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Jawline improvement using patient-specific angle implants with virtual planning in orthognathic surgery

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ABSTRACT

There has been a recent increase in the global demand for jawline augmentation. Managing angle definition in patients undergoing orthognathic surgery remains challenging owing to the characteristics of classic mandibular osteotomy, which mostly allows sagittal mandibular movements but cannot modify the ramus height. The advent of computer-assisted surgical planning and computer-aided design/computer-aided manufacturing techniques for patient-specific implant fabrication has introduced new methods for jawline management. In this study, we aimed to assess jawline improvement using patient-specific angle implants in 18 patients undergoing orthognathic surgery with standard osteotomies. Since jawline's shape is an aesthetic refinement of orthognathic surgery, it has to be assessed with the inclusion of the soft tissues. Therefore, this study focused on jawline improvement by comparing the preoperative and postoperative 3D-photographs of each patient's face using the VECTRA H2 Imaging System camera device and software. Quantitative analysis revealed that the mean volumetric angle expansion was 4.6 mm (males, 4.71 mm; females, 4.48 mm). Qualitative and quantitative analyses revealed that the jaw angle parameters were concordant with the ideal female and male jaw angle parameters proposed in the literature. Patient-specific titanium angle implants are a promising and safe method for jawline improvement in patients undergoing orthognathic surgery.

1. Introduction

Recently, the jawline has become one of the most important criteria for beauty and youthfulness. The jawline is the mandibular plane determined by chin propulsion and mandibular angles (shape, height, and lateral projection). Notably, many techniques have been reported to improve jawline definition, such as the injection of temporary fillers, which remain temporary and only modify soft tissue without actually correcting the underlying bone surface, or the surgical placement of permanent alloplastic materials, such as solid silicone implants or porous polyethylene implants (Medpore®, Stryker, Kalamazoo, MI, USA) (Aiache, 1992; Eppley, 1999, 2019; Yaremchuk, 2000; Yaremchuk and Chen, 2007; Terino and Edwards, 2008; Gui et al., 2008; Al-Jandan and Marei, 2018; Morrison and Satterwhite, 2019). Alloplastic implants can be easily inserted; however, they are associated with the risk of infection (Hasson et al., 2007) or asymmetry due to misplacement, implant displacement, and bone resorption (Gui et al., 2008; Polo, 2017; Al-Jandan and Marei, 2018).

For maxillofacial surgeons, the primary outcome of orthognathic surgery is malocclusion correction. Therefore, managing the jawline has not been a priority for many years. However, a few surgeons remain dissatisfied with the postoperative jawline shape, even if good occlusion is achieved. Notably, the aesthetic result of bimaxillary osteotomy can be disappointing if the angles are not included in the treatment plan, especially in patients with short ramus height or angle asymmetry. Different types of osteotomies have been described over the years, and some can be used to correct the position of angles or avoid pregonial notches during orthognathic surgery. Caldwell–Letterman, Trauner, and L-inverted osteotomies allow the surgeon to increase the ramus height without permitting the usual amplitude of sagittal movements, occasionally forcing the surgeon to compromise the inclination of the occlusal plane. They also imply using a specific saw and screwdriver (90° angulation or transjugal devices) if performed using an intra-oral approach. A cervical approach has been described; however, it may

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affect the facial nerve and result in a cervical scar. Chin wing osteotomy was first described by Albino Triaca in 2010 and was designed to improve the definition of the chin and angle with the same osteotomy trait. It benefits jawline definition and can be performed with orthognathic surgery (with a high sagittal oblique osteotomy) as a modified genioplasty. Initially, the results of chin wing osteotomy were revolutionary; however, many relapses due to bone resorption at the angles were observed after a few months, even with a bone graft (Pouzoulet et al., 2018). Notably, several cases of bone resorption at angles have been associated with the chin wing plus bone graft technique; however, bone resorption (mostly as pregonial notches) has also been observed in cases of a standard bilateral sagittal split osteotomy (BSSO). Loncle et al. (2017) and Perrin (Grimaud et al., 2017) osteotomies were described in 2017 and developed to prevent pregonial notches. The osteotomy trait begins as a classical BSSO but is prolonged by a supra-basilar trait, enabling the surgeon not to disrupt the basilar line and thus prevent pregonial notches. This osteotomy can also increase the ramus height but does not change the lateral projection of the angles, and bone grafting is usually necessary.

Patient-specific cutting guides and plates are well-known and used worldwide in orthognathic (Scolozzi, 2015; Suojanen et al., 2016; Suojanen et al., 2017; Greenberg et al., 2021; Rios et al., 2022) and reconstructive (Goodson et al., 2019; Alasseri and Alasraj, 2020; Olate et al., 2021a,b; Yang and Oh, 2022) surgeries. The advent of computer-assisted surgical planning and computer-aided design/-computer-aided manufacturing (CAD-CAM) techniques for patient-specific implant (PSI) fabrication has introduced new methods for managing jawlines in orthognathic surgery. Titanium angle implants were first used unilaterally to correct facial asymmetry and mandibular defects using mirroring techniques (Scolozzi, 2015; Staal et al., 2016). Using them bilaterally (or unilaterally for asymmetrical patients) in addition to classical mandibular osteotomy could allow surgeons to correct the mandibular angle, position, and shape.

Creating one implant by mirroring the healthy side is relatively simple; however, creating bilateral implants can be challenging. Unlike the chin, for which a quantitative assessment of its ideal projection and vertical length has long been established, no specific numerical measurements exist for the jaw angle because it is not a pure profile structure (Eppley, 2019). Based on previous studies, a good male jaw angle is defined as one that sits well below the ear, looks long, and has a low profile. From the front view, the bigonial width should equal the bitemporal width and slightly smaller than the bizygomatic width. The soft tissue gonion should be more lateral than the lateral tissue plane of the neck. The profile should indicate adequate ramus height and distinct body-to-ramus transition (Eppley, 1999, 2019; Yaremchuk, 2000; Yaremchuk and Chen, 2007). Mommaerts et al. (Mommaerts, 2016a,b; Mommaerts and Cleymaet, 2023) recently proposed guidelines for ideal male and female jaw angles using an online survey of two-dimensional photographs. This approach allowed them to propose ideal jawline parameters assessed with soft tissues. Their findings indicated that the ideal intergonial width in males corresponded with the interzygomatic width. The inclination of the jawline in frontal view was parallel to the line extending from the lateral canthus to the ipsilateral alare. Ideally, the jaw angle should be at the height of the oral commissure in frontal view and not lower than the lower lip border. Furthermore, the gonial angle (formed by the intersection of the posterior and inferior ramus borders) should ideally be 130°. The angle between the posterior mandibular border and the Frankfort horizontal plane should be 65–75°. For females, the following criteria were considered ideal: gonial angle of 125.5° and 142° in the profile and anterior views, respectively, an intergonial/interzygomatic width ratio of 0.83, and the vertical position of the jaw angles being at the level of the stomion or upper lip.

Three-dimensional (3D) stereophotogrammetry is a technique that enables the reproduction of surface geometry and the mapping of realistic colour and data by taking two or more photographs of the same subject from different positions. The photographs are then stitched together using a software tool to generate a composite 3D model. The combination of 3D-stereophotogrammetry with software analysis enables the measurements of landmarks with validated precision (Savoldelli et al., 2019; De Stefani et al., 2022). Volumetric measurements and surface superimposition can also be evaluated. In the present study, we aimed to assess if the adjunction of titanium angle implants to traditional orthognathic surgery could improve postoperative jawline's parameters. Given that the shape of the jawline constitutes an aesthetically refined outcome of orthognathic surgery, it is essential to assess this outcome with the inclusion of the surrounding soft tissues. Consequently, this study focuses on the improvement of the jawline by comparing the preoperative and postoperative 3D photographs of each patient's face using the VECTRA H2 3D Imaging System camera device and software (Canfield Scientific, Inc., Fairfield, NJ, USA) before and three months after surgery. To our knowledge, the present study is the first to assess the use of patient-specific angle implants to enhance the jawline aesthetic and rectify the potential deficiency in angle position and projection after orthognathic surgery.

2. Materials and methods

2.1. Study design

This retrospective case series included 18 patients who underwent orthognathic surgery. Patient-specific angle implants were placed during the same procedure in 13 patients, whereas the implants were placed secondarily after orthognathic surgery in five patients who were dissatisfied with their jawline shape due to bone resorption at the angles or pregonial notches. Sixteen patients underwent genioplasty. All patients underwent surgery at the Head and Neck Institute at our University Hospital Center between May 2017 and August 2022.

2.2. Study sample

This study was conducted in accordance with the World Medical Association Declaration of Helsinki on Medical Research, approved by the ethics committee of our University Hospital Center (approval number xxxx; approval date: xxxx), and registered on clinicaltrial.gov (registration number: xxxxxxxxxxx; registration date: xxxx). Informed consent was obtained from each patient preoperatively, and written consent was obtained from the three patients regarding using their 3D photographs. In accordance with data protection regulations, every patient was informed of this study and the use of their data; none refused to participate. All patient data were anonymised prior to analysis.

The inclusion criteria were a history of orthognathic surgery and jawline correction using patient-specific angle implants and access to preoperative and postoperative (3 months after surgery) 3D photographs. The exclusion criterion was a history of maxillofacial trauma (Fig. 1). Patient characteristics are presented in Table 1.

2.3. Set-up

During the presurgical workup, 3D photographs, dental impressions, and cone beam computed tomography (CBCT) images of the patient were obtained. To acquire a preoperative 3D replica of the patient's skull, we used numerical toothprints obtained using Carestream 9600 (Carestream Dental, Atlanta, GA, USA) and standardised CBCT 1 month preoperatively (field of view: 22 × 16 cm; scan time: 40 s; and voxel size: 0.4 mm) (I-CAT 3D imaging System, Imaging Sciences International, Inc., Hatfield, PA, USA). The CBCT data were exported in digital imaging and communications in medicine format. To acquire a preoperative 3D model of each patient's face, we used 3D-photographs, obtained with a VECTRA H2 3D Imaging System camera device. Three photographs of each patient's face taken at 3 different positions (front, ¾ lower right and ¾ lower left) are necessary to reconstruct the surface replica of the patient's face in the Vectra Mirror Suite software (Canfield Scientific,

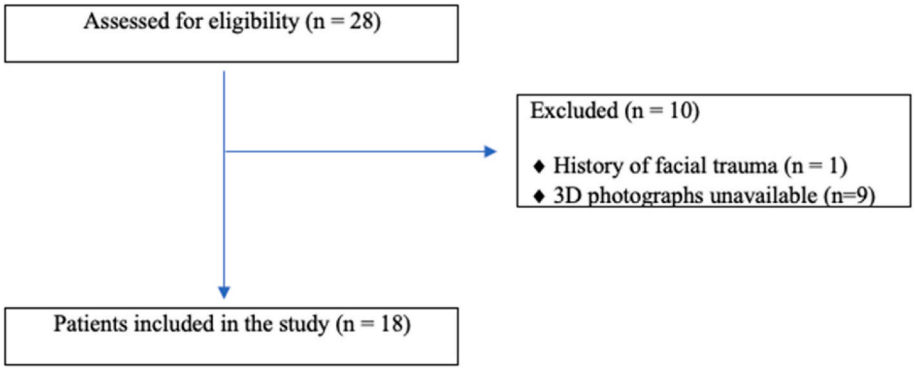

Fig. 1. Study flowchart.

Table 1
Participant characteristics.

Variables		
Mean age (years)	28.5	
Range	18–39	
Sex	16 F	
	2 M	
Type of surgery	➢ Primary: in addition to bimaxillary orthognathic surgery	13
	➢ Secondary:	
	- after bimaxillary orthognathic surgery for pregonial notches	3
	- after mandibular osteotomy for pregonial notches	1
	- after chin wing osteotomy for angle resorption	1

Inc., Fairfield, NJ, USA).

2.4. Virtual surgical planning

The CBCT data and the numerical toothprints recorded during the set-up were sent to Materialise (Malakoff, France). The same clinical engineer virtually planned all cases included in the present study using ProPlan CMF 3.0 software (Materialise, Leuven, Belgium). 3-Matic Medical (version 18.0, Materialise, Leuven, Belgium) was used to generate solid 3D models of titanium plates and angle implants. Virtual planning was performed at a web meeting (Fig. 2). The surgeon determined the shape and lateral and inferior projections of the angle implant according to each patient's morphology and sex using the criteria described above. Delaire and Steiner cephalometric analyses were used to determine the ideal positions of the gonion (theoretical gonion), chin (pogonion and theoretical chin), and F3 (ramus ideal posterior border) and F7 (basilar line) lines. Because soft-to-hard tissue ratios have not been published for this research area, we assumed that 1 mm of bone augmentation resulted in 1 mm of soft tissue augmentation in the lateral and vertical directions.

2.5. Surgical technique

All patient-specific angle implants were inserted subperiosteally using an intra-oral approach with an incision of the sagittal split osteotomy when performed or a thinner incision when placed secondarily. They were fixed with 3–5 (5.5)-mm transjugal screws (Fig. 3). In orthognathic surgery, they were inserted at the end after occlusion verification, disinfection (betadine), and haemostasis at all sites.

2.6. Study variables

The primary outcome was the postoperative aspect and position of the gonial angle, assessed 3 months postoperatively, using the 3D-model

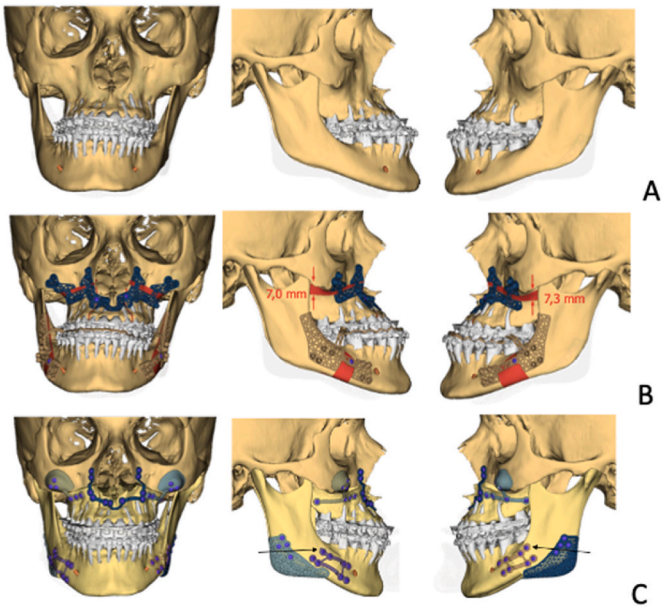

Fig. 2. Model of the patient skull (A), virtual planning of the patient-specific cutting guides (B), and virtual planning of the patient-specific plates and angle implants (C).

of each patient's face in the Vectra Mirror Suite software. The gonial angle is automatically calculated by the software after manual placement of 3 landmarks: one on the soft-tissue Gonion, one on the soft-tissue Menton and one at the intersection between the posterior mandibular border and the Frankfort horizontal plane (Fig. 4). The postoperative aspects and positions were compared with those of guidelines in the literature. Preoperative and postoperative volumes were also compared using fully automatic surface superimposition, evaluated in 3D, and indicated using isovalor colour codes (Figs. 5 and 6). The secondary outcomes were patient satisfaction and the number and types of complications.

3. Results

Eighteen patients were included in this study between May 2017 and August 2022, according to the inclusion and exclusion criteria. There were 16 females and two males with a mean age of 28.5 years. Thirty-two patient-specific angle implants were placed (four patients required only a unilateral implant to harmonise their jawline and correct a preexisting asymmetry). The malocclusion type was type II in 10 patients, type III in four patients, and type I in four of five patients who required re-intervention for jawline defects (one had a relapse of class II

Fig. 3. Example of bilateral patient-specific angle implants with five holes.

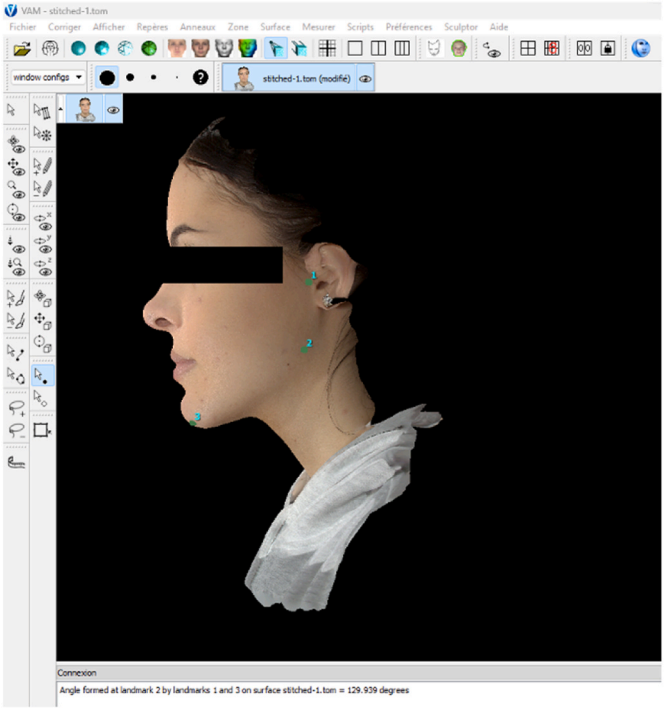

Fig. 4. Angle measurement using the VECTRA H2 3D Imagine System software.

malocclusion). All 13 patients who underwent orthognathic surgery and implant placement using the same procedure had brachyramia with a potential lack of postoperative angle projection. Four of the five patients who underwent secondary implant placement had either postoperative pregonial notches or bone resorption at the angles. One of these patients, as shown in Fig. 5, was diagnosed with a relapse of class II malocclusion, pregonial notches, and brachyramia at another centre. We decided to perform bimaxillary orthognathic surgery and genioplasty with the adjunction of angle implants.

According to the literature guidelines, the ideal intergonial width in males corresponds with the interzygomatic width. Ideally, the jaw angle should be at the height of the oral commissure in frontal view and not lower than the lower lip border. Furthermore, the gonial angle (formed by the intersection of the posterior and inferior ramus borders) should be 130°. For females, gonial angles of 125.5° and 142° in the profile and anterior views were considered ideal. An intergonial/interzygomatic width ratio of 0.83 is ideal, and the vertical position of the jaw angles should be at the level of the stomion or upper lip. Overall, the mean gonial angle in the profile view was 131.5° and 128° in males and females, respectively. The mean gonial angle in the anterior view was 145° and 142.9° in males and females, respectively. The angle was at the level of the stomion in 15 patients (13 females and two males) and below the level in two patients (only two females). The intergonial/interzygomatic width ratio was 0.97 and 0.84 in males and females, respectively. The average volume gain in the gonial region was 4.6 mm (4.71 and 4.48 mm in males and females, respectively). The jawline parameters are presented in Table 2.

These results are consistent with the guidelines proposed in the literature. However, we observed a 2.5° difference in the mean gonial angle in the profile view in females. Among the 32 implants that were placed, two angle implants were removed from one patient (patient no. 11 in Table 2) at 4 weeks postoperatively because of an infection on one side. The infection resolved after implant removal and standard antibiotic therapy was initiated. No further implants were placed. At 1-year follow-up, all patients had stable occlusion. Patient's satisfaction was evaluated at the end of follow-up using a 5-point Likert scale. At the question "are you satisfied with your jawline's shape?", 7 patients (39%) were "very satisfied", 8 patients (44%) were "satisfied", 2 patients (11%) were "neutral", 1 patient (6%) was "dissatisfied", and none were "very dissatisfied".

4. Discussion

The present study assessed whether patient-specific angle implants could efficiently improve jawline definition during orthognathic surgery. A comparison of the preoperative and postoperative 3D images of each patient revealed that (1) patient-specific angle implants improved angle projection and jawline definition and achieved patient satisfaction, (2) there was no increase in the risk of infection compared to classic orthognathic surgery, and (3) there was good alternative to complex osteotomies in managing the angle position and a good solution to correcting bone resorption resulting from mandibular or chin wing osteotomy.

Compared with other types of implants, angle titanium implants tend to decrease the risk of displacement because their shape is specifically designed for one patient, matching their mandibular contours. These implants may produce long-lasting results because titanium is made for osseointegration, whereas porous polyethylene implants can induce bone resorption. Porous titanium has the closest mechanical characteristics to the human bone. The intra-oral approach to placing titanium angle implants does not differ from the oral incision of orthognathic mandibular osteotomy, allowing surgeons to perform orthognathic movements and osteosynthesis and end with a patient-specific angle implant. The titanium and polyethylene implants require transjugal devices for fixation. Adding patient-specific angle implants to orthognathic surgery increases the surgical time by 10–15 min. Because we

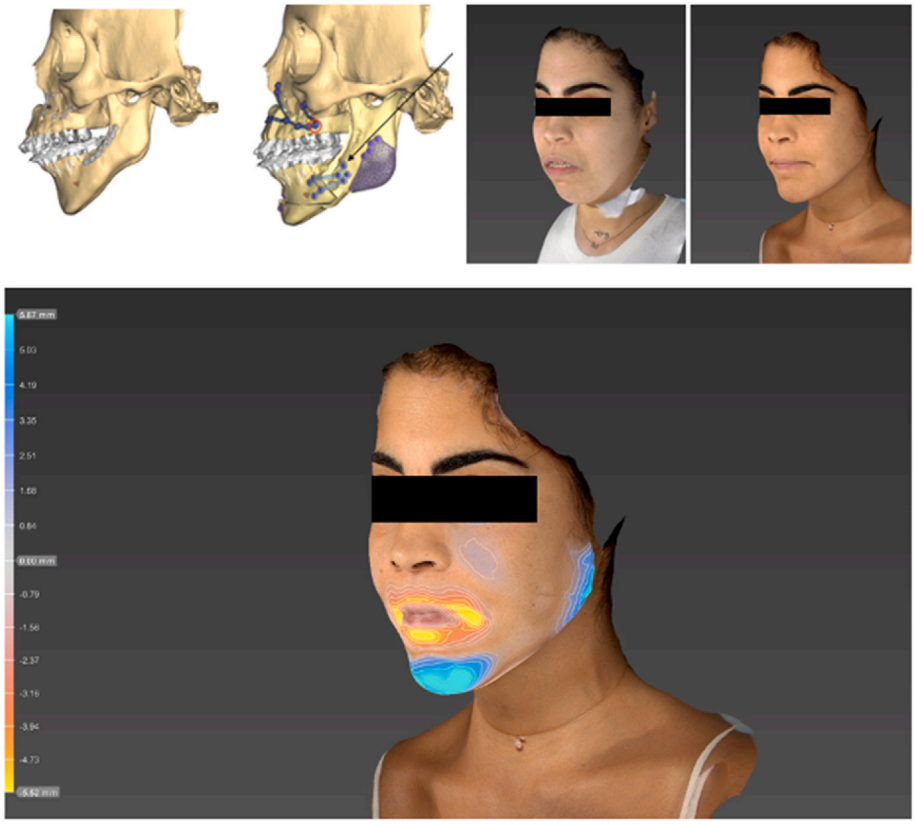

Fig. 5. Comparison of preoperative (note the brachyramia) and postoperative volumes at the chin and the left angle in a patient with relapse of class II malocclusion using surface superimposition. The preoperative and postoperative volumes are indicated using isovalor colour codes: increased volume added is indicated in blue, whereas decreased volume is indicated in orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

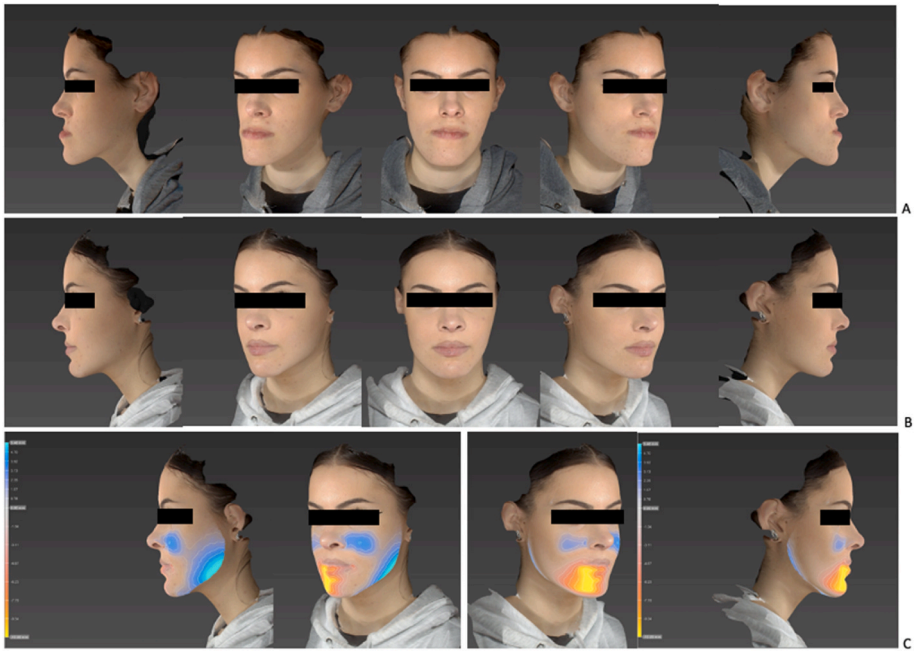

Fig. 6. Jawline aspect preoperatively (A) and postoperatively (B) in a patient with type III malocclusion using 3D photogrammetry. Illustration of the modifications in the gonial angle region and chin using isovalor colour codes obtained with VECTRA H2 software: increased volume is indicated in blue, whereas decreased volume is indicated in orange (C). The patient's surgical plan is shown in Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Jawline parameters measured using the Vectra Mirror Suite software on the 3D-model of each patient's face. Gonial angle anterior view (Gav); Gonial angle lateral view (Glv); Inter-gonial width (IGw); Inter-zygomatic width (IZw); and Patient-specific implant (PSI).

Patient n°	Sex	Age	Occlusion type	Treatment	Gav (degrees)	Glv (degrees)	IGw (mm)	IZw (mm)	IGw:IZw	Maximal Volume expansion (mm)	Position to stomion	Nb of PSI angle implants
1	F	19	I	Reoperated after bimaxillary orthognathic surgery + genioplasty mini wing for pre-gonial notches correction	145	135,7	112.8	123.9	0.91	5.468	At level	2
2	F	34	III asymmetric	Bimaxillary orthognathic surgery + genioplasty	142	130	104.3	126.9	0.82	3.051	Below	1
3	F	37	I	Reoperated after bimaxillary orthognathic surgery for pre-gonial notches correction	140	122,5	108.8	129.9	0.84	5.431	At level	2
4	F	34	II asymmetric	Bimaxillary orthognathic surgery + genioplasty	143	124,6	109	138.6	0.79	3.69	Below	1
5	F	29	II asymmetric	Bimaxillary orthognathic surgery + genioplasty	140	127	103	129	0.8	3.864	At level	1
6	F	18	II asymmetric	Bimaxillary orthognathic surgery + genioplasty	140	128	114.7	130	0.88	4.846	At level	1
7	F	27	II	Bimaxillary orthognathic surgery + genioplasty	150	130	103.2	125.5	0.82	3.35	At level	2
8	F	37	II	Bimaxillary orthognathic surgery + genioplasty	143	130	107.7	127.9	0.84	7.1	At level	2
9	M	34	III	Bimaxillary orthognathic surgery + genioplasty	145	130,2	120.4	125.8	0.96	4.083	At level	2
10	F	26	II	Reoperated after chin wing genioplasty for bony resorption at the angles	142,5	128	114.2	134.6	0.85	4.2	At level	2
11	F	26	II	Bimaxillary orthognathic surgery + genioplasty	Not measurable	Not measurable	Not measurable	Not measurable	Not measurable	Not measurable	Not measurable	2
12	F	25	III	Bimaxillary orthognathic surgery + genioplasty	142	129,5	111	133.7	0.83	4.31	At level	2
13	M	39	I	Reoperated after mandibular orthognathic surgery + genioplasty for pre-gonial notches correction	145	128	124.3	128.1	0.97	5.34	At level	2

(*continued on next page*)

Table 2 (*continued*)

Patient n°	Sex	Age	Occlusion type	Treatment	Gav (degrees)	Glv (degrees)	IGw (mm)	IZw (mm)	IGw:IZw	Maximal Volume expansion (mm)	Position to stomion	Nb of PSI angle implants
14	F	18	I	With genioplasty	144	127,6	115.4	129	0.89	4.99	At level	2
15	F	33	II	Reoperated after bimaxillary orthognathic surgery for relapse and pre-gonial notches correction: bimaxillary orthognathic surgery + genioplasty	140	124,1	107.8	134	0.8	5.87	At level	2
16	F	18	III	Bimaxillary orthognathic surgery	143	129,9	107.7	125.8	0.86	5.48	At level	2
17	F	32	II	Bimaxillary orthognathic surgery + genioplasty	145	125,6	109.9	127.6	0.86	2.43	At level	2
18	F	27	II	Bimaxillary orthognathic surgery + genioplasty	145	124,7	99.5	122.3	0.81	3.18	At level	2
Mean		**28,5**	**Class I: 4 Class II: 10 Class III: 4**		**F: 142.9 M: 145**	**F: 128 M: 131.5**			**F: 0.84 M: 0.97**	**F: 4.48 M: 4.71**		**32**

only used patient-specific titanium angle implants in the present study, we could not compare the surgical time with another type of implant procedure. However, according to previous studies, the surgical time is lower when compared with that of non-specific implants (Olate et al., 2021a,b).

Other materials, such as polyetheretherketone (PEEK), have also been investigated with good results (Olate et al., 2021a,b; Nocini et al., 2022; Avci et al., 2022). However, the choice of titanium over PEEK is based on the European belief that it is better to prevent long-term complications caused by non-osseointegrated PEEK implants than to handle the complications associated with osseointegrated titanium (Federal and Drug Administration philosophy) (Mommaerts, 2016a,b).

We encountered several challenges in creating titanium implants. First, associating two patient-specific implants on the same side of the mandible (one patient-specific plate and one patient-specific angle implant) is occasionally impossible because the implant must cover the osteotomy trait. Therefore, we attempted to use an angle implant for osteosynthesis. This is risky because all the material must be removed simultaneously if an infection occurs. This can be dramatic if it occurs within 2 months of critical consolidation. Fortunately, the plate and angle implants were distinct in infectious cases in the present study. However, this risk should be addressed (Fig. 7).

Second, the jawline depends on the aspect of the angles (shape and lateral projection), ramus height, and chin propulsion. Analysis of the gonial region implies understanding whether the patient lacks lateral projection, has brachyramia, or both. When designing an angle implant, it should be considered that the BSSO tends to increase the intergonial distance. Facial surgeons should systematically appreciate occlusion, chin propulsion, and shape during the clinical analysis of the patient, and an evaluation of the chin region must include dynamic analysis of the peribuccal muscles. Chin augmentation can be performed using implants; however, osteotomy is preferred. Facial surgeons should also appreciate and integrate treatment plans based on each patient's morphology, sex, ethnicity, and skin thickness. Increased attention should be paid to patients with asymmetry during analysis. An accurate determination of the origin of the asymmetry and an analysis of the compensative mechanisms, occasionally present (soft tissue and muscular compensation), should be performed. Neglecting soft tissue analysis increases the risk of residual asymmetry, even with symmetrical implants.

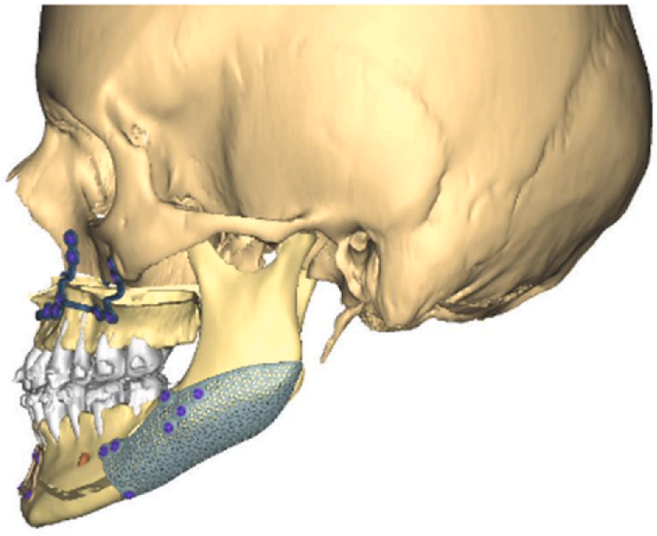

Fig. 7. Visualization of a patient-specific angle implant contributing to the osteosynthesis of the sagittal split osteotomy and mini-wing osteotomy.

Third, in a study by Scolozzi (2015), PSIs were safe enough to correct residual chin contours and mandibular defects after mandibular osteotomies and genioplasty. In the present study, we used patient-specific angle implants. Good aesthetic results were achieved, and the patients were satisfied. Mommaerts (2016a,b) proposed a two-piece puzzle-designed mandibular border implant to facilitate

insertion without jeopardising the mental nerve in cases of larger defects. In the present study, the bone defects were asymmetric in one of the cases requiring reintervention for mandibular pregonial notches and bone resorption after bimaxillary osteotomy. This type of case can be challenging if non-specific implants are used due to residual asymmetry risk. Using PSIs allowed us to use two different angle implants, thus achieving good symmetrical outcomes (Fig. 8).

The addition of foreign materials to the operative site increases the risk of different types of complications. Previous reports on specific complications associated with mandibular angle augmentation or reduction exist (Ousterhout, 2021; Semergidis et al., 1996; Lee and Kim, 1999). The most common complications are infection, haematoma, and asymmetry, although they are relatively rare. Other reported complications include temporary total facial nerve palsy, marginal mandibular palsy, mental nerve palsy, and retromandibular vein rupture (Thomas and Yaremchuk, 2009). To place porous polyethylene and patient-specific titanium angle implants, the surgeon must perform subperiosteal dissection and liberate the inferior border of the mandible. This exposure may disrupt the pterygomasseteric sling and cause the masseter muscle to retract superiorly, leading to a loss of soft tissue volume over the mandibular angle and a skeletonised appearance (Thomas and Yaremchuk, 2009; Bastidas and Zide, 2010). The alternative osteotomies described in the introduction section of this manuscript also imply the necessity of pterygomasseteric disruption. To minimise the risk of masseteric disruption and retraction, Thomas et al. (Thomas and Yaremchuk, 2009) suggested five practices: infiltration of the operative site with an epinephrine-containing solution to maximise haemostasis, generous intraoral incisions to optimise operative site exposure and facilitate implant placement, strict subperiosteal dissection to minimise sling disruption, use of implants that provide lateral and vertical augmentation compatible with the patient's soft tissue envelope, and screw fixation of the implant to prevent implant movement and lessen the likelihood of revision surgery. We did not observe pterygomasseteric disruption or dehiscence in the present study; however, surgeons must clinically analyse the masseter force before placing the implant. We hypothesised that patients with type II malocclusion, brachyramia, and a hypodivergent face might have strong masseters that could not tolerate excessive augmentation.

There were several limitations to this study. First, the measurements were performed by one investigator, which could have introduced bias. The software is validated for precision, but each point must be manually placed to perform angle and distance measurements. Automated or semi-automated analysis would be helpful in such cases. Second, the cohort was relatively small, which can be explained by the novelty of this use of PSIs. Further, most patients were of similar age and ethnicity, allowing us to perform patient-specific angle implants relatively consistently across patients. The guidelines proposed in the literature are also based on patients of similar demographics. Patients' needs vary considerably depending on ethnicity and culture; in Asian countries, a slim and smooth jawline is preferred for both males and females. Many jawline reduction procedures are proposed (V-Line surgery). Thus, creating an angle implant should be thoroughly discussed with the patient. There is currently no widely available simulation software to predict the results of jaw augmentation with good accuracy, and existing software should be used with great caution.

Finally, studies on ideal male and female jawline parameters are lacking. The criteria used in the present study were mostly based on the guidelines proposed by Mommaerts et al. (Mommaerts, 2016a, 2016b; Mommaerts and Cleymaet, 2023) for patient-specific jawline definition using titanium implants in aesthetics, deformity, and malformation surgery. Mommaerts et al. proposed ideal jawline parameters after two online surveys (one for males and one for females) in which facial and non-facial surgeons rated the attractiveness of males and females through different questions and Likert scales. Our results are consistent with the parameters proposed in the literature, showing good surgeon and patient satisfaction. However, we observed a 2.5° difference in the mean gonial angle in the profile view in females. To explain this discrepancy, we formulated two hypotheses: (1) too much inferior projection of the implant or (2) the fact that the 3D images were obtained 3 months postoperatively. Orthognathic surgery, which involves extensive subperiosteal dissection of the corpus and osteotomies, results in oedema and soft tissue reorganisation several weeks postoperatively. Notably, most facial surgeons hypothesise that 3 months postoperatively is relevant for assessing postoperative occlusal and aesthetic results. However, further investigations on soft tissue recovery after orthognathic surgery are required.

5. Conclusion

In this study, patient-specific angle implants appeared to be an effective and safe material for improving patients' jawline undergoing orthognathic surgery. They can also be used to correct bony defects following orthognathic osteotomies. Further studies are required to assess the long-term outcomes of these implants and orthognathic surgery.

Author contributions

Conceptualization: C. Savoldelli; **Data curation**: O. Rios, R. Pradel, J. Pradel; **Formal analysis**: O. Rios; **Investigation**: O. Rios; **Methodology**: C. Savoldelli; **Project administration**: C. Savoldelli; **Resources**: C. Savoldelli; **Software**: C. Savoldelli, O. Rios; **Supervision**: C.

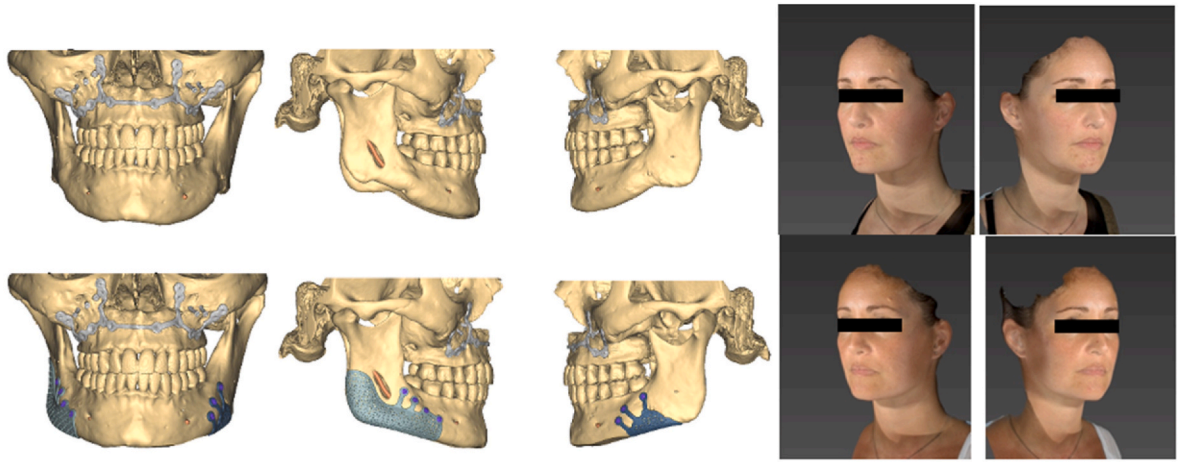

Fig. 8. Asymmetrical patient-specific angle implant.

Savoldelli, B. Lerhe; **Validation**: C. Savoldelli, B. Lerhe; **Visualization**: C. Savoldelli, B. Lerhe, O. Rios, R. Pradel, J. Pradel; **Writing - original draft**: O. Rios; and **Writing - review & editing**: C. Savoldelli, B. Lerhe, O. Rios.

Data availability statement

Not applicable.

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Conflict of interest

None.

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