

Article

Enhancing Surgical Outcomes via Three-Dimensional-Assisted Techniques Combined with Orthognathic Treatment: A Case Series Study of Skeletal Class III Malocclusions

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Abstract: (●) Orthognathic surgery is a necessary procedure for the correction of severe skeletal discrepancies, among which are skeletal Class III malocclusions. Currently, both conventional fixed braces and clear aligners can be used in orthognathic surgery. However, the use of clear aligners remains a little-chosen option. The present study aimed to evaluate the skeletal and aesthetic improvements in adults with Class III malocclusion after surgical treatment and compare the results achieved by fixed appliances versus clear aligners. The study sample included four patients (three males and one female, aged 18 to 34 years) with skeletal Class III malocclusion, three of whom underwent a bimaxillary surgery and one of whom underwent only a bilateral sagittal split osteotomy. Two patients were treated with fixed appliances and two with clear aligners. The pre- and post-surgical hard and soft tissue cephalometric measurements were performed and compared for each patient and between fixed appliances and clear aligners. One year after surgery, all patients showed an essential modification of the face’s middle and lower third with an increase in the convexity of the profile and the Wits index and a reduction in the FH[⊥]NB angle. No differences were noted between fixed appliances and aligners. Therefore, thanks to the 3D-assisted surgery associated with orthodontics, every participant achieved proper occlusal function and an improved facial aesthetics. In addition, the clear aligners can be considered a valid alternative for pre- and post-surgical orthodontic treatment.

Keywords: orthognathic treatment; surgical treatment; class III malocclusion; osteotomy; clear aligners; computer-assisted surgery



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1. Introduction

Skeletal Class III malocclusion is characterized by maxillary retrusion, excessive mandibular growth (progenism) or both conditions.

The therapy for skeletal Class III malocclusion depends on its severity and the patient’s age. During childhood, an orthopedic approach using a maxillary expander and/or face-mask can manage the skeletal proportions.

Modifying the bone bases using only an orthodontic treatment is usually impossible in adult patients with skeletal Class III. Indeed, the only purely orthodontic treatment is a compensatory approach through changing in teeth faciolingual inclinations. In particular, these dental movements modify the upper and lower teeth torque, buccally in the maxillary arch and lingually in the mandibular one. Previous studies investigated the torque variations obtained with clear aligners or fixed therapy in order to examine the efficacy of torque movement and the incidence of root resorption in the maxillary and mandibular teeth using cone-beam computed tomography (CBCT). The aligners can

properly manage the tooth torque without relevant root length loss [1]. The external apical root resorption may be caused by multiple factors, which are correlated with orthodontic treatment and/or individual biologic variability. The incidence and severity of root length reduction is correlated with comprehensive fixed appliance therapies [2]. The treatment duration and the magnitude and direction of the applied force may modify the root length. Indeed, both heavy and intrusive forces, as well as a long treatment time, increase the risk of root resorption [3]. Moreover, the incidence of root resorption is higher in extraction cases due to greater anteroposterior apical root displacement [4]. Among patient-related factors, genetic predisposition, such as Turner syndrome, previous dental trauma, and systemic conditions related to medications or hormones may favor apical root resorption [5,6]. Therefore, a proper management of orthodontic forces and a careful initial evaluation of individual predisposition should be considered in order to avoid or minimize external apical root resorption.

Camouflage is possible in case of slight skeletal discrepancy, whereas orthognathic surgery is the only therapy that leads to the best aesthetic and functional outcomes in severe skeletal malocclusions [7]. Adult patients with skeletal Class III malocclusion account for a great proportion of those who undergo an orthognathic surgery. Therefore, case selection based on clinical evaluation and radiographic examination is essential for choosing the most predictable treatment between the two therapeutical options. Camouflage may exacerbate the excessive compensatory proclination of upper incisors with possible root resorptions [8].

When considering reasons for choosing orthognathic surgery as a treatment option, it is crucial to integrate “Face-driven orthodontics” principles along with Ackerman’s cephalometric analysis. This approach emphasizes a thorough assessment of facial morphology and aesthetics to ensure optimal treatment outcomes. By combining these methodologies, clinicians can tailor the surgical plan to not only address functional issues but also enhance facial harmony and aesthetics. This comprehensive approach ensures that patients receive personalized treatment that considers both functional and aesthetic aspects, ultimately improving their quality of life. Facial morphology and aesthetics play a significant role in orthodontics and orthognathic surgery. Clinicians are urged not to base treatment only on cephalometric parameters but to deeply analyze facial soft tissue characteristics, especially in the lower third of the face. This approach, termed “facially driven orthodontics” by Dr. Ackerman, emphasizes integrating facial aesthetics into treatment planning. Previously, facial soft tissue data were acquired using 2D methods (latero-lateral cephalography), but now, with tridimensional face scanners, these data can be obtained more efficiently. Additionally, integrating these data with CBCT scans allows for a comprehensive evaluation of skeletal, dento-alveolar, and soft tissue components in a “real” 3D digital patient model [9].

Clinically, a dysgnathia may make function difficult but not impossible; thus, considerable effort is required to compensate the anatomical deformity with consequent possible muscular and joint problems [10]. Temporomandibular joint (TMJ) disorders’ signs and symptoms, such as bruxism, joint deviation during the opening, reduced opening/lateral/protrusive movements, and myofascial pain, were observed in 15.5% of subjects with Class III malocclusion [11].

A surgery treatment is generally planned in severe skeletal malocclusions and orofacial deformities. For instance, among birth defects, the cleft lip and cleft palate require a long-term multidiscipline treatment in which many reconstructive and/or plastic surgeries are performed [12]. An ideal result of correcting a skeletal malocclusion should consider function, aesthetics, and long-term stability. Indeed, improving aesthetics and function is very important for patient’s motivation and life quality.

The combination of orthodontic and surgical treatment should be considered for patients who would not have satisfactory aesthetics following orthodontic treatment alone. The orthognathic surgery aims essentially to establish a harmonious profile of the soft tissues in a balanced skeletal framework. Predicting postoperative soft tissue changes is equally crucial as indicating hard tissue displacement; in fact, the extent of the cosmetic change is correlated with the degree of hard tissue repositioning.

The management of the relationship between hard and soft tissues may be highly complex due to the morphology, tone, posture, and thickness of the soft tissues, which vary from person to person. Nowadays, the implementation of three-dimensional examinations, such as cone-beam computed tomography (CBCT), provides more accurate assessments [13,14]. CBCT allows us to perform precise measurements and undertake 3D surgical planning thanks to dedicated software [15,16]. Three-dimensional-assisted orthognathic surgery, acting on the hard and soft tissues, aims to reposition the maxilla and mandible in order to ensure a marked improvement in facial proportions and balance.

Currently, the orthognathic surgical techniques for treating Class III mainly include Le Fort I advancement osteotomy of the maxilla, bilateral sagittal split osteotomy to reduce the mandible length, and genioplasty. During the treatment planning stage, the extraction of the third molars must be considered; this can be performed before orthognathic surgery or at the same time as the surgery. Extraction before the surgery involves a postoperative recovery period of several months. On the contrary, extraction during surgery does not require a significant increase in operating times and does not negatively affect the postoperative course.

Nowadays, the sequence of osteotomies is based on preoperative 3D planning and a surgical model. The introduction of virtual treatment planning has been revolutionary in orthognathic surgery [17]. By means of digital approach, it is possible to improve the diagnosis and treatment planning stages thanks to a better visualization of pre-, mid- and postoperative phenotypic changes. Through computer-assisted surgery, it is also possible to plan osteotomies, manufacture accurate surgical guides, and produce intraoperative and final splints [18,19].

Bilateral sagittal split osteotomy (BSSO) is a surgical procedure primarily used to correct mandibular deficiencies, such as protrusion or retrusion, without addressing other facial skeletal discrepancies. In case of a single jaw repositioning surgery, a final splint is used to guide the occlusion of the repositioned jaw respect to the remaining one. This procedure is commonly indicated for patients with mandibular prognathism and normal values for the maxilla position, following the cephalometric criteria used in orthodontics. In this study, a single patient was treated with BSSO only.

Otherwise, when both maxillary and mandibular osteotomies have been planned, an intermediate splint is necessary to guide the movement of one over the other. The maxilla is normally repositioned before the mandible; however, the sequence can be reversed using the appropriate intermediate splint. The remaining jaw is then repositioned according to the final splint. Once the maxilla and mandible are in the final positions, the surgeon evaluates the chin morphology, and, if modification is necessary, performs a genioplasty.

Several studies demonstrated the reliability of customized surgical guides, abandoning the use of intermediate CAD/CAM splints [20,21]. In addition, other authors proved the greater accuracy of customized surgical guides in transferring pre-surgical planning during surgery [22,23]. Recently, some papers focused on the material using which the surgical guides were performed. Indeed, the mechanical properties of resins could influence the precision of surgical guides and, consequently, compromise accuracy during orthognathic surgery. For instance, both polishing and artificial aging could affect the properties of 3D-printed resins used for the realization of surgical guides [24].

As regards the complications, since orthognathic surgery consists of several steps, the drawbacks may be multiple and include bleeding, infections, scars, lack of union, incorrect division in bilateral sagittal split osteotomy, bone or dental relapse, neurological injuries, neuropathic pain, unsatisfactory results regarding nasal aesthetics, TMJ dysfunctions, necrosis of bone segments, respiratory stress, pseudoaneurysm, dental injuries, venous thromboembolism, and blindness [25,26]. Complications during orthodontic surgery can occur before, during, or after the procedure. Complications that may arise before orthodontic surgery include the inadequate preparation of the teeth and surrounding structures, failure to address underlying dental or skeletal issues, or incorrect treatment planning. During the surgical procedures, there could be bleeding, nerve damage, infection, an adverse

reaction to the used materials, or errors in technique. After surgery, complications may include delayed wound healing, infection, pain, swelling, and discomfort.

In rare cases, some degree of jaw asymmetry could potentially persist or develop postoperatively if there are complications during surgery or there is insufficient stability in the surgical correction.

It is important to note that orthognathic surgery is carefully planned and executed by experienced surgeons and orthodontists to achieve optimal results and minimize the risk of complications. Additionally, thorough postoperative care and follow-up are typically provided to monitor healing and address any concerns that may arise.

Even seemingly more complex cases such as laterognathia can be treated with orthognathic surgery. The treatment of laterognathia involves the surgical repositioning of the jawbones to correct the lateral asymmetry. This surgery aims to realign the jaws and improve facial harmony and function. Orthodontic treatment may also be part of the comprehensive treatment plan to optimize tooth alignment before and after surgery, as described in this study.

The successful surgical correction of dentoskeletal malocclusions is also determined by proper pre-surgical treatment in order to eliminate dental compensation.

Orthognathic surgery requires a preoperative orthodontic phase lasting an average of two years, during which a dental decompensation must be obtained, thus aggravating the dental Class III. The orthodontist has to create appropriate dental decompensation, dentition alignment, and coordination of the upper and lower arches for postoperative stability, causing temporary malocclusion worsening and a strongly negative overjet [27,28]. The orthodontic phase is mostly performed using fixed appliances. The use of clear-aligner therapy associated with orthognathic surgery represents a novel concept, with limited supporting evidence [29]. However, a few studies have demonstrated that aligners are equally effective at solving surgical skeletal malocclusion [30,31]. Furthermore, a small number of papers have described an orthodontic treatment combined with orthognathic surgery. Those studies demonstrated that multiple-jaw orthognathic procedures could be successfully performed in patients treated with clear aligners. Moreover, the postoperative and short-term clinical outcomes were not compromised [32,33].

The present study aimed to examine morphological variations before and after orthognathic treatment. Moreover, we compared the results obtained using fixed appliances versus clear aligners during the orthodontic phases. Our study focused on the 3D techniques associated with orthognathic intervention, previously performed only through analogical planning.

2. Materials and Methods

2.1. Patient Selection

The study sample was recruited from subjects who searched for an orthognathic treatment at the Department of Innovative Technologies in Medicine and Dentistry of "G. d'Annunzio" University of Chieti-Pescara.

The inclusion criteria were the following:

- Patients over 18 years old, both female and male;
- Skeletal Class III malocclusion requiring an orthodontic therapy combined with orthognathic surgery.

The exclusion criteria were the following:

- Absence of any craniofacial malformations, including orofacial clefts;
- Absence of TMJ disorders;
- Patients with systematic diseases.

A total of 4 patients (3 males and 1 female) were eligible to undergo combined surgical and orthodontic treatment. The patients' ages were between 18 and 34 years, with an average age of 24 years and 3 months. The participants were treated between October 2014 and December 2019.

Ethical approval (number 23) was obtained by the Independent Ethics Committee of Chieti hospital. The study protocol was drawn following the European Union Good Practice Rules and the Helsinki Declaration. All patients provided written informed consent before the beginning of the orthodontic and surgical therapies.

2.2. Orthodontic and Surgical Procedures

At the first visit (T0), clinical records were collected, consisting of the following: (1) general and dental anamnesis; (2) extraoral and intraoral orthodontic clinical examination; (3) gnathological clinical examination; and (4) visual analogue scale (VAS) and muscular palpation to estimate the pain intensity ratio on each patient's face and neck.

Each patient underwent a CBCT scan using Planmeca Promax[®] 3D MID unit (Planmeca Oy, Helsinki, Finland) according to a low-dose protocol with these parameters: an acquisition time of 15 s, 80 kVp, 5 mA, 35 microSievert (μSv), a field of view (FOV) of 240×190 mm, and normal image resolution [34]. The patient's CBCT was performed with the head oriented according to the Natural Head Position (NHP). After X-ray scanning, DICOM (Digital Imaging and Communications in Medicine) image files were processed using Dolphin Imaging 3D software v. 12.0 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) for storage and interpretation. After the orientation of the head, the virtual 2D radiograms were extracted. Subsequently, extraoral photos (each patient's face in frontal, right-side, and left-side views) and intraoral photos (frontal, right, and left lateral photos and upper and lower occlusal photos) were taken, and the dental arches were scanned using an intraoral scanner.

The subjects underwent pre- and post-surgical orthodontic treatment; two patients were treated with straight-wire fixed appliances (patient 3 and patient 4), and two were treated with clear aligners (patient 1 and patient 2). The patients treated with clear aligners changed the aligner every 14 days and wore it for at least 22 h/day. The pre-surgical orthodontic planning stage included decompensatory mechanics, leveling, and the alignment of teeth. In the clear aligner cases, the orthodontic brackets with Kobayashi hooks were bonded before surgery, and the refinement aligners were planned after the surgical operation and worn in the post-surgical phase. At the end of pre-surgical orthodontics, the surgical guides were made through a digital workflow that included the use of CBCT scans and intraoral scanners.

All patients were operated upon under general anaesthesia.

The choice between single jaw surgery and bimaxillary surgery was based on the cephalometric analysis carried out using Dolphin software and on the soft tissue profile analysis: bimaxillary surgery was performed when there was a discrepancy ≤ 0 degrees between the angles SNA and SNB and a notable disharmony on an aesthetic level.

Three patients underwent bimaxillary orthognathic surgery (Le Fort I osteotomy of the maxilla associated with bilateral sagittal split osteotomy), whereas one patient (patient 2) underwent only bilateral sagittal split osteotomy. The bone segments were locked with rigid fixation using osteosynthesis plates and screws in all participants. One year after surgery (T1), extraoral and intraoral photos and a CBCT scan were taken for each patient. The 2D virtual radiograms were obtained, as previously described. Among 2D virtual radiograms, the pre- and post-surgical lateral telerradiographies were used to perform hard and soft tissue cephalometric measurements. The acquisition of post-surgical data was performed one year after surgery, that is, when a complete recovery of the soft tissues was achieved.

In patients treated with aligners, pre-surgical therapy lasted 15 months for patient 1 and 21 months for patient 2; post-surgical treatment lasted 33 months for patient 1 and 25 months for patient 2. On the other hand, in patients 3 and 4 treated with fixed appliances, pre-surgical treatment lasted 3 years, and post-surgical treatment lasted 6 months.

2.3. Cephalometric Analysis

The cephalometric analyses of hard and soft tissues before and after orthognathic surgery were performed for each participant and compared both individually and between the two orthodontic technique groups.

The cephalometric landmarks considered were as follows: N (Nasion); S (Midpoint of Sella); A (point A); B (point B); Xi (the center of the ascending ramus of the mandible); Pm (chin point); Go (Gonion); Me (Menton); Ar (articular point); Gn (Gnathion); Pog (Pogonion); Me (Menton); Ls (upper labial point); and Li (lower labial point).

2.4. Hard Tissues Measurements

With regard to hard tissues, the following measurements were evaluated: the facial angle (angle between the Nasion—Pogonion and the Frankfurt plane (FH)); the convexity (distance between the Pog/N line and point A); the lower facial height (angle formed by the oral vector SNA-Xi-Pm); $FH \wedge Na-A$; the axis of the mandibular body Xi-Pm; the inter-incisal angle; overjet; overbite; S-Go; N-Me; S-PNS (posterior nasal spine); the upper anterior facial height N-ANS (anterior nasal spine); ANS-Me; $FH (Frankfurt) \wedge NB$; the gonial angle AR-Go-Me; Ar-ANS; Go-Gn; SN-MP (mandibular plane); the Y-axis (angle between the Sella—Gnathion and the horizontal plane of Frankfurt); IMPA (the angle between the axis of the lower incisor and the mandibular plane); the Wits index (segment Ao-Bo, where Ao and Bo, respectively, indicate the projection of point A and point B on the occlusal plane); the angle SNA (the angle between the Sella—Nasion plane and the Nasion—point A plane); the angle SNB (the angle between the Sella—Nasion plane and the Nasion—point B); ANB (the difference between the angles SNA and SNB); the angle of the palatal plane (the angle between the Frankfurt plane and the ANS-PNS palatal plane); A-N perp (the linear distance from point A to the perpendicular of the Nasion); Pog to N perp (the linear distance from the Pogonion to the Nasion's perpendicular); and FMA or the angle of the mandibular plane (the angle formed by the Frankfurt horizontal plane and the mandibular plane (Go-Me)).

2.5. Soft Tissue Measurements

Concerning the soft tissues, the following measurements were evaluated: the Li-Apo distance (the distance between Li and the A-Pog line); the Ls-Apo distance; the li-Apo angle; Ls-N perp; Li-N perp; the distance between the Li point and the E line (the line that goes from the tip of the nose of the soft tissues to the Pogonion of the soft tissues); the labio-mental angle (the angle between the tangent lines to the lower lip and the Pogonion passing through the sublabial point); the nasolabial angle (NLA); and the stomion angle (angle between the upper and lower lip)

3. Results

The pre- and post-surgical lateral telerradiographies were analyzed using a series of cephalometric linear and angular measurements. Then, these values were collected into comparison tables (Tables 1 and 2).

Table 1. Comparison of hard tissue measurements of the patients from T0 to T1. The measurements were performed on the latero-lateral stratigraphies from CBCTs.

Hard tissue measurements	Patient 1		Patient 2		Patient 3		Patient 4	
	T0	T1	T0	T1	T0	T1	T0	T1
Facial angle between Nasion-Pogonion and the Frankfurt horizontal plane	84.4°	83.3°	81.5°	86.2°	88.1°	87.0°	97.1°	97.9°
Convexity distance between the Pog/N line and point A	−1.2 mm	−0.7 mm	0.2 mm	0.2 mm	−0.5 mm	0.6 mm	−0.3 mm	0.5 mm
Lower facial heigh evaluated by measuring the angle formed by the oral vector SNA-Xi-Pm	43.6°	39.0°	42.0°	40.4°	45.4°	35.9°	46.2°	43.3°
FH (Frankfurt plan)^Na-A	90°	94.9°	91.9°	91.9°	86.3°	87.4°	90°	93.7°
Mandibular body axis Xi-Pm	54.7 mm	56.8 mm	57.7 mm	64.3 mm	59.3 mm	59.6 mm	69.9 mm	47.6 mm
Inter-incisal angle	142.4°	142.7°	140.5°	143.6°	123.0°	112.7°	131.0°	122.4°
Overjet	0.5 mm	3.0 mm	−0.5 mm	3.3 mm	4.1 mm	2.1 mm	1.9 mm	2.0 mm
Overbite	0.6 mm	2.4 mm	−1.3 mm	3.8 mm	2.0 mm	1.6 mm	−1.6 mm	2.5 mm
S-Go	75.7 mm	75.5 mm	79.0 mm	78.5 mm	84.3 mm	78.4 mm	61.5 mm	68.4 mm
N-Me	109.9 mm	111.3 mm	118.0 mm	118.3 mm	127.9 mm	121.4 mm	114.9 mm	115.7 mm
S-PNS (posterior nasal spine)	44.9 mm	45.0 mm	46.9 mm	48.3 mm	47.6 mm	48.4 mm	42.8 mm	44.6 mm
Upper anterior face height N-ANS (anterior nasal spine)	49.0 mm	46.1 mm	54.2 mm	54.2 mm	59.7 mm	54.7 mm	52.0 mm	51.1 mm
ANS-Me	61.5 mm	64.4 mm	65.9 mm	64.6 mm	67.9 mm	64.7 mm	64.2 mm	65.4 mm
FH^NB	96.0°	94.2°	97.1°	92.4°	90.7°	88.3°	95.7°	94.1°
Gonionic angle Ar-Go-Me	135.2°	130.5°	133.1°	129.9°	126.5°	124.6°	136.6°	133.5°
Ar (articular point)-ANS	89.5 mm	90.3 mm	83.3 mm	83.3 mm	85.9 mm	97.0 mm	77.6 mm	79.2 mm
Go-Gn	81.0 mm	79.7 mm	76.9 mm	74.3 mm	82.4 mm	76.9 mm	72.8 mm	72.4 mm
SN-MP (mandibular plan)	33.4°	29.1°	36.0°	41.8°	38.6°	38.1°	28.5°	38.8°
Y-axis angle between Sella-Gnathion and Frankfurt horizontal plane	64.9°	64.1°	64.4°	67.8°	58.1°	57.1°	52.0°	40.5°
IMPA angle between the axis of the lower incisor and the mandibular plane	79.3°	88.3°	87.7°	89.1°	82.8°	96.3°	74.3°	86.4°
Wits index	−9.1 mm	−4.8 mm	−4.2 mm	1.7 mm	0.2 mm	1.7 mm	−5.3 mm	4.0 mm
SNA angle between the Sella-Nasion plane and the Nasion-point A plane	81.9°	83.3°	85.0°	85.0°	82.0°	85.7°	79.9°	81.0°
SNB angle between the Sella-Nasion plane and the Nasion-point B plane	87.5°	81.0°	83.9°	81.4°	82.5°	81.1°	81.4°	80.1°
ANB angle the difference between SNA and SNB	−5.6°	2.3°	1.1°	3.6°	−0.5°	4.6	−1.5	0.9
Palatal plane angle (PP) the angle between the Frankfurt plane and the palatal plane (ANS-PNS)	6.3°	7.3°	3.1°	3.1°	13.0°	1.4°	6.7°	5.8°
A to N perpendicular (A-N perp) the linear distance from point A to the perpendicular of the Nasion	0.8 mm	2.4 mm	2.0 mm	2.0 mm	3.9 mm	4.9 mm	3.7 mm	5.1 mm
Pog to N perpendicular (Pog-N perp) the linear distance from the Pogonion to the perpendicular of the Nasion	12.7 mm	9.8 mm	14.0 mm	3.5 mm	3.4 mm	5.4 mm	12.5 mm	13.6 mm
FMA o Mandibular plane angle (MP) the angle formed by the horizontal Frakfurt plane and the mandibular plane (Go-Me)	19.5°	14.0°	23.0°	25.0°	33.4°	21.4°	27.4°	24.9°

Table 2. Comparison of soft tissue measurements of the patients from T0 to T1. The measurements were performed on the profile photographs of the four patients.

Soft tissue measurements	Patient 1		Patient 2		Patient 3		Patient 4	
	T0	T1	T0	T1	T0	T1	T0	T1
Distance Li-Apo distance between Li and line A-pog	10.9 mm	14.7 mm	53.9 mm	51.7 mm	19.8 mm	18.1 mm	17.0 mm	15.1 mm
Distance Ls (upper labial point)-Apo (line A-Pogonion)	18.1 mm	17.4 mm	21.9 mm	17.6 mm	21.2 mm	21.2 mm	15.4 mm	16.5 mm
Angle Li (lower labial point)-Apo	25.9°	27.9°	31.5°	25.4°	35.0°	31.5°	27.7°	26.3°
Upper lip-N perp	19.3 mm	21.0 mm	27.8 mm	19.9 mm	17.8 mm	25.7 mm	20.4 mm	23.0 mm
Lower lip-N perp	22.2 mm	19.1 mm	27.8 mm	18.6 mm	16.0 mm	22.3 mm	23.8 mm	24.6 mm
Distance between point Li and E line	6.7 mm	7.1 mm	5.0 mm	4.0 mm	−1.2 mm	1.5 mm	2.8 mm	3.3 mm
Labio-mental angle (Lab) angle between the lines tangent to the lower lip and pogonion passing through the sublabial point	160.5°	147.5°	143.0°	113.5°	91.7°	104.4°	104.1°	95.9°
Nasolabial angle (NLA)	86.7°	86.4°	104.3°	110.6°	89.7°	85.0°	119.4°	107.4°
Stomion angle between upper and lower lips	80.3°	114.8°	111.8°	66.6°	80.0°	67.4°	78.9°	86.8°

3.1. Hard Tissue Measurements Analysis

Table 1 illustrates all hard tissue changes following surgery.

The convexity increased in all patients, indicating the achievement of profile harmonization. All subjects showed mandibular length reduction. The upper anterior face height decreased in all participants, except for the patient who underwent a bilateral sagittal split osteotomy (patient 2) (Figure 1). The lower facial height decreased in all patients.

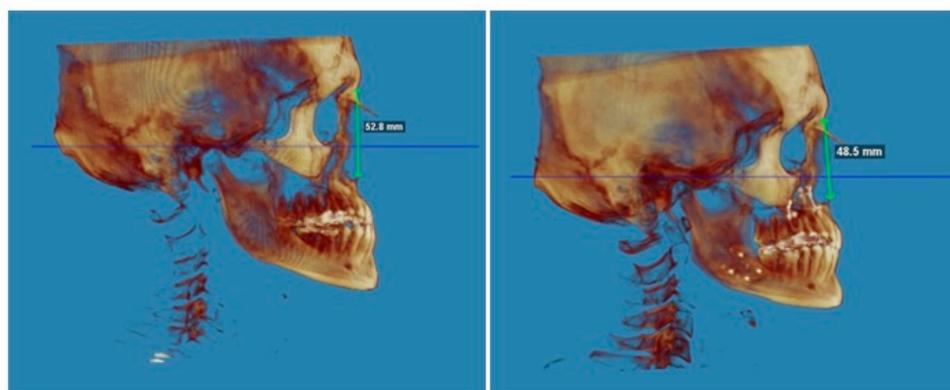


Figure 1. Lateral vision from the CBCT. The head is oriented on the Frankfurt plane (Or-Po). On the left (T0), the upper anterior face height measured 52.8 mm; on the right (T1), it measured 48.5 mm. This result shows a reduction in the upper anterior face height (N-ANS) from T0 to T1 after orthognathic surgery.

The A to N perp value decreased in the three patients subjected to bimaxillary surgery, which indicated a mandibular advancement. The Pog to N perp value increased or decreased depending on whether the initial position of the Pogonion was posterior or anterior to the perpendicular to the Nasion. The IMPA angle increased in all cases; indeed, through the pre-surgical decompensation orthodontic phase, the lower incisor torque, initially lingualized to compensate for the skeletal Class III malocclusion, was modified following the treatment. The Wits index increased in all patients, confirming the achievement of a correct relationship between the bone bases at T1. The FH'NA angle and the Ar-ANS distance increased in patients undergoing bimaxillary surgery due to a maxillary advancement,

while they remained unchanged in the one patient subjected to mandibular surgery (patient 2) (Figure 2).

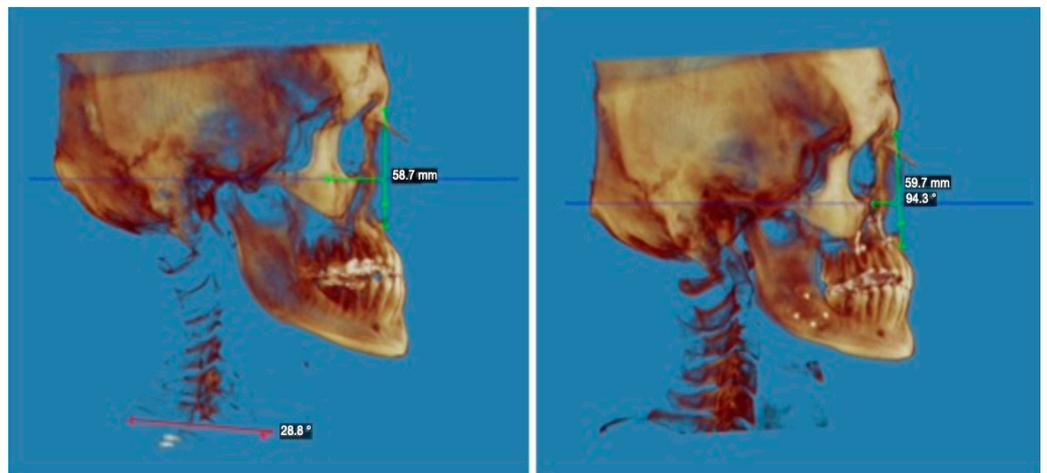


Figure 2. Latero-lateral vision from the CBCT. The head is oriented on the Frankfurt plane (Or-Po). Variation in the FH^{NA} angle from T0 to T1.

The FH^{NB} angle and the gonial angle decreased in all patients as a consequence of a mandibular reduction and the decrease in the facial divergence, respectively (Figure 3).

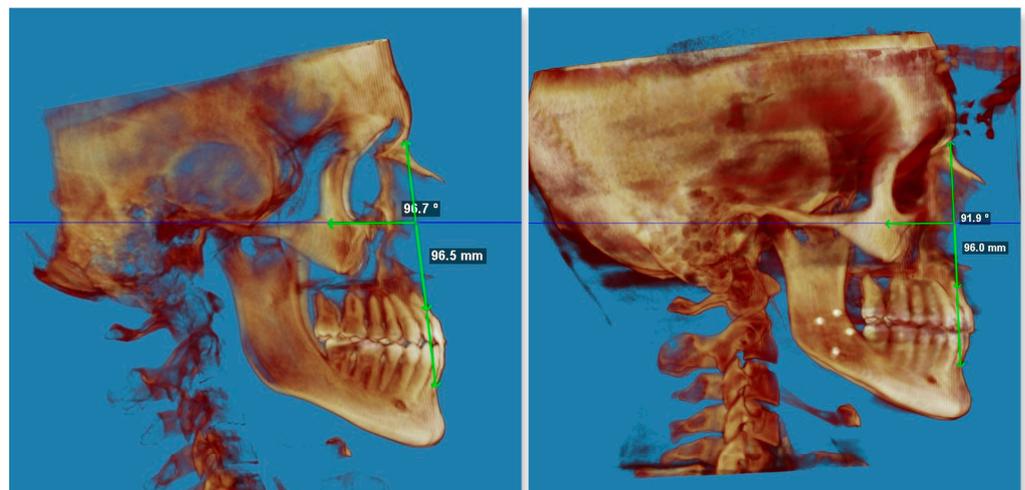


Figure 3. Latero-lateral vision from the CBCT. The head is oriented on the Frankfurt plane (Or-Po). Variation in the FH^{NB} angle from T0 (Left) to T1 (Right) with a decrease in the prognathism.

Overall, overjet and overbite increased, whereas in one patient (patient 3), they decreased, since a strong dental compensation with excessive proclination of the upper incisors was present prior to therapy (Figure 4).

The SNA and SNB angles increased and decreased overall, respectively. Consequentially, the ANB angle increased in each patient, confirming the achievement of skeletal Class I.

Most angular values concerning the maxillary and mandibular orientation and rotation in the space showed a fluctuating trend depending on the initial situation and the need to perform variable-degree rotations of the bone bases during surgery in order to obtain an optimal occlusion.



Figure 4. Patients treated with pre- and post-surgical clear aligners. In both cases, a proper overjet and overbite were achieved after the surgical interventions. In the bottom left photo, an upper incisor proclination and a reduced overbite can be noted before therapy.

3.2. Soft Tissue Measurement Analysis

Table 2 illustrates the soft tissue variations following surgery.

Figures 5 and 6 show the skeletal and aesthetic changes between the start and end of orthognathic treatment.



Figure 5. Pre-surgical lateral telerradiograph and right profile photo. A maxillary retrusion combined with a mandibular protrusion can be noted. The face photo shows a reduced cheek volume and, in general, a poor projection of the midface.

The nasolabial angle decreased in patients subjected to bimaxillary surgery; indeed, at T1, the upper lips were more everted and less flattened than at T0. The labiodental angle and the distance between the Li point and the E line decreased in three patients. The upper lip–Nperp distance increased in patients subjected to bimaxillary surgery. The Li–Apo distance decreased in three patients. Lastly, the stomion angle, the lower lip–Nperp distance, the Ls–Apo distance, and the Li ^ Apo angle showed heterogeneous results. Overall, a noticeable lower lip retrusion was achieved simultaneously with mandibular retrusion (Figures 7 and 8).



Figure 6. Post-surgical lateral teleradiograph and right profile photo. A convex facial profile with a proper upper and lower lip position was achieved at the end of treatment. Both the lateral teleradiograph and photo show a decreased nasolabial angle.

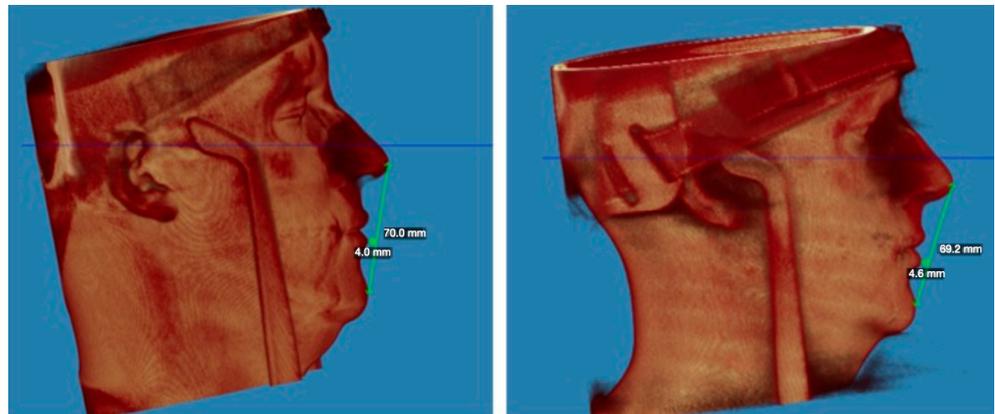


Figure 7. Facial right profile. Soft tissue improvement with the variation in the distance between the Li point and the E line from T0 to T1.



Figure 8. Variation in the right profile from T0 to T1. At T1, a greater cheek projection and less everted lower lip were achieved.

4. Discussion

The present study aimed to describe combined surgical and orthodontic treatments and compare fixed appliances versus clear aligners used in pre- and postoperative orthodontic phases.

Orthognathic surgery associated with pre- and postoperative orthodontics represents the gold standard for treating skeletal malocclusions in adult patients. Previous studies also reported the long-term skeletal stability of the results, especially after bimaxillary correction [35,36]. Orthognathic surgery positively affects the patient's psychology and self-esteem, improving psychosocial relationships and quality of life, especially in subjects with skeletal Class III malocclusion [37,38].

In our study, the skeletal and aesthetic modifications following orthognathic surgery were analyzed by the comparison of lateral telerradiographies between T0 and T1. Indeed, lateral telerradiography allows us to evaluate hard and soft tissue measurements, as well as the anatomical characteristics of upper airways [39]. In the present study, we focused on aesthetic and skeletal changes following orthognathic surgery. Regarding the possible surgical consequences on airways, Park et al. described a reduced volume in posterior airway space in some subjects after bimaxillary surgery [40]. However, the onset of sleep-disordered breathing or obstructive sleep apnea after orthognathic surgery still remains unclear.

The skeletal measurements detected at T0 were compatible with skeletal Class III malocclusion that qualifies patients to receive surgical treatment, whereas the relative T1 variations were related to the type of maxillofacial surgery performed [41]. In line with previous papers, we described the post-surgical changes a year after the orthognathic surgery, when the soft tissues had completed the healing process without any postoperative solid edema [42,43]. Our results showed an essential modification of the face's middle and lower third, as confirmed in previous papers [44]. The increase in the convexity of the profile and the decreases in the lower and anterosuperior facial heights demonstrated how the surgery led to the achievement of a more orthognathic profile. We noted heterogeneous measurements regarding Pogonion that were probably due to possible mandibular rotation during surgery. The angular and linear cephalometric measurements evaluated in our study were consistent and reliable for performing pre- and post-surgical comparisons of hard and soft tissues in patients with skeletal Class III malocclusion who underwent an orthognathic surgery. As described in previous papers, our study further confirmed that a modification in the bone bases was associated with a variation in the soft tissues, leading to facial harmonization [45,46].

Regarding the orthodontic phase, most previous papers dealt with conventional fixed brackets. On the contrary, few works examined clear aligners, despite their widespread use in orthodontics in recent years. The aligners associated with surgery show some undeniable advantages, such better aesthetics and home oral hygiene and less pain intensity [47]. On the other hand, the aligners are removable and, thus, require good patient compliance. We noticed analogous outcomes between fixed brackets and clear aligners, similar to previous papers [48]. In clear aligner cases, differently from other studies, we bonded metal fixed appliances before orthognathic surgery in order to facilitate intermaxillary fixation. For instance, CAD/CAM-designed acrylic splints or temporary anchorage devices (TADs) could be used for maxillomandibular fixation; however, conventional orthodontic brackets still represent a valid and simple approach for intermaxillary fixation, especially in multisegmental Le Fort osteotomies [49]. Therefore, the aligners were equally effective and, simultaneously, allowed us to satisfy the patients' aesthetic demands [50]. Similarly, Liou et al. described similar results between the two orthodontic techniques; however, in their study, the clear aligners also showed better immediate findings than fixed appliances [51].

As is well known, treatment with clear aligners involves an initial phase of digital treatment planning. The virtual setup provides the possibility to simulate the surgical repositioning of the bone bases in order to ensure perfect alignment between the bone bases and teeth. The digital treatment planning stage offers the benefits of precise planning for

tooth movements before surgery and accurate visualization of the post-surgical occlusion through simulated surgery. The combination of CBCT scans with virtual setups also avoids potential root displacements outside the original bone structure. Therefore, in line with other studies, we observed the achievement of desired skeletal and aesthetic outcomes following orthognathic surgery associated with clear aligners [52,53].

Regarding the treatment duration, pre-surgical orthodontic therapy was shorter in patients treated with clear aligners than those with fixed appliances (15–21 months versus 3 years). On the contrary, post-surgical treatment was much shorter in patients with fixed appliances (6 months) compared to those with clear aligners (25–33 months). Overall, therapy with clear aligners lasted 4–6 months longer than the fixed one. Surgical treatment takes time, and, thus, a patient's motivation is essential. One of the most critical problems for patients is undergoing orthodontic treatment for several months with a temporary deterioration in aesthetics and oral hygiene, especially in the case of fixed appliances. However, it is likely that combining a digital design and a surgery-first approach may reduce the treatment duration [54].

Thanks to orthodontic treatment and orthognathic surgery, our adult patients with skeletal Class III malocclusion showed better function and aesthetics, achieving an optimal occlusion, a proper relationship between bone bases, a balanced profile, and improved overall facial aesthetics. The same results would hardly have been achieved without the aid of 3D-assisted orthognathic surgery. In fact, the orthodontic treatment alone would have led purely to dental compensation without showing predictable functional and aesthetic improvements.

When planning orthognathic surgery, it is crucial to consider temporomandibular joint disorders (TMD) to ensure success and minimize complications. Key considerations include comprehensive preoperative evaluation, involving the assessment of TMJ signs and symptoms through imaging studies and clinical examination. The surgery's effect on occlusion and the potential risk of exacerbating pre-existing TMJ disorders should be carefully weighed. Close postoperative monitoring and management of TMJ function are crucial, with interventions such as physical therapy or pharmacotherapy being needed. The decision to proceed with orthognathic surgery in the presence of TMD depends on various factors, including skeletal malocclusion, occlusal abnormalities, the ineffectiveness of conservative TMD treatments, the severity of TMJ pathology, and patient preference. Collaboration between specialists is essential for developing individualized treatment plans.

Pre-existing TMJ pathology, whether symptomatic or not, can lead to unfavorable outcomes when only orthognathic surgery is performed. These conditions include articular disk dislocation, idiopathic condylar resorption (ICR), condylar hyperplasia, osteochondroma, and congenital deformities. Symptoms may include TMJ pain, headaches, myofascial pain, and TMJ dysfunction. When these conditions coexist with dentofacial deformities, they are best treated with concomitant TMJ and orthognathic surgery. With accurate diagnosis, treatment planning, appropriate surgical procedures, and proper post-surgical management, favorable outcomes can be achieved [55].

Many studies reveal that most patients with TMD who undergo orthognathic surgery experience improvement in pain-related symptoms, as well as jaw function, after surgery [56,57]. Nonetheless, other authors found that orthognathic surgery caused a decrease in TMD symptoms for many patients who had symptoms before surgery, but it created symptoms in a smaller group of patients who were asymptomatic before surgery [58,59].

The present study was subjected to the following limitations. We included a small number of participants. Expanding the sample, future studies will further highlight the validity of treatment with clear aligners for resolving surgical Class III cases. We excluded other surgical approaches, such as the surgery-first protocol or corticotomy. Lastly, we did not perform any measurements concerning airway space. The orthognathic surgery may modify the overall volume of upper airway, as mentioned above. A further consideration concerned some heterogeneous findings obtained in the present study. The well-known

inter-individual variability in facial features could increase when the facial hard and soft structures are subjected to external alterations such as surgery or orthodontics.

In order to achieve more predictable results, future studies could examine the use of artificial intelligence (AI) combined with surgical and orthodontic treatments. AI could improve the prediction of facial changes and the accuracy of soft and hard tissue variations.

Within analysis limitations, our study described the remarkable skeletal and aesthetic improvements following orthognathic surgery associated with conventional fixed appliances or clear aligners. Therefore, the aligners can be considered a valid treatment alternative for surgical correction in adult patients with skeletal Class III malocclusion.

5. Conclusions

The patients with skeletal Class III malocclusion subjected to 3D-assisted surgery associated with orthodontic treatment showed considerable skeletal and aesthetic improvements. Indeed, the introduction of pre-surgical orthodontic planning, computer-aided surgical simulation, CBCT scans, and intraoral scanners enhanced the reliability and accuracy of orthognathic surgery.

In addition, despite the limited sample size, the findings of our study demonstrated how aligners associated with orthognathic surgery can yield successful outcomes similarly to fixed orthodontic appliances. Moreover, the use of clear aligners can be implemented thanks to their multiple benefits regarding patient's life quality and the possibility to perform coronal and radicular virtual setups during the preoperative phase. Certainly, with the ongoing advancements in new technologies in digital surgical treatment planning, there will be a simplification of surgical–orthodontic treatment, increasingly oriented towards new, effective methodologies.

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