 ± 8	96.2	95.3	110.2
Upper lip protrusion: Ls to (Sn-Pg′)	3 ± 1	4.4	4	3.7
Lower lip protrusion: Li to (Sn-Pg′)	2 ± 1	8	6.5	3.8
Mentolabial sulcus: Si to (Li–Pg′)	4 ± 2	3.5	4.3	3.8
Vertical lip chin ratio: Sn-Stm/Stm-Me′ (HP)	0.5	0.43	0.43	0.49
Maxillary incisor exposure: Stm-1	2 ± 2	7.2	7.1	5.1
Interlabial gap: Stms-Stmi	2 ± 2	4.1	6.5	5.1

[a] Pre-tx indicates pretreatment; Pre-sx, pre-surgical.

Postoperatively, the patient was seen by both services at 2, 4, and 6 weeks. At the 4-week postoperative visit, the surgical wounds were healing well and the residual interdental spacing was examined. The surgical splint remained wired to the maxillary arch for 6 weeks to promote better segment stability during the initial healing period. At 6 weeks, the surgical splint was removed and TADs were placed between the lateral incisor and canine in all four segments to facilitate predictable postsurgical space closure (Figure 8a,b). The patient returned for an orthodontic adjustment the same day and continuous titanium molybdenum alloy wires with "T" loops were activated utilizing anchorage from the TADs to the canines in both arches. Spaces closed in 3 months followed by 3 months of final arch coordination, detailing, and finishing.

Six months after surgery, a stable well-interdigitated bilateral Class I canine occlusion was obtained. Prior to debond, a panoramic radiograph (Figure 9) was taken to assess the interdental surgical site healing. This was reviewed by both services, and an additional 6 weeks of healing was prescribed. The patient was debonded and given a maxillary Hawley retainer and fixed lingual mandibular retainer from canine to canine. Posttreatment records (Figure 9 through 11)

Figure 4. Presurgical photographs demonstrating the three maxillary and three mandibular dental segments to facilitate the planned surgery.

and 2-year post-debond photographs (Figure 12) were obtained and the patient was scheduled for retention appointments.

RESULTS

Following 24 months of treatment, NK's treatment was completed. Significant improvement in function

Figure 5. Presurgical panoramic radiograph demonstrating root parallelism in the area of the planned bone cuts.

and appearance were observed and reported by the patient. Following treatment, a well-interdigitated and functional occlusion with significantly improved facial balance was created. The patient reported that she was able to eat much more efficiently and she was very pleased with the treatment result.

The pre- and posttreatment tracings superimpositions demonstrated the dentition was well-positioned within basal bone with mild proclination of the maxillary and mandibular incisors. In addition, the magnitude of surgical change and enhanced facial balance were well-demonstrated (Figure 13).

DISCUSSION

Utilizing enhanced true 3D diagnosis and treatment planning technology and principles for both the orthodontic and surgical aspects of this patient's case enabled both the orthodontist and the surgeon to perform a precise yet atypical orthognathic surgery plan to maximize the treatment outcome and treatment efficiency. The camouflage treatment conducted by

Figure 6. Presurgical lateral cephalogram.

the initial provider not only introduced negative axial inclinations of the teeth but created positive overjet, making insurance authorization more complex and delaying approval.

Two-dimensional surgical simulation has been part of the surgical orthodontic informed consent process since orthognathic surgery became a routine and viable part of the orthodontist's armamentarium.[14] The 2D presurgical prediction process helped patients better understand the potential outcome, but the surgical treatment plan still had to be performed by hand and several time-consuming steps were required including obtaining centric relation bite, mounting, measuring, and performing model surgery, remeasuring the models, and fabricating interim and final splints. The multiple steps increased the chance of error and in some cases led to less than optimal outcomes.

With CASS, surgical orthodontic teams can now precisely combine an entire digital data set (CBCT, digital scan of models) to perform precise, accurate
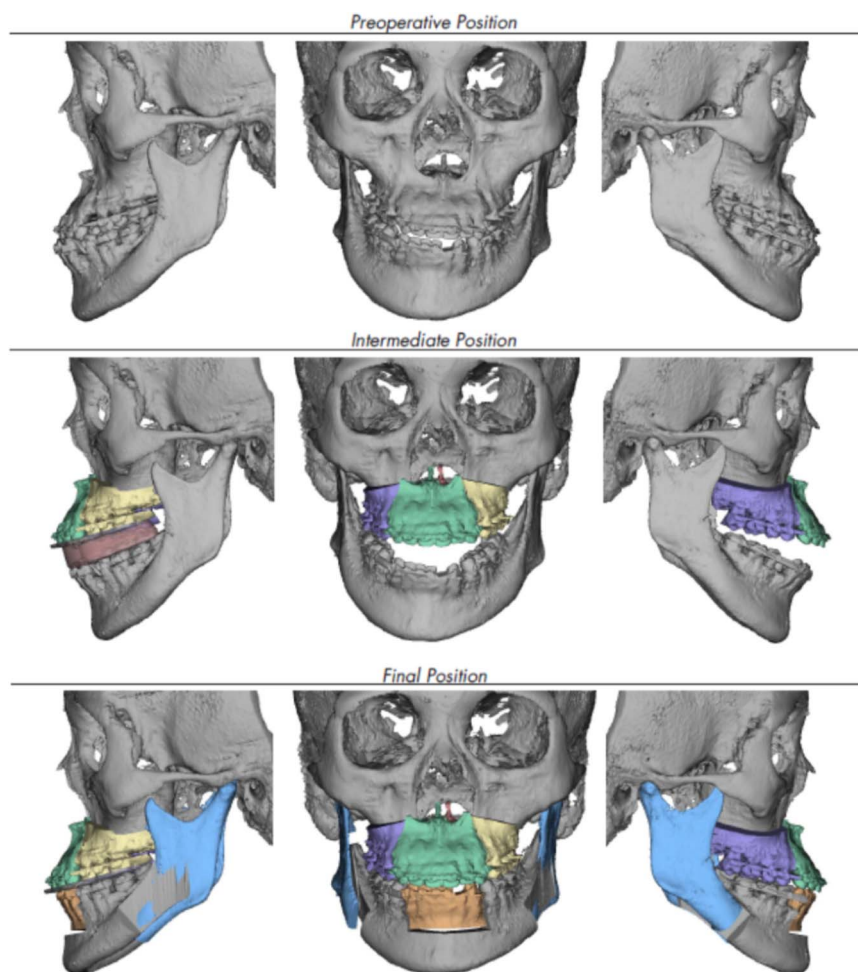
Figure 7. Computer-aided surgical simulation. (A) presurgery, (B) simulation of the segmental LeFort I osteotomy, and (C) the combined mandibular anterior subapical with BSSO.

Table 2. Summary of the Planned Surgical Movements[a]

Point	Definition	AP Movement (mm)	Frontal Movement (mm)	Vertical Movement (mm)
ANS	Anterior nasal spine	3.86 (A)	3.44 (Rt)	2.20 (Up)
A	A point	3.79 (A)	3.28 (Rt)	2.25 (Up)
U1	Midpoint of upper incisors	3.00 (A)	1.24 (Rt)	2.00 (Up)
UL3	Upper left canine	2.87 (A)	1.35 (L)	3.55 (Up)
UR3	Upper right canine	3.21 (A)	1.44 (Rt)	0.89 (Up)
UL6	Upper left first molar	7.77 (A)	0.32 (Rt)	1.88 (Up)
UR6	Upper right first molar	4.51 (A)	0.92 (Rt)	2.04 (Down)
L1	Midpoint of upper incisors	2.17 (P)	3.74 (L)	4.59 (Up)
LL6	Lower left first molar	1.96 (A)	3.73 (L)	4.03 (Up)
LR6	Lower left first molar	2.69 (A)	3.49 (L)	1.42 (Down)
B	B point	0.7 (A)	6.36 (L)	3.85 (Up)
Pg	Pogonion	4.23 (A)	7.96 (L)	2.07 (Up)

[a] A indicates anterior; P, posterior; Rt, right; L, left.

surgical simulation.[20,22] The technique also creates a highly accurate interim and final splint allowing the surgeon to perform the operation once on the computer rather than having the additional time and limitations of trying to replicate the computer-based plan on traditional models. This technique is increasingly useful, accurate to <1 mm, and provides enhanced surgical outcomes in complex 3D malocclusion correction compared to traditional plaster model surgery.[20]

Figure 8. (a) 4-week postoperative visit and (b) 6-week postoperative view with four TADs and closing loops in place.
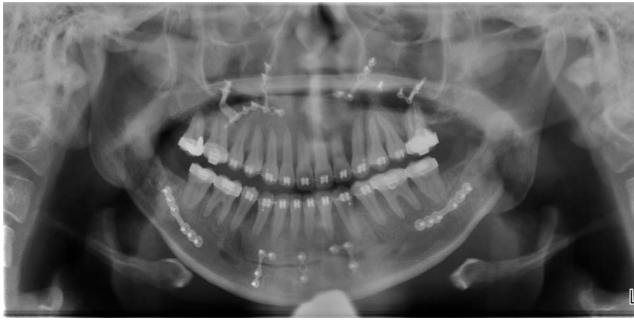
Figure 9. Progress pan (and final due to proximity to date of debond and ALARA or as low as reasonably possible principle).

As technology evolves, historical orthodontic and surgical content can be "lost." The mandibular subapical technique was initially described in the early 20th century literature and, at that time represented one of the few ways to attempt surgical correction of a Class III malocclusion. Its limitations to fully address mandibular body deformities ultimately led to development of today's more common surgical techniques such as the bilateral sagittal split ramus osteotomy (BSSO) or the intraoral vertical ramus osteotomy (IVRO). Unfortunately, as these newer techniques became common, previous surgical techniques were abandoned in some centers. The uncommon features of this case demonstrate the continued utility and treatment efficiency of "historical" surgical approaches. This unique case merged the best of the new technology (CBCT, TADs, and CASS) with the best of the "old" mandibular segmental surgery approach.

CONCLUSIONS

- Proper diagnosis and treatment planning by multiple specialties remains the critical first step in any orthognathic surgery case, which is highlighted by the initial misdiagnosis.
- The coordinated team-based CASS approach with the orthodontist and surgeon all having input before the initiation of treatment facilitated a unique way to achieve efficient, stable, functional, and esthetic results.
- Merging new technology with respect for historical surgical techniques provided the patient with a dramatic skeletal, dental, and medical improvement.

Figure 10. Posttreatment photographs demonstrating Class I canine, ideal overbite and overjet, resolution of symmetry, and facial balance.

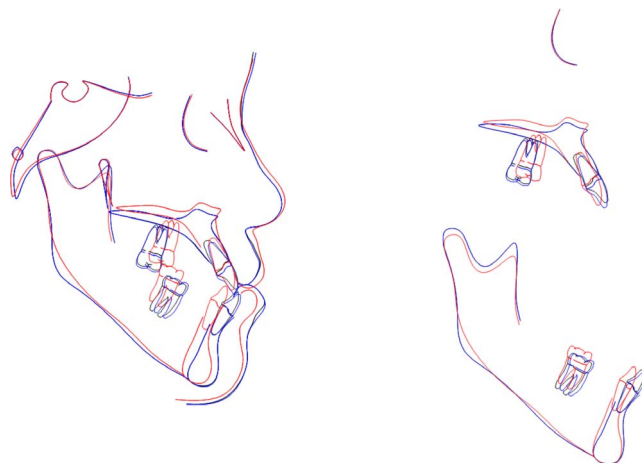**Figure 11.** Posttreatment lateral cephalometric radiograph and tracing.

Figure 13. Treatment superimposition. The dentition is well-positioned within basal bone with mild proclination of the maxillary and mandibular incisors.

Figure 12. Two-year post-treatment photographs demonstrating excellent stability of the patient's skeletal and dental correction.

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