Computer-assisted Planning and 3D-Printed Splint Manufacturing in Orthognathic Surgery for Correction of Skeletal Class III Patients with Facial Asymmetry: Case Report

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Abstract

The treatment of skeletal facial asymmetry, especially accompanied with skeletal Class III deformity, could be complex and challenging. In this case report, we present the orthodontic and surgical management of a 20-year-old girl who had a severe craniofacial deformity, including skeletal facial asymmetry and mandibular prognathism. During preoperative orthodontics, 2 upper first premolars were extracted to allow the retraction and upright of upper anterior teeth, while the lower anterior teeth were proclined for decompensation. The upper and lower arch width were also coordinated before surgery. Computer-assisted 3-dimentional (3D) planning and simulating was used to define the exact special position of maxilla, mandible and chin. Intermedial and final splints were also manufactured by computer designing and 3D printing. The preoperative planning was thus precisely transferred to patient during surgical procedure. Postoperative orthodontic treatment completed the final occlusal adjustment. The clinical results showed that the patient's facial esthetics was significantly improved with good symmetry and straight profile, and a desirable occlusion was achieved.

Key Words: Facial asymmetry, Skeletal deformit, Orthognathic surgery, Computer-assisted design, Class III malocclusion

Introduction

Facial asymmetry is relatively common in the orthodontic population. It is more frequently found in skeletal class III patients with a higher incidence of more than 40% [1], the reason may be due to the asymmetrical growth of the prognathic mandible. Since facial symmetry is one of the most significant factors in determining facial attractiveness, a successful correction of facial asymmetry is important for both doctors and patients.

Traditional surgical simulation using frontal and lateral cephalometrics and plaster casts on articulators is reported to be imprecise [2,3]. 2-dimentional (2D) images have inherent sources of orientation error due to visual phenomena, and 2D cephalometry does not provide enough information on the cranio-maxillo-mandible complex and soft tissues [4,5]. What’s more, the plaster casts on articulators cannot provide doctors a fully display of the entire facial structure and its special position, which reduces the accuracy during the classical model simulation [3,6].

Advances in computing have resulted in the use of computers in every aspect of our daily life, and there is no exception in medical field. Computer technology has been recognized for its potential in permitting virtual evaluation and operation with digital control of the 3-dimentional (3D) movements, computer-aided designing and manufacturing of intermediate and final splints [7]. Computer-assisted orthognathic surgery can overcome the technical problems of management of the spatial positions of the jaws with reference to the entire craniofacial hard and soft tissues when treating patients with skeletal facial asymmetry.

The purpose of this case report is to describe a clinical case of a patient with skeletal class III deformity accompanied with facial asymmetry who received a successful correction of deformity, by using computer-assisted planning and 3D-printed splint manufacturing in orthognathic surgery. The advantages and routine procedures of computer-assisted orthognathic surgery are also discussed below.

Case Report

Clinical evaluation and diagnosis

A 20-year-old young woman visited the orthodontic department at the School of Stomatology attached to the fourth military medical university in China with chief complaints of facial asymmetry, mandibular prognathism and cross bite of anterior teeth. She denied the history of trauma or relevant dental treatment. But she reported that her father had similar malocclusion of anterior cross bite.

Pretreatment facial photographs (*Figure 1*) showed an obvious asymmetric face with the chin deviated approximately 6 mm to the left side relative to the craniofacial midline. Her oral fissure was unparallel to the transverse plane, especially when smiling. Bilateral zygomatic and facial contour were also asymmetry, which made the craniofacial deformity more complicated. The profile exhibited a concave facial profile with an acute nasolabial angle and a relatively protrusive lower lip. The height of lower third of face increased slightly with a relatively protrusive mandible and chin. Besides, an obvious paranasal concavity could be noticed, which represented a severe developmental deficiency in middle face. Intraoral examination (*Figure 1*) revealed a bilateral Class III molar and canine relationship with a 2-3 mm reverse overjet and 2 mm reverse overbite. No functional shift of mandible could be examined.

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Figure 1. Pretreatment facial and intraoral photographs.

Mild crowding was observed in both arches. The upper dental midline was shifted 1.5 mm toward the right side of the craniofacial midline, while the lower dental midline shifted 5 mm toward the right. The transverse occlusal plane canted to the right side, which caused a discrepancy in vertical height between bilateral angulus oris. Functional examination showed that the patient had a normal mouth opening, and no signs or symptoms of TMDs could be found.

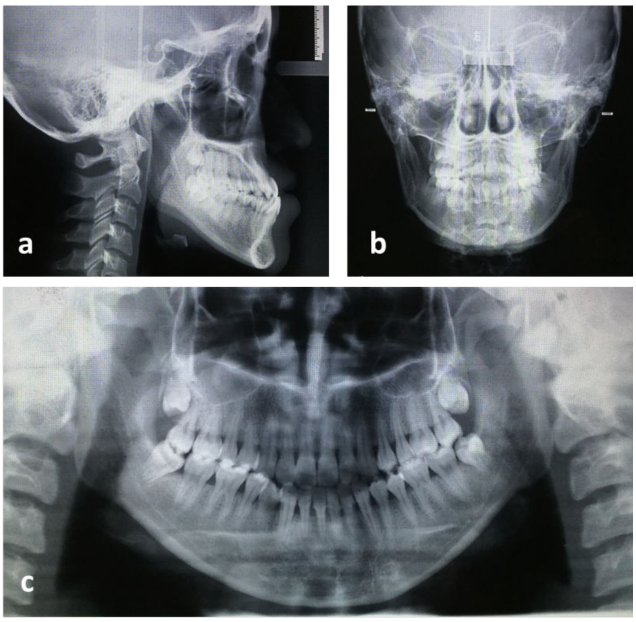

Figure 2. Pretreatment radiographs. a: pretreatment lateral cephalogram; b: pretreatment frontal cephalogram; c: panoramic radiograph.

The cephalometric analysis (*Figure* 2a) (*Table 1*) demonstrated that the patient had a skeletal Class III jaw relationship with a prognathic mandible and a retrognathic maxilla. The compensation of upper and lower anterior teeth is obvious. Moreover, the angle of the mandible was larger than normal, which indicated a clockwise rotation of mandible and an increase in lower facial height. Frontal cephalogram (*Figure* 2b) showed the asymmetry of maxilla and mandible, with a shortened mandibular ramus and body in the left side and a prolonged ram and body in the right side.

Table 1. Pre-treatment cephalometric analysis.

Stainer analysis			
	normal	**pre**	**change**
SNA	82.5 ± 4.0	77.5	↓
SNB	80.1 ± 3.9	81.5	
ANB	2.7 ± 2.0	-4	↓
SND	77.3 ± 3.8	83	↑
U1-NA (mm)	5.1 ± 2.4	7	
U1-NA	22.8 ± 5.7	29.5	↑
L1-NB (mm)	6.7 ± 2.1	4	↓
L1-NB	30.3 ± 5.8	22	↓
Po-NB	1.0 ± 1.5	1	
U1-L1	124.2 ± 8.2	134	↑
OP-SN	16.1 ± 5.0	18.5	
GoGn-SN	32.5 ± 5.2	39.5	↑

The transverse occlusal plane was canted as we observed in clinical examination. Panoramic radiograph (*Figure* 2c) showed a mild absorption of the alveolar bone and the existence of 4 third molars.

Treatment objectives

To address the patient's chief complaints, the treatment objectives were determined as follows: (1) level, align and coordinate the dental arches; (2) dental decompensation; (3) correct the asymmetric facial appearance; (4) correct the concave facial profile; (5) level the cant of transverse occlusal plane; (6) establish normal overbite and overjet; (7) achieve an ideal intercuspation.

Treatment plan

There were two options to treat this patient: orthodontic treatment and orthognathic surgery. The first option was a camouflage treatment which was indicated for patients with functional or mild skeletal Class III malocclusion. Occlusal correction could be achieved by extracting two lower first premolars and retracting lower anterior teeth to establish a normal overbite and overjet, maintaining the compensation in both arches, but the skeletal deformity, especially the facial asymmetry, could not be corrected. Took the patient's chief complain in to consideration, we decided to choose the treatment option of orthognathic surgery. (1) Pre-operation orthodontic treatment: extracting of 4 third molars and 2 upper first premolars; leveling, aligning and coordinating the dental arches; retracting upper anterior teeth and labial inclining lower anterior teeth to decompensate both arches. (2) Operation: coordinating skeletal relationship between maxilla and mandible by Le Fort I osteotomy and bilateral sagittal split ramus osteotomy (BSSRO). Using 3D simulating and planning techniques based on CT reconstruction to obtain a surgical plan, which is aimed to correct the facial deformity and establish an ideal occlusion at the same time. Intermedial and final splints is then designed on computer and manufactured by 3D print technique. This is to ensure the accurate transfer of surgical plan to actual surgical procedure. (3) Post-operation orthodontic treatment: detailing the occlusion and maintaining the treatment results.

Treatment progress

Before active treatment began, the patient was referred to specialists for extraction of 4 third molars and 2 upper first premolars. After that, 0.022” × 0.028” pre-adjusted edgewise appliances with MBT prescription were placed in both arches. Bands with the same prescription were placed in upper first and second molars and in lower first molars. A transpalatal arch was placed from UR6 to UL6 for upper arch expansion. The treatment began with 0.014” nickel-titaniu (NiTi) archwires on both arches. Dental alignment and leveling were achieved with the use of sequential NiTi archwires and the width of both arches was coordinated. 0.019” × 0.025” NiTi archwires were finally placed on both arches at the end of this stage.

Subsequently, a bilateral posterior bite block was used for bite opening and upper arch width maintaining. A 0.019” × 0.025” NiTi reverse-curve archwire was placed on lower arch to labially incline the lower incisors for further decompensation. A 0.018” × 0.025” stainless steel (SS) archwire with keyhole loops and Ω loops was placed on upper arch at the same time, in order to retract and upright upper anterior teeth for decompensation and space closure. Pre-operation orthodontics was ended with 0.019” × 0.025” SS straight archwires on both upper and lower arches. Short hooks were welded on archwires from UR6/LR6 to UL6/LL6 for post-operative elastic traction (*Figure 3*).

Figure 3. *Pre-operative facial and intraoral photographs. Maxillary bilateral bite block was used to relieve occlusal interference. Reverse-curve archwire was placed on lower arch. Short hooks were welded on archwires for post-operative elastic extraction.*

After that, the patient was required to get a skull CT scan in centric occlusion with relaxed lips. This would help to decrease the reconstruction and simulation errors caused by tight lip and mentalis muscles. Study models were also obtained. The plaster casts of both preoperative occlusion (*Figure 4*a) and postoperative occlusion (*Figure 4*b) were scanned with a high resolution optical scanner (3shape R700, 3shape, Denmark). DICOM (Digital Imaging and Communications in Medicine) images of both skull and occlusion were then imported into Mimics 19.0 (Materialise, Leuven, Belgium) to develop a virtual 3D model of the hard and soft tissue of the head (*Figure 5*). A 3D cephalometric analysis was done by Mimics (*Table 2*).

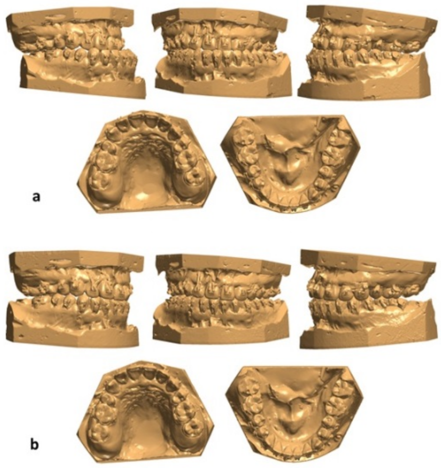

Figure 4. *Plaster casts scanning. a: pre-operative occlusion; b: post-operative occlusion.*

Table 2. *Pre-operative and post-treatment cephalometric analysis.*

Stainer analysis				
	Normal	**Pre**	**Post**	**Change**
SNA	82.5 ± 4.0	77	82	↑
SNB	80.1 ± 3.9	81.5	80.5	↓
ANB	2.7 ± 2.0	-4.5	2.5	↑↑
SND	77.3 ± 3.8	82.5	78.5	↓
U1-NA (mm)	5.1 ± 2.4	5.5	5	↑
U1-NA	22.8 ± 5.7	24.5	26	↑
L1-NB (mm)	6.7 ± 2.1	6	5.5	↓
L1-NB	30.3 ± 5.8	28	28.5	↑
Po-NB	1.0 ± 1.5	1	0.5	↓
U1-L1	124.2 ± 8.2	126	125.5	↓
OP-SN	16.1 ± 5.0	19.5	19	↓

GoGn-SN	32.5 ± 5.2	40	37	↓

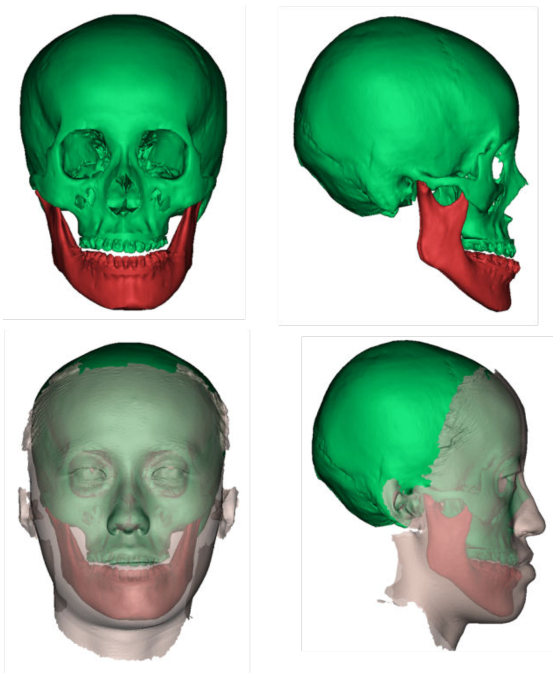

Figure 5. Virtual 3D model of the hard and soft tissue of the head reconstructed by software Mimics 19.0.

Planning of treatment included virtual osteotomies (*Figure 6*a) based on preoperative cephalometric analysis, and simulation of both soft and hard tissue relationships (*Figure 6*b). Different components of the skull were segmented (mandible, maxilla, skull) using a threshold method. The preoperative occlusion cast was registered to the corresponding upper and lower jaws via point-based registration and global registration to form composite models of the maxilla and the mandible. With registering the final occlusion cast, both jaw bones were moved to a desired position.

The first-made surgical plan and postoperative outcome simulation were shown to patient using the computer and 3D display. Patient could participate in the discussion and a final surgical plan was decided. Then the registered casts were exported from the Mimics project and imported into 3-matic software (Materialise, Leuven, Belgium) to design the virtual maxillary osteotomy guide (*Figures 7*a *and 7*c), fixed guide (*Figures 7b and 7d*), intermedial (*Figure 8*a) and final splints (*Figure 8*b). These were then precisely fabricated in biocompatible material (*Figures 7e and 7f*) (*Figure 8*c) using a 3D printer (Eden 260V, Stratasys, USA) with a slice thickness of 0.03 mm. Surgeons would use osteotomy and fixed guide to decide the position and direction to maxillary osteotomy during operation (*Figure 9*). After the reposition and fixation of maxilla, the final splint was applied to decide the position of mandible (*Figure 10*).

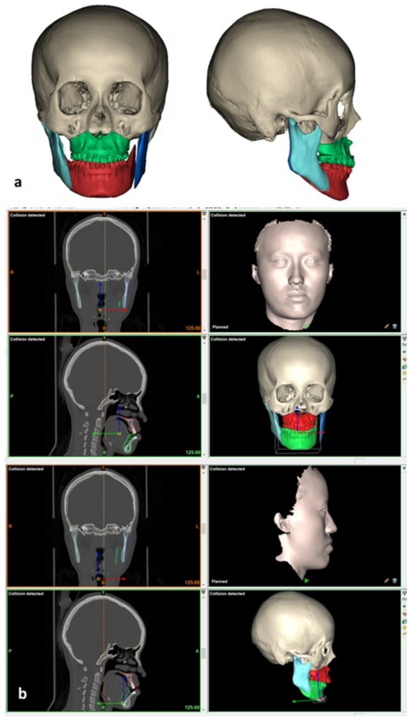

Figure 6. a: Virtual osteotomies. b: Simulation of post-operative soft and hard tissue relationships.

According to the computer-assisted planning, the final surgical plan was determined as follows: (1) two-jaw operation; (2) maxillary Le Fort I osteotomy for an anterior advancement of 1 mm; (3) maxillary anterior segmental osteotomy for a clockwise rotation in sagittal plane, which meant an apical advancement of 2 mm while the incisal edges remained unchanged. This was aimed to improve the paranasal concavity and to increase nasolabial angle; (4) mandibular BSSRO for a posterior setback of 6.5 mm with a yaw to the right side, which was aimed to correct the facial asymmetry; (5) facial contours restoration.

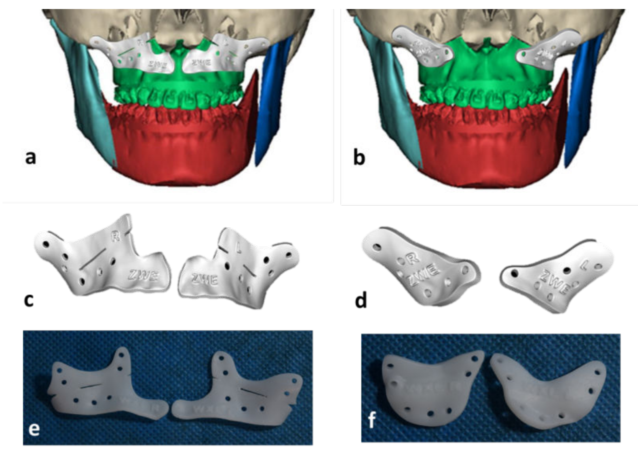

Figure 7. a and c: Virtual osteotomy guide; b and d: Virtual fixed guide; e and f: Both guides were precisely fabricated in biocompatible material.

After surgery, the reestablished jaw relationship was fixed for 4 weeks via final splint and elastic rubber band.

Postoperative orthodontics included the realignment of upper arch and the refinement of the occlusion. 0.019” × 0.025” SS were placed as the finishing archwires with short class III intermaxillary elastic traction to maintain an ideal intercuspation (*Figure 11*).

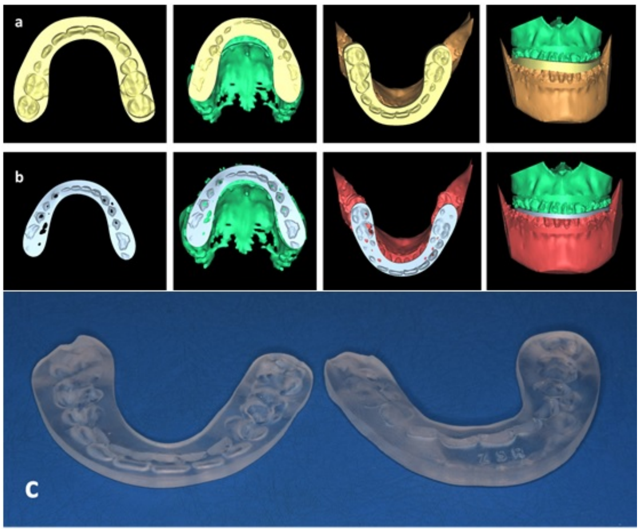

Figure 8. *Designing of intermedial (a) and final splints (b) by software 3-matic. Splints were then precisely fabricated in biocompatible material (c).*

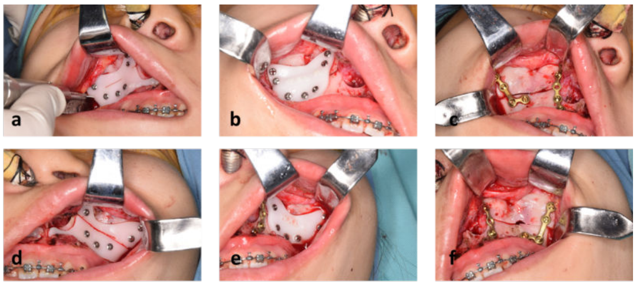

Figure 9. *The applying of osteotomy guide (a, d) and fixed guide (b, e) during operation. The maxilla was finally repositioned and fixed with 4 titanium plates across the bilateral osteotomy lines (c, f).*

The total active treatment period was approximately 17 months. After removal of the fixed appliances, Hawley’s retainers were used for retention.

Treatment results

The post-treatment facial photographs (*Figure 12*) showed a substantial improvement in the patient's facial esthetics. As a result of the correction of the canted occlusal plane, the oral fissure was rotated to a position paralleled to the transverse plane. Moreover, facial contour restoration also contributes a lot to the correction of facial asymmetry. But it was a pity that the asymmetrical zygomatic bone was left untreated, which made the middle face still asymmetry to some extent. An improved soft tissue profile could be seen in the lateral photographs, with a normal nasolabial angle and a well-positioned lower lip.

Figure 10. *The final splint was apply to decide the position of mandible.*

Figure 11. *Facial and intraoral photographs after operation.*

The middle face concavity caused by the developmental deficiency of maxilla was improved but still remained, and that could not be well resolved due to the technical limitations of Le Fort I osteotomy. The pre- and post-operative soft and hard tissue 3D superimposition (*Figures 13a and 13b*) confirmed that there was an obvious improvement on paranasal concavity (blue) and a retraction and reposition of lower lip and chin (red). The virtual planning and post-treatment hard tissue 3D superimposition (*Figure 13*c) showed an acceptable accuracy of surgery.

The intraoral photographs (*Figure 12*) showed that the patient had a bilateral Class I canine relationship and Class II molar relationship with normal overjet and overbite. The dental midlines were coincident with the facial midline.

Figure 12. Facial and intraoral photographs after treatment.

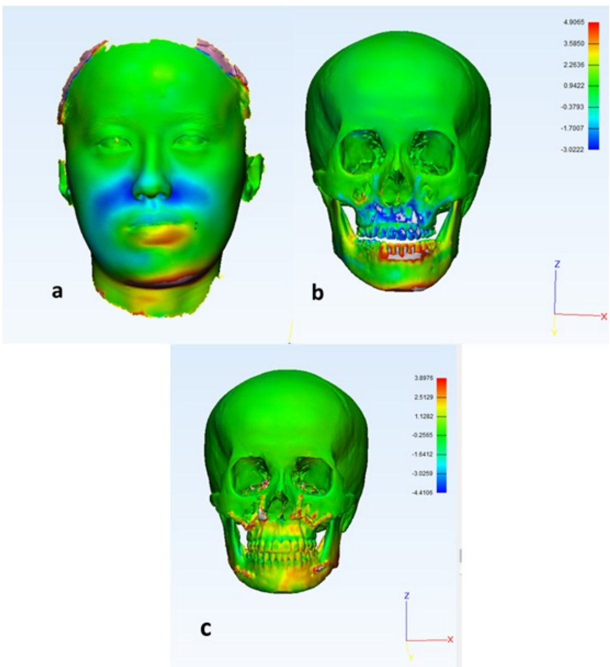

Figure 13. Pre- and post-operative soft (a) and hard tissue (b) 3D superimposition confirmed that there was an obvious improvement on paranasal concavity (blue) and a retraction and reposition of lower lip and chin (red). The virtual planning and post-treatment hard tissue 3D superimposition (c) showed an acceptable accuracy of surgery.

Cephalometrically (*Figure 14*a) (*Table 2*), a significant change in the sagittal measurements could be observed, leaning towards a skeletal Class I relationship with an advanced maxilla and a setback of mandible. The maxillary incisors were retroclined while the mandibular incisors were proclined as a result of decompensation. Panoramic radiograph (*Figure 14*b) and CT scanning (*Figure 14*c) indicated that all teeth roots were paralleled. Neither apical root resorption nor alveolar bone loss could be detected.

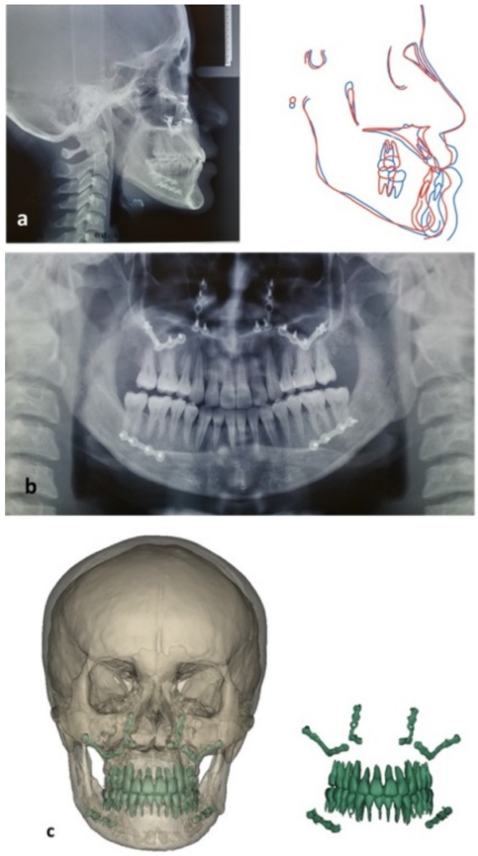

Figure 14. Post-treatment radiographs. a: posttreatment lateral cephalogram and pre- and posttreatment 2D superimposition (blue: pre-treatment; red: post-treatment); b: panoramic radiograph. c: CT scanning and 3D reconstruction of skull, dental occlusion and titanium plates. We could see there was a safety space between titanium screws and the roots of bilateral lower second molars.

Discussion

Facial asymmetry is relative common in the orthodontic population. The prevalence of clinically apparent asymmetry has been reported as 34-38.6% [8,9] in patients with dentofacial deformities. It is more frequently found in skeletal Class III patients with a higher incidence of more than 40% [1], the reason may be due to the asymmetrical growth of the prognathic mandible. Patients with skeletal facial asymmetry, especially accompanied with skeletal Class III deformity, have skeletal asymmetry not only restricted to the mandible, but also existed in the maxilla, zygoma, orbital bone, and even cranial base and soft tissues [4]. Therefore, thorough evaluation and appropriate planning of surgical procedure can be complex and challenging.

The orthognathic surgical procedure involves osteotomy of jaw bones to correct facial disharmony as well as to establish good occlusal relationship [10]. Conventionally, a "classic" surgical protocol may involve clinical examination, cephalometric analysis and anatomically articulated plaster cast of the dental arches. The latter is used to plan skeletal movements and to fabricate splints, which will be used to replicate those movements during surgery [11].

Although evolving over decades, surgical planning to obtain desired effect and accuracy still remains difficult and time-consuming. The dental-maxillofacial bones are anatomically complex structures and should be moved and repositioned precisely within 3D space. Prediction of this movement is invisible and the accuracy largely depends on the experience of orthognathic surgeon and orthodontist involved. Surgical simulation on plaster casts on articulator also allows some risk of inaccuracy [12-14]. Besides, interaction with the patients and laboratory work for surgical splint construction are far more time-consuming than the surgery itself [11].

Advances in computing have resulted in the use of computers in every aspect of our daily life, and there is no exception in medical field. Computer technology has been recognized for its potential in simplifying this process. Computer-assisted surgical simulation provides the surgeon with a digital three-dimensional composite of the skull, soft tissues and dentition. Osteotomy and reposition of the segmented jaw bones then can be performed virtually on the screen, which allows surgeon and patient to have a reasonable preview of post-operative outcome [15]. 3D printing technology, together with the surgical navigation system, can help to generate surgical splint and guide template in order to transfer the virtual plan to actual surgical procedure [15,16].

The virtual 3D model in professional software allows surgeons to perform several 3D cephalometric analyses. Image superimposition errors in 2D cephalometric radiographs are avoided. The anatomical structures and occlusal contacting points can be visualized, thus surgeons can simulate osteotomy and segmented bone movement on computer prior to surgery, trying possible plans and evaluating outcomes, with no risk to the patient. Surgical splint or guide template can then be designed and manufactured 3D print technology [17]. This is beneficial for surgeons in saving time during surgery analysis, treatment planning, model surgery, and construction of resin splints [18,19]. The accuracy can also be guaranteed since the literature provides strong indications that computer-assisted simulation and planning is more accurate than classic methods [7,10,20-24].

For facial asymmetrical patients with skeletal class III deformity, planning the correction of asymmetry is more difficult than planning the correction of sagittal deformities. Therefore, computer-assisted simulation is ideal for these patients because both the skull and the overlying soft tissues, and the upper airway if necessary, can be precisely simulated and visualized at the same time [15]. That gives surgeon, orthodontist and patient a chance to sit together in front of a screen to watch the proposed outcome. The treatment plans and available options are also described at the same time, allowing the orthodontist and the patient to participate more in the treatment decision. What's more, the education of other professionals, residents and students is facilitated by using this type of presentation. This ability of preoperatively simulating and planning the orthognathic surgery provides a better surgical result, with potentially less time and expense in the operating room, greater surgical accuracy, and less chance of surgical revision [10,11,25].

The key to a successful correction of facial asymmetry combined with skeletal Class III deformity is to evaluate the deformity from all three dimensions in space. Sagittally, decompensation of anterior teeth is a crucial step before surgery. Decompensation aims to retrocline the proclined upper incisors and upright the retroclined lower incisors to a more normal axial inclination. This procedure increases the severity of the dental maxillofacial malocclusion and often results in a temporarily aggravated facial esthetics. The lack of adequate dental decompensation will compromise the quality of the treatment result [26]. In this case, even with no obverse dental crowding in upper arch, we still chose to have 2 upper first premolars extracted for the retroclination of upper incisors. But the subsequent disadvantage is that we have to establish an Angle Class II molar relationship after treatment. In other cases with mild or no incisor compensation, nonextraction strategy with or without temporary anchorage devices (TADs) to distalize the upper arch may be a good choice [27]. Once the compensation is removed, the sagittal skeletal relationship is easy to coordinate by Le Fort I osteotomy or BSSRO or both of them. Dental crowding is another factor we have to take into consideration when choosing from extraction and nonextraction. Severe crowding with proclined incisors always indicates extraction of 2 first premolars. Crowding accompanied with upright or retroclined incisors may suggested the extraction of 2 second premolars.

Skeletal Class III patients often have developmental deficiency in the middle face by presenting paranasal concavity. This could not be well resolved due to the technical limitations of Le Fort I osteotomy. According to our experience, high level Le Fort I osteotomy and advancement, or anterior segmental osteotomy and apical advancement, would help improve the paranasal concavity. But the effect is subject to the anterior positon of maxillary alveolar bone. Other alternatives to improve more serious paranasal concavity are Medpor implantation or Le Fort II osteotomy.

Frontally, the mandibular deviation is usually associated with a canted occlusal plane. Oral fissure is always canting as a result of occlusal plane canting. Correction of the occlusal plane cant is usually a prerequisite of facial harmony reconstruction. Consequently, correction typically includes a combination of Le Fort I osteotomy and BSSRO [28,29], just as we did in this case. There are published case reports demonstrating non-orthognathic correction of the occlusal plane canting before orthognathic surgery. Posterior bite-blocks, high-pull headgear or osteotomy with the use of TADs has been used to intrude the molars conventionally [29-31]. Traditionally, it is difficult to evaluate the canting of occlusal plane through the plaster cast on the articulator because of a lack of references for the soft tissues. With computer-assisted 3D planning, all necessary structures are provided simultaneously through the integration of the patient's entire data into a single 3D image, which make simulation of occlusal plane adjustment and prediction of post-operative soft tissue position much more convenient.

For most patients with facial asymmetry, the asymmetry is always not restricted to the mandible or the lower face. Maxilla, zygomatic bone, orbital bone and even the cranial base could be involved [4]. There are studies found that cranial base asymmetry was related to mandibular asymmetry in patients of skeletal Class III [32]. The temporomandibular joint position and mandibular shape are reported to be affected in plagiocephalic patients with an asymmetric cranial base [33]. Therefore, lot of facial asymmetrical patients could not be completely corrected by simple orthognathic surgery. In such cases, facial contours restoration may be help.

Vertically, the lower facial height is also important to facial esthetics. Most of skeletal Class III patients show a high angle facial type due to the over-developed mandibular bodies, relatively short ramus and a clockwise rotation in sagittal plane, which could subsequently cause the increase in the lower facial height. For these patients with such "long face", mandibular setback and counter-clockwise rotation of occlusal plane could help decrease the lower facial height. This rotation process could not simulate on traditional plaster casts on articulator either. Computer-assisted 3D planning and simulation can provide a good choice.

For adults with skeletal mandibular asymmetry, many practitioners prefer to perform BSSRO because it is a relatively safe and standardized technology with predictable treatment results. However, for patients needing a large increase in mandibular length or height (>10 mm), BSSRO will increase the risk of bone segment necrosis and postoperative relapse. For these patients, unilateral distraction osteogenesis (DO) could become an alternative. Compared with BSSOR, DO could reach much greater mandibular extension with fewer possibilities of relapse and nerve damage, which may be ascribed to gradual adaptation of soft-tissue components to the change of mandibular length or height over the distraction and consolidation periods [34,35]. Today, computer technology can also facilitate the surgical planning and simulating of DO and the result shows its great value in improving the accuracy of DO and restoring facial symmetry [36,37]. In all, computer assisted planning and simulating are regarded as a valuable technique for such potentially complicated procedure as orthognathic surgery and DO.

Conclusion

The treatment of skeletal facial asymmetry, especially accompanied with skeletal Class III deformity, could be complex and challenging. Traditional 2D planning and plaster casts simulating have inherent sources of errors which can make the treatment result compromised. Our results demonstrate that computer-assisted 3D planning and simulating is considered as an effective way to simplify the planning procedure and to improve the accuracy of orthognathic surgery. Continuing changes in computer science will be going on with the ever-increasing adoption of computer-assisted techniques in medicine field and, more specifically, in orthognathic surgery.

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