# 14 Decision-Making in Orthognathic Surgery by Virtual Planning and Execution

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## Introduction

Orthodontic surgery is based on a close collaboration of orthodontists with maxillofacial surgeons. The definition of treatment goals and the movements of teeth and jaws are based on elaborated treatment protocols. In general, teeth should be aligned in an ideal teeth arch, including a normalized curve of Spee. Jaws should be placed in a normalized position, according to reference planes (e.g., the Frankfurt horizontal level). In conventional planning for orthognathic surgery, surgeons use two-dimensional cephalometric analysis and dental casts mounted on the articulator with a facebow transfer of the patient's occlusal plane. Manual model surgery is performed to predict the direction and extent of movement in the jawbone segment. Splints are then fabricated in the dental laboratory, to be used during the operation (Fig. 14.1). When two-jaw surgery is performed, an interocclusal splint is fabricated to work as an intermediate guide for repositioning the maxilla relative to the intact mandible, and a final splint is fabricated to determine the desired surgically planed occlusal position [1]. Several sources of error and inaccuracy are associated with the whole cranial situation in plaster model surgery because of insufficient control of the three-dimensional transfer of the dental occlusion to the skull.

Compared with such a conventional orthognathic surgery planning, computer-assisted orthodontic and surgical analysis using 3D digital models has improved the effectiveness of the treatment planning process by eliminating previous procedures such as the mounting of casts on the articulator or the cutting and gluing of the casts [2–6]. Additionally, the visualization of complex structures in craniofacially malformed patients (dental, skeletal, and soft tissues) within a dentofacial deformity has been greatly enhanced through three-dimensional (3D) data generation. The computer-assisted data integration allows a precise and three-dimensional virtual model of the patient's anatomy. The 3D model creates an environment that provides a standardized, safe, and flexible platform for the assessment of various anatomical regions of the head for examination, diagnosis, and planning. Computer simulation can demonstrate the extent of yaw rotation in the maxilla and mandible, occlusal plane canting, and differential length of a mandibular body or the ramus [7–12]. It is also a

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© Springer Nature Switzerland AG 2023
U. Meyer (ed.), *Fundamentals of Craniofacial Malformations*,
https://doi.org/10.1007/978-3-031-28069-6_14

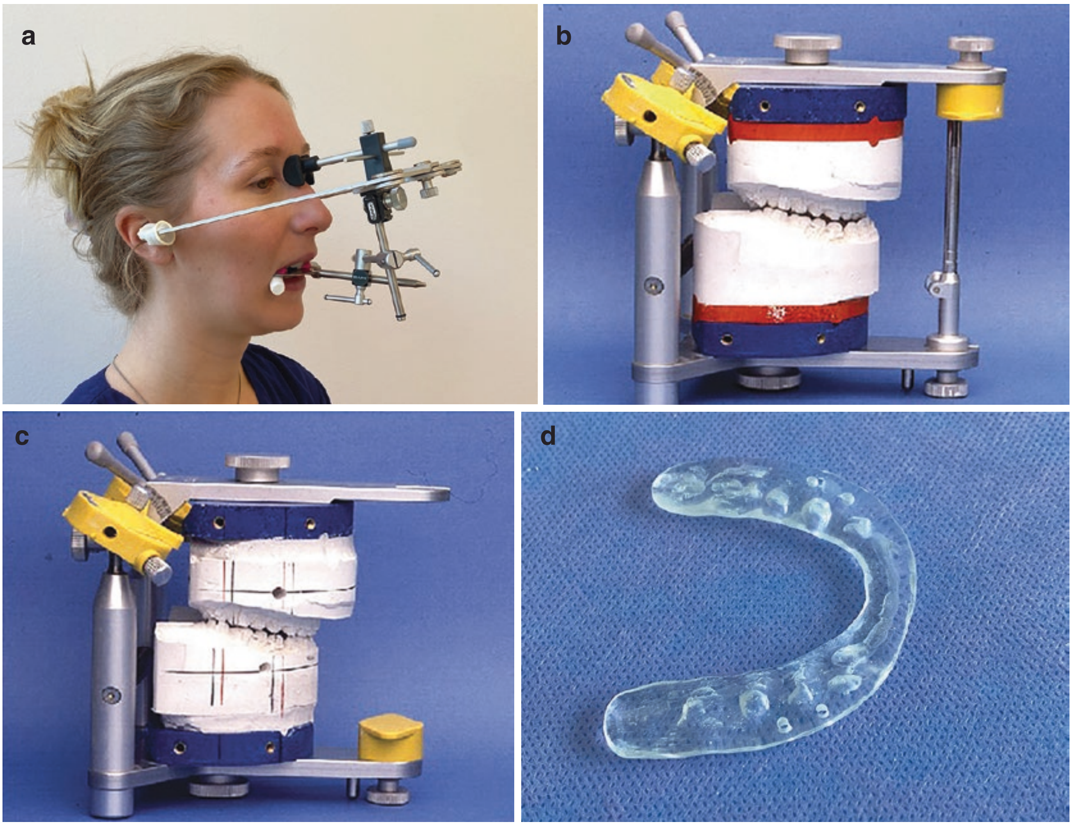


**Fig. 14.1** Steps of conventional split-based plaster model surgery. **a**) Clinical bite registration, **b**) articulation of plaster model in dysgnathic situation, **c**) model surgery in class I relation, **d**) splint fabrication

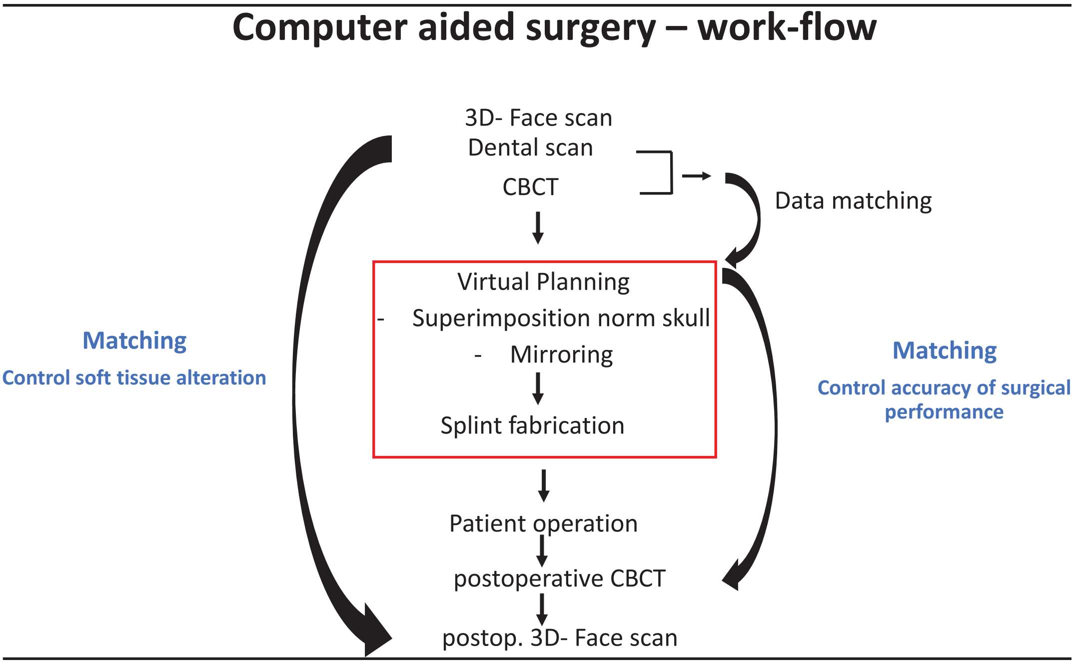
worthwhile tool for surgical training [13]. Favorable occlusal interdigitation and an optimized position of the mandibular condyle after surgery are essential for obtaining favorable results. Many studies have demonstrated that the condyle position changes somewhat after OGS despite the efforts of clinicians to maintain the condyle's original position [14–19].

Whereas some studies have noted the advantages of computer-assisted techniques in predicting possible difficulties and complications [20] and enabling the precise visualization of osteotomized segments and the calculation of bony interferences [21–24], computer simulation has also significant limitations. A computer allows segmentations (in real osteotomies) and movements of bones in all directions and to an unlimited extent. In the real patient situation, osteotomies as well as bone movements are limited by multiple factors: the course of nerves and vessels, the soft tissues (muscles, ligaments, mucosa, skin) surrounding the bone, and others.

In general, as demonstrated in a systematic literature evaluation, virtual planning seems to be an accurate and reproducible method for orthognathic treatment planning. When comparing this technique with the classical planning, virtual planning appears to be more accurate, especially in terms of frontal symmetry [25, 26].

In computer-assisted orthognathic surgery, different extents of surgical execution can be distinguished:

**Table 14.1** Steps in computer-aided surgery




– Surgical positioning of jaw segments through the help of custom splints (Table 14.1)
– Surgical osteotomies of bones through the help of prefabricated cutting and drilling guides and surgical positioning of bone segments through prefabricated osteosynthesis plates

The possibilities and technical performance are described in the planning of a bimaxillary osteotomy case with simultaneous resection of a condyle.

## Data Generation

In computer-assisted orthognathic surgery planning and simulation using digital 3D models, various patients' data are of importance: both dental arches with the accompanying occlusion (data acquisition is necessary with a high resolution; 20 μm), the skull morphology (ideally with a relevant bone resolution (e.g., by CBCT; 300 μm)), and the facial surface (acquired by a 3D surface scan; resolution 50 μm).

### Data Generation of Dental Arches and Occlusion

Image artifacts are another limitation of CBCT; artifacts such as streaking, shading, and distortion are usually produced due to the presence of metallic restoration, fixed orthodontic appliances, or implants that are affecting the quality of the images. Therefore, the image of the defective dentition of the CBCT is usually replaced with the 3D image of the scanned dental models using either CT or laser scanner. The fusion of the images can also be achieved with high accuracy between the CBCT and the intraoral scans for orthognathic surgery planning.

### Data Generation of the Bony Skull

Patients undergoing planning require preoperative cone beam or conventional computed tomography (CT). The dataset is exported in Digital Imaging and Communications in Medicine (DICOM) format.

## Data Generation of Facial Texture

Even though CBCT is excellent in the imaging of hard tissue, the soft tissues are of poor contrast and the method does not produce the normal photorealistic appearance and the texture of the skin of the face. Modern color scans allow the 3D recording of facial texture, which can be easily superimposed on the 3D surface image of the CBCT. The time required for image acquisition is less, and it is highly accurate and reliable for the capture of face morphology. The capture of 3D image of the skin can be accurately superimposed on the CBCT to produce a photorealistic image of the face over the captured facial skeleton.

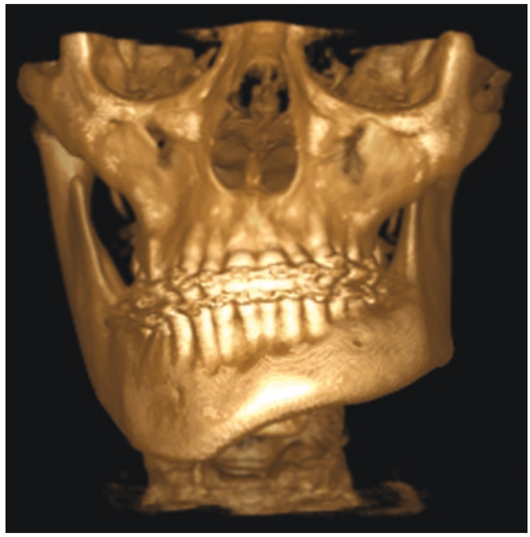


**Fig. 14.2** CBCT view of patient with right-sided hemifacial hypertrophy

## Planning Procedure

Planning of orthognathic surgery (demonstrated here by a splint-based system) is done through a stepwise approach (System Onyx Ceph®).

### Data Import

1. Various data must be imported in the planning system:
   (a) CBCT (or CT) data (Fig. 14.2).
   (b) Dental data through scanning of plaster models or intraoral scanners of both dental arches (Fig. 14.3).
   (c) Definition of the patient's occlusion prior to surgery.
   (d) Ideally, a facial scan with high resolution and a photograph should be integrated into the planning procedure (Fig. 14.4a, b).
2. The CBCT data must be imported. After definition of each region of interest (ROI) modification, the intensity histogram (characteristic) is updated since only voxel inside the ROI is considered. The dental scan is then matched with the CBCT data (Fig. 14.5).
3. The horizontal ROI borders must be defined. Special care has been done that bony condyles and soft tissue nose are covered.
4. The facial surface data (generated through an optical face scanner (Fig. 14.6)) can be included in the system (objects can be displayed in color).
5. The mandible as well as the maxilla (and in defined surgical situations, the TMJ and chin) are segmented (Fig. 14.7).
6. In order to get a good 3D view of the patients, preoperative bony and skin surface appearance, color, and transparency of the soft tissue can be adjusted (Fig. 14.8).
7. Extracted surface should be displayed in lateral, frontal, and transversal view.
8. The dental scan is then important (maxillary scan, mandibular scan, occlusion scan). Since the surgical pretreatment situation usually has brackets on the crowns, a manual correction for the crown border will often be required.
9. The TMJ rotation axis has then to be defined (Fig. 14.9).
10. The dental scans are then matched (registered) to the corresponding dental data (maxilla and mandible) in the CBCT scan.
11. All data are registered as the completed phenotyping of the patient.

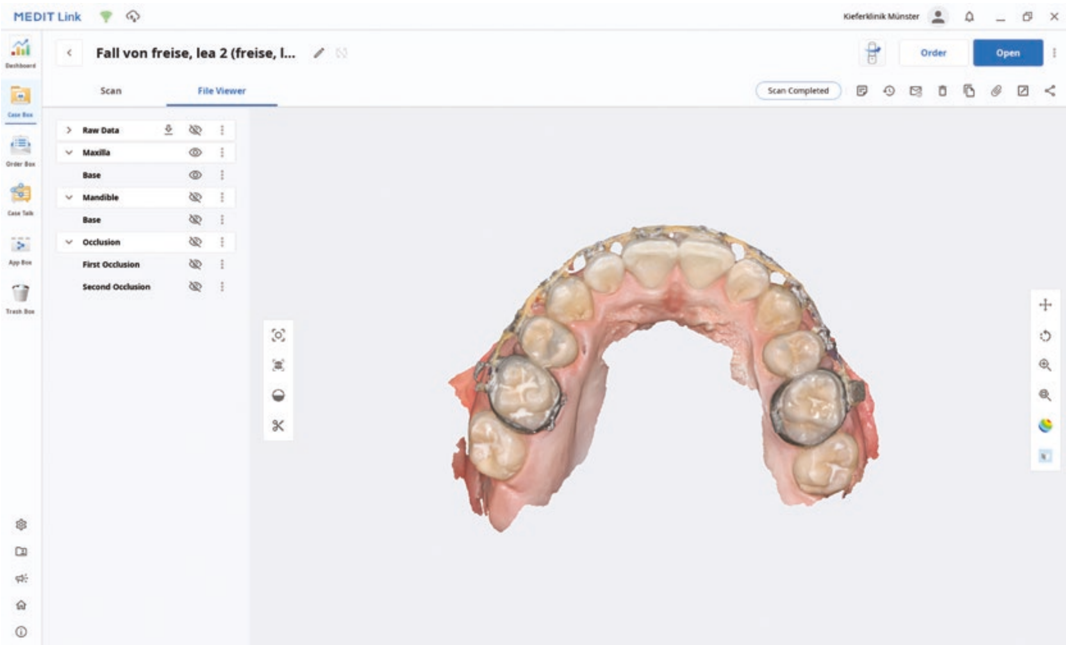



**Fig. 14.3** View of intraoral dental arch scan. Both dental scans (maxilla and mandible) as well as an occlusal scan must be imported into the system

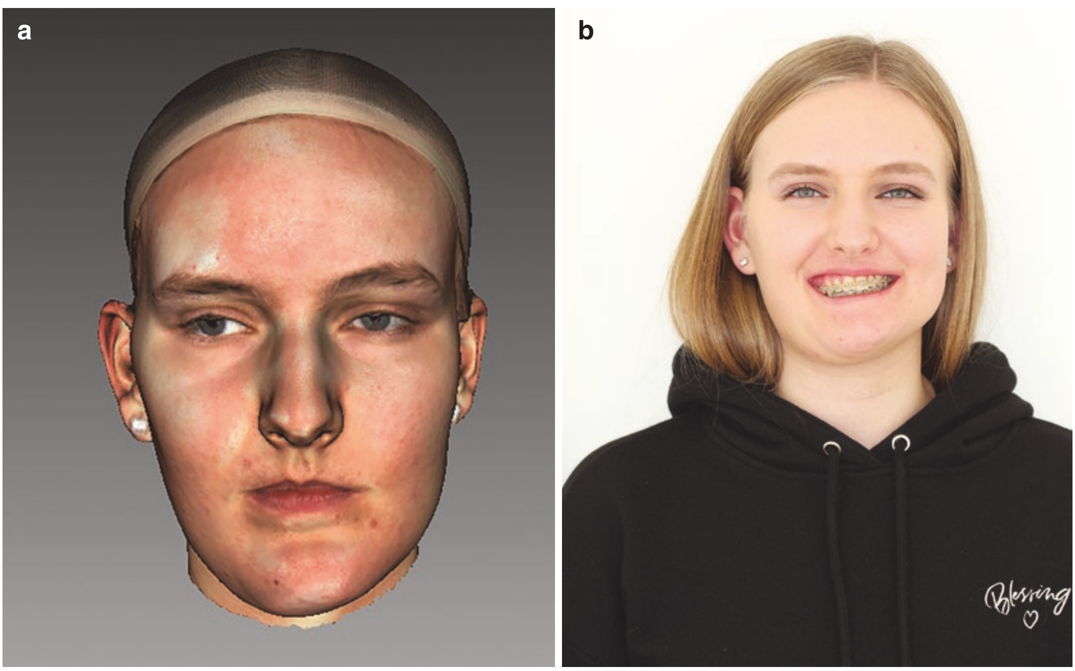



**Fig. 14.4** (**a**) The 3D colored facial scan can be integrated in patients' phenotyping, (**b**) a conventional photograph is important for the case documentation

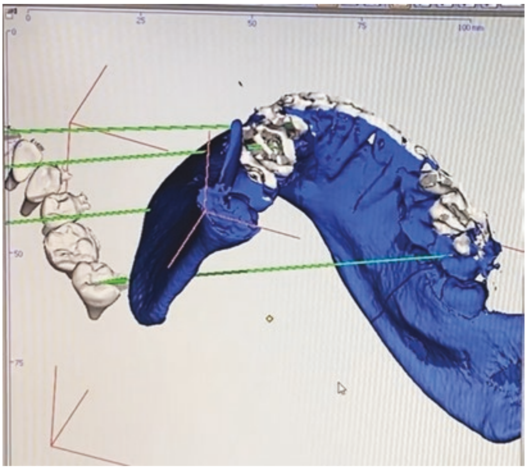



**Fig. 14.5** All data are integrated into the system. The dental scan data are matched with the bone data

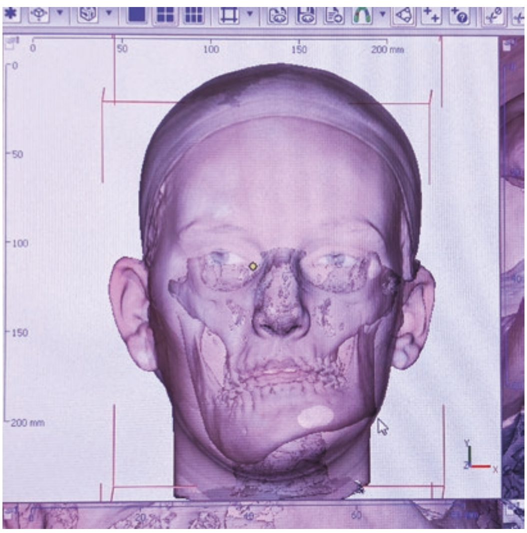



**Fig. 14.6** Patients' color surface view based on the face scan, integrated into the bony and dental anatomy

## Planning Procedure

There are three types of planning steps:

- Orthodontic repositioning
- Surgical segmentation
- Surgical positioning

While orthodontic movements are normally planned prior to surgery, surgical segmentation and segment movements are needed.

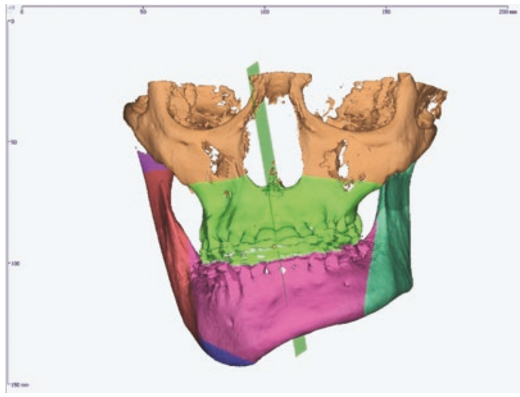


**Fig. 14.7** Transparent view on the soft and bone tissue phenotype

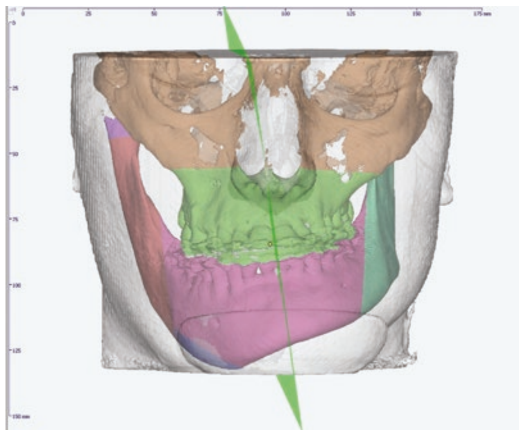


**Fig. 14.8** Segmentation of the skull bones according to the surgical strategy

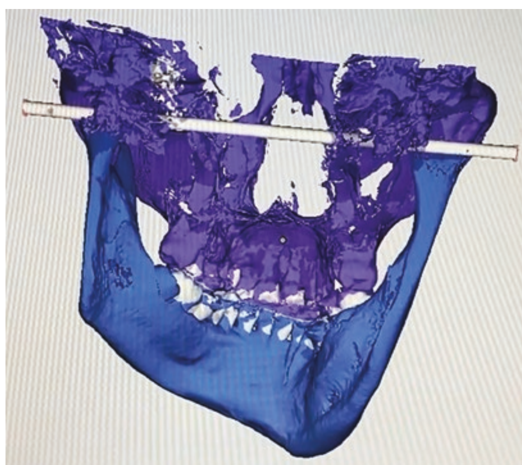


**Fig. 14.9** The TMJ axis is defined

## Decision-Making in Planning of Jaw Movements

The aim of orthognathic surgery is to achieve symmetric faces with ideal esthetic proportions. Whereas this aim can be reached in most simple cases (not based on syndromal craniofacial diseases), complex anatomical deviations from norm impose a significant challenge in multiple aspects:

(a) The extent of bone movements is often significant, making distraction osteogenesis the only surgical approach.
(b) Anatomical deficits (deficit ramus in branchial arch diseases) have to be considered, making special osteotomies necessary.
(c) Soft tissue deficits emphasize the need to combine orthognathic surgery principles with soft tissue augmentations.
(d) Most skulls have complex deviations from normal in the sagittal, transversal, and frontal aspects.
(e) Facial asymmetry is common.
(f) Typical planning tools (lateral cephalograms) with norm values cannot be used.

The aim to correct the deficient anatomy in such patients is to generate a normal anatomy. The standard of planning is the development of visual treatment objectives. Accurate and realistic visual treatment objectives are developed by the combined elaboration of the patient's skull data (CBCT data) superimposed by an age- and size-adapted norm skull. In asymmetric facial conditions, mirroring of the less affected side can be used as a second simulation tool (Table 14.2). The decision of the surgical strategy is difficult, when complex 3D skeletal malpositions with major bony deficiencies do exist (Table 14.3).

The following questions are then needed to be answered:

1. Will it be possible to create the skeletal change within the biological boundaries?
2. What kind of approach should be executed for each skeletal component (distraction versus immediate placement)?
3. How many segments are needed to gain a normal anatomy?
4. What is the appropriate osteotomy line in each segment?

From a frontal view, jaws should be placed concerning the interocclusal plane, the mandibular angle plane, and the chin plane parallel towards the bi-pupillar plane.

In mono-maxillary surgery of symmetric faces, planning is relatively simple since the

**Table 14.2** Development of visual treatment objectives. In facial asymmetries, it is recommendable to superimpose a norm skull and to mirror the less affected side. Both phenotypes give information on the treatment goal. The surgeon has to decide whether the final jaw position can be surgically reached within the biological limitations of each patient

**Development of visual treatment objective**

Superimposition

- Pre-operative Data
- Surgical planning
- Norm Skull
- Mirroring less effected side

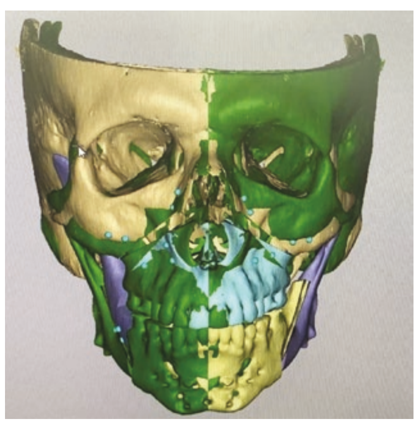
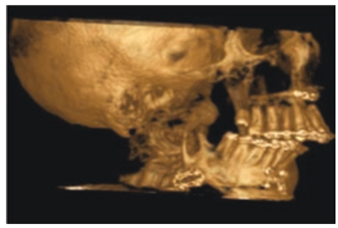


**Table 14.3** CBCT of patient with Goldenhar syndrome. Multiple factors must be considered prior to planning

**Decision making in severely affected bony and soft-tissue malformations (Goldenhar syndrome)**

Aspects:

- Extreme torsion of the midfacial and mandibular complex
- Extreme mandibular retrognathia
- Significant facial asymmetry
- Altered bone anatomy in the right mandibler
- Soft tissue deficiency



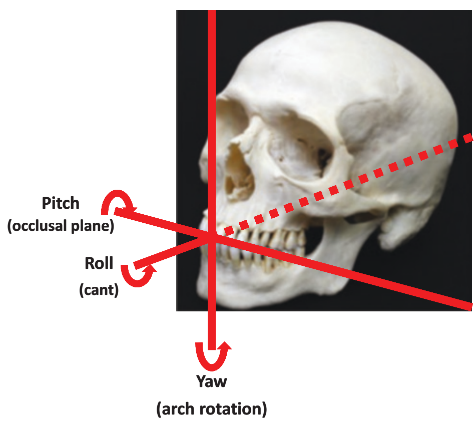
operated jaw should be placed in a class I relation. Two aspects have to be considered: (1) if the maxilla is moved, the vertical height has to be defined, and (2) if the mandible is moved, the thickness of the splint can vary, according to a orthodontic driven bite enhancement post-surgery.

In bimaxillary surgery, all freedoms of jaw placements are present. In multiple-segment surgery (often necessary in craniofacially malformed patients), bone segment placement is even much more difficult. The treatment goal of all orthognathic procedures is to place teeth and bone into a normal (average) position within the skull (for details of decision-making, see [1]).

The key to successful orthognathic surgery in complex cases is to place the maxilla and especially the maxillary incisors in the optimum anteroposterior and vertical relation to the upper lip and face. The key for virtual planning is to normalize the maxilla-mandibular complex concerning all spatial axes. Therefore, the pitch, roll, and yaw of the complex must be positioned first. Coronal occlusal cants and midline rotations must be corrected. The vertical position of the anterior and posterior maxilla should be normalized to an average distance to the skull base. The mandible is then placed into a class I relation, with a normal leveling of dental arches (Table 14.4).

**Table 14.4** The axes of the maxillomandibular complex should be set in an ideal phenotype. As most bimaxillary surgeries start with positioning the maxilla, this bone has to be positioned according to a normal yaw, pitch, and roll first

**Axes of the maxillo-mandibular complex**



In cases of mandibular hypertrophy (often associated with hemifacial hypertrophy or enlarged condylar states), bimaxillary surgery is mandatory, and resection of the condyle is necessary to normalize the mandibular angle level. As asymmetric facial diseases have also an anatomical asymmetry of the chin, the chin must be corrected. This can be done during primary surgery after a thorough digital planning; it can also be performed later. A later approach might help to gain an optimized result.

## Virtual Surgery

1. The maxilla osteotomy is applied. Special attention should be given to locate the anterior paranasal osteotomy height, since this has a major effect of the final facial appearance (Fig. 14.10).
2. The maxillary movement is defined and registered (Fig. 14.11). It is important to note that in virtual planning of the jaw movement, no technical restrictions exist. In reality, multiple factors limit the movement of a maxillary complex. Therefore, practical experience in orthognathic surgery is of major importance for this most decisive point in virtual planning of bimaxillary surgery.
3. The first splint must be created at this stage.
4. The mandibular osteotomy is then applied (Fig. 14.12a). The system allows various segmentations during the surgical planning procedure (Fig. 14.12b displays a Delaire-Joos osteotomy in a right mandibular angle (different patient)).
5. The mandible is moved to reach the planned occlusion (Fig. 14.13). The planned occlusion is generally the intersection of orthodontic and surgical treatment. During this

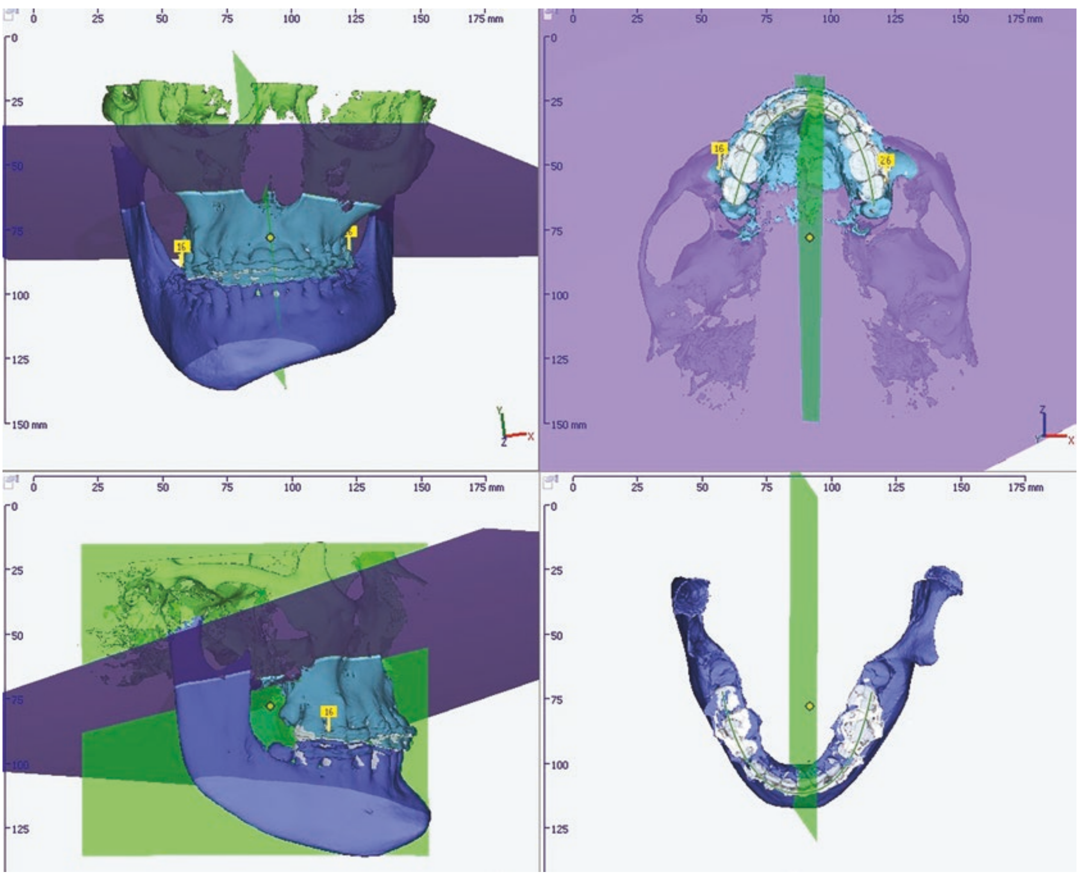


**Fig. 14.10** Special attention should be placed to the anterior position of a LeFort I osteotomy line since this will have a major effect on the final patients' midfacial appearance

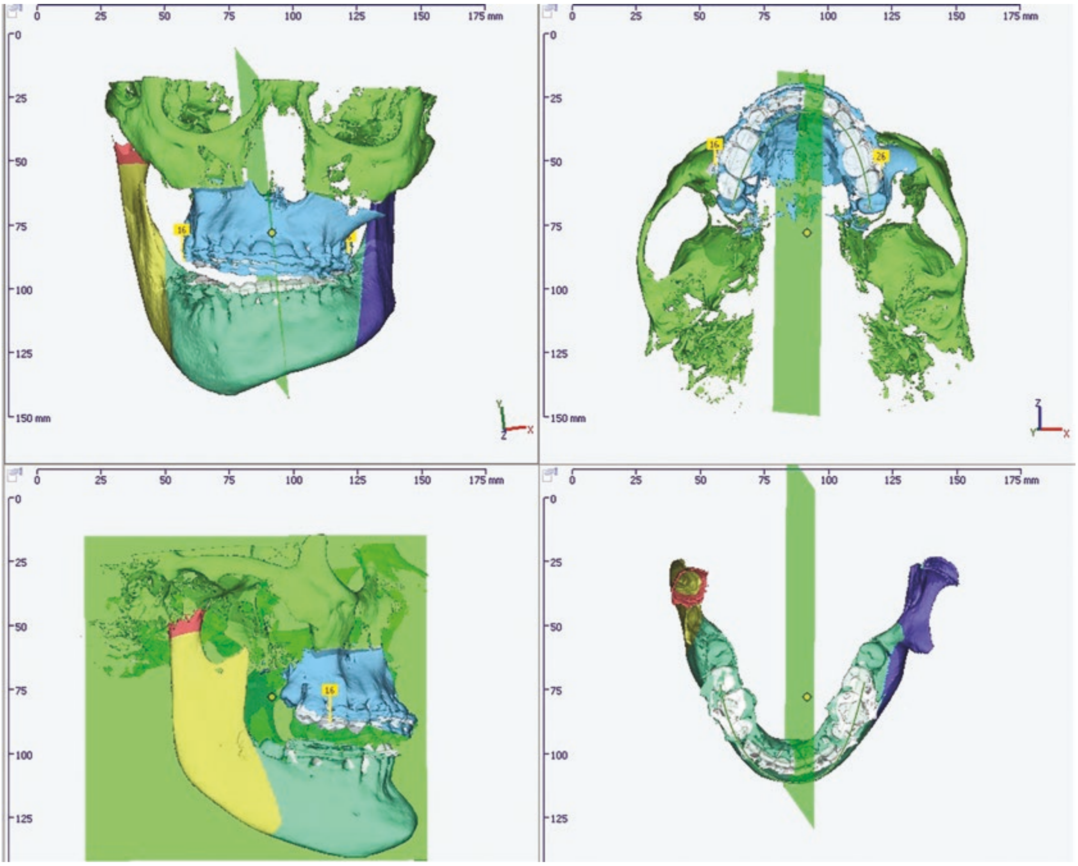


**Fig. 14.11** The positioning of the maxilla is the crucial step in bimaxillary surgery

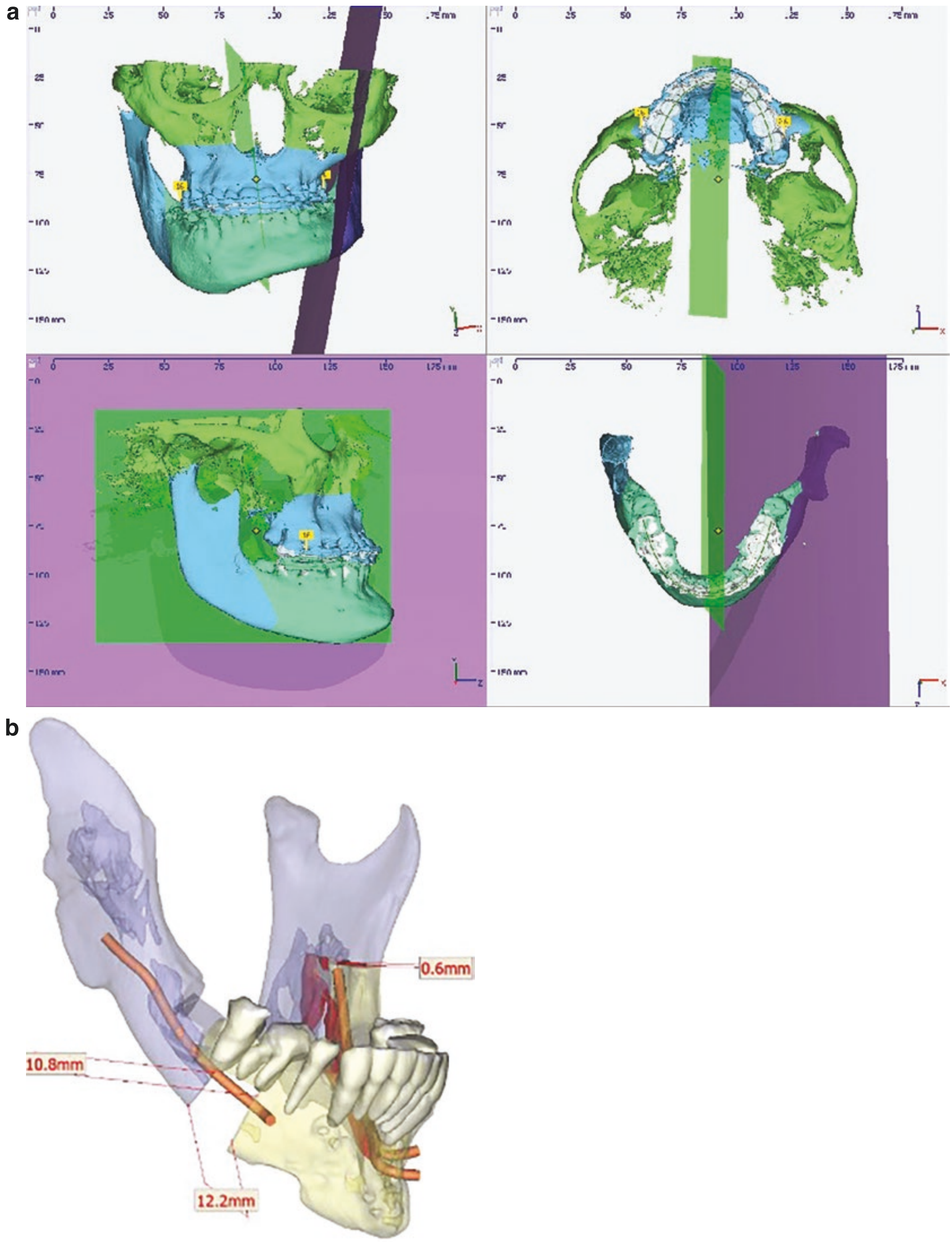



**Fig. 14.12** (**a**) Application of the mandibular osteotomy (in the presented case, a BSSO split). (**b**) Osteotomies can generally be done in all planes and directions (Delaire-Joos osteotomy)

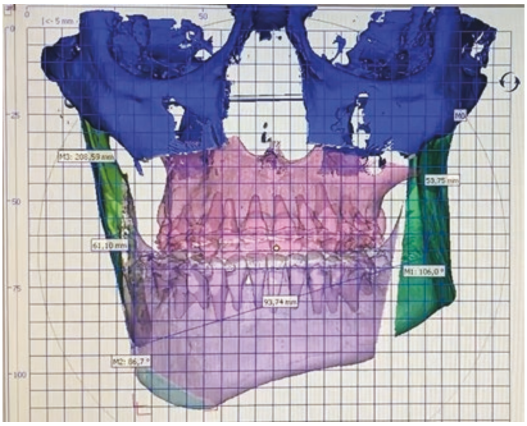


**Fig. 14.13** The anterior mandible is moved to gain a class I relation

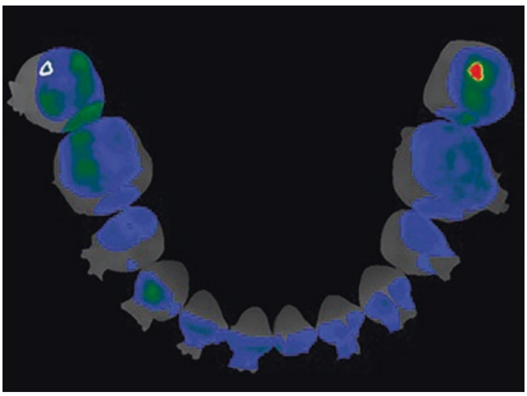


**Fig. 14.14** The occlusogram allows a fine adjustment of the mandibular position to have control over the planned final occlusion

step (check of the occlusogram (Fig. 14.14)), the orthodontist may be included in the planning.

6. The ramus must be set back in the preoperative position. In the cases of condyle resection, the condylar fragment (Fig. 14.15) must be excised and the newly created condyle has to be placed in an optimized articular position (Fig. 14.16).
7. Autorotation of the ramus is an option to alter the mandibular angle position.
8. To adopt the occlusal situation for splint creation, a slight bite opening by autorotation will be required.
9. After saving the digital planning process, the soft tissue simulation helps to have control over the expected final patient appearance. The soft tissue deformation is calculated by a force-minimizing method between the beginning and the planning goal in the final occlusal relation. If the result is not desired, planning of surgery can be altered at this time (Fig. 14.17).
10. The exported jaw situations can be used to design the final surgical splint.

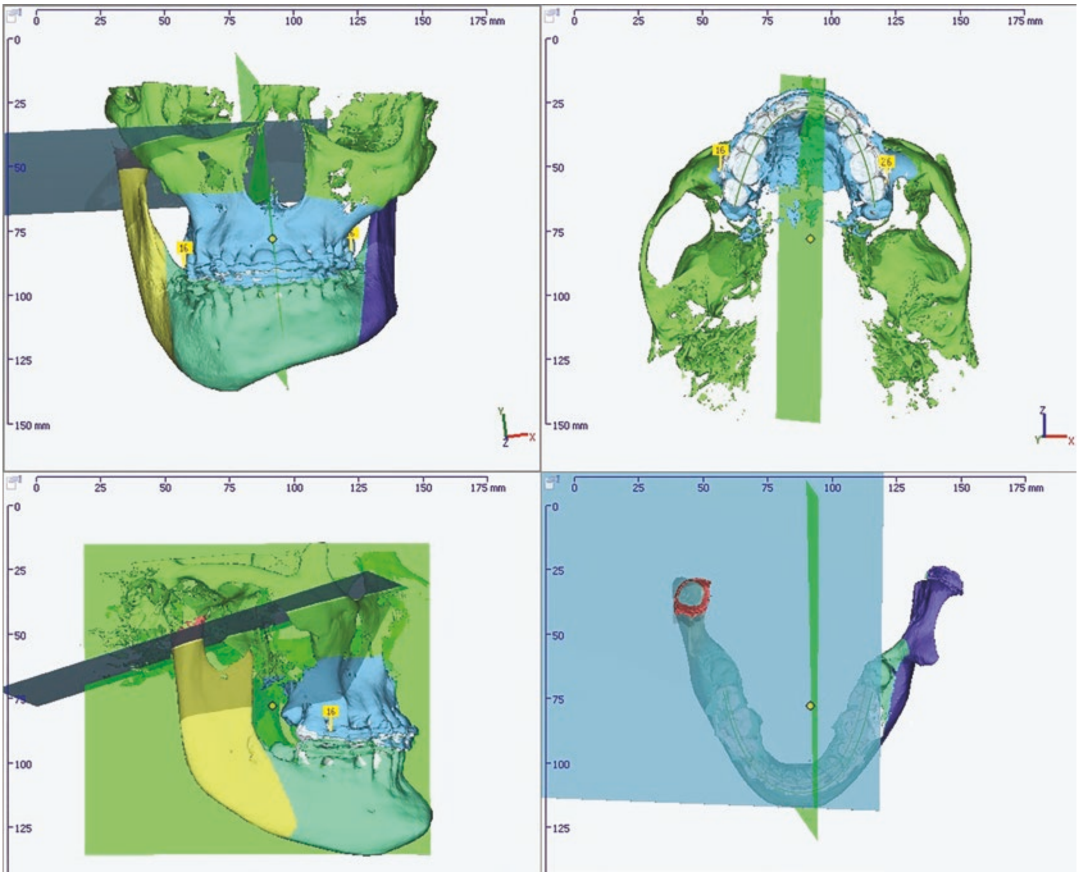


Fig. 14.15 The resected condylar fragment must be defined

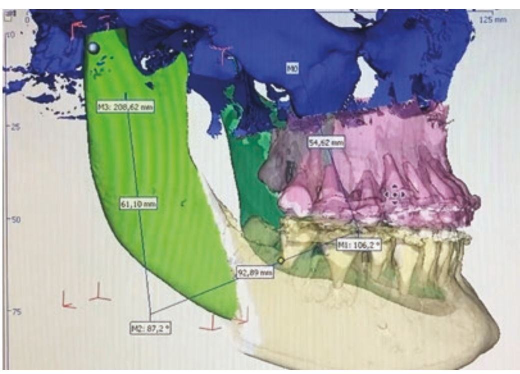



Fig. 14.16 The ramus must be set in the appropriate position with placement of the newly shaped condyle in the center of the fossa and a rotation of the ramus according to the left side

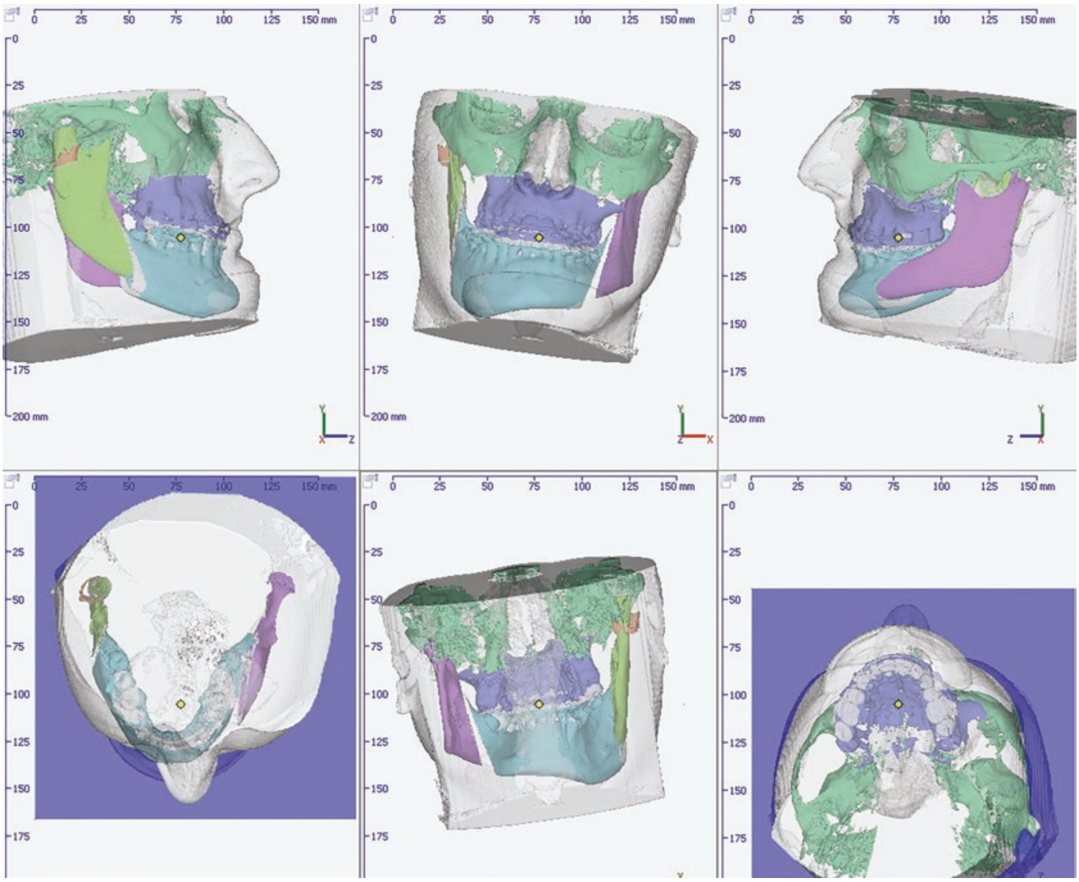


**Fig. 14.17** The soft tissue simulation helps to get an idea of the postoperative facial appearance

## Splint Fabrication

Three-dimensional (3D) guided orthognathic surgical planning utilizing custom splints or patient-specific cutting/drilling guides and prefabricated osteosynthesis plates may well become one of the basic standards enabling the surgeon to better predict the skeletal maxilla/mandible relationship following surgery in most cases [27–33]. Complex facial reconstructions with prefabricated drilling guides and osteosynthesis plates are a domain for the more complex craniofacial malformations. One disadvantage is the fact that they are much more expensive; another one is that they often need more extended soft tissue incisions and enlarged areas of bone denudation.

Three-dimensional (3D) guided orthognathic surgical planning utilizing custom splints can nowadays be performed in an in-house setting, a major advantage of this kind of planning and execution system. Even complex diseases, like hemifacial hypertrophy, can be treated based on a splint-based surgery.

1. The digital data of the splint (in an STL mode) is then transferred to the printer (Fig. 14.18).
2. The printer fabricates the final splint, used for the intraoperative transfer of the planning during surgery (Fig. 14.19).

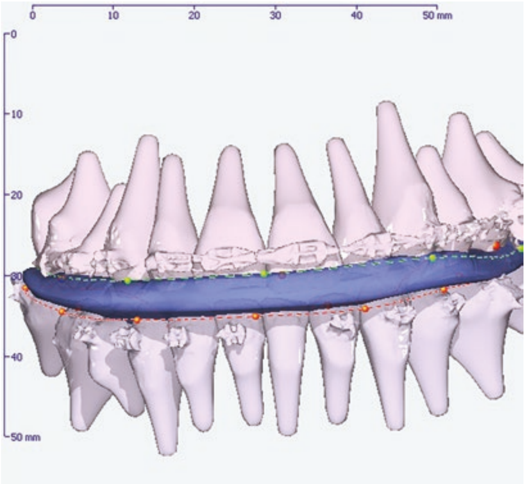



**Fig. 14.18** The bite splints (first splint to define the maxillary position, second splint to define definite occlusal situation) are created and sent in an STL format to the 3D printer

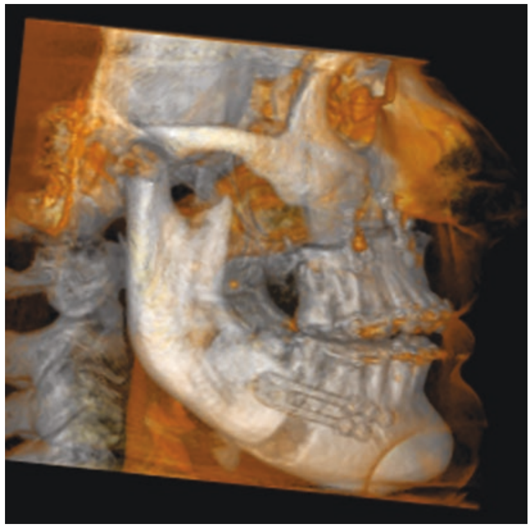


**Fig. 14.20** Postoperative CBCT view of the patient

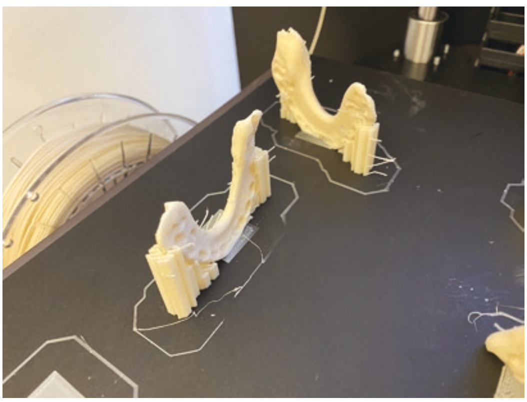


**Fig. 14.19** In-house splint fabrication by a 3D printer

## Control of Operative Outcome

One of the most frequently used methods to evaluate the accuracy of virtual planning is the use of the mean error differences in superimposition between the virtual plan and the postoperative outcomes. Baan and colleagues used this technique to assess the degree of correspondence between the planned and performed positions [34]. De Riu and co-workers also suggested that the simple superimposition of the simulation and the cephalometric results is an unsatisfactory method, as it fails to consider the magnitude of the surgical manipulation leading to an error of a given magnitude [35]. For instance, a slight positional error can be completely acceptable for large manipulations but would be unacceptable when the manipulation takes place at a small scale and thus needs to be extremely precise [36].

The control of the presented case demonstrates the outcome of a virtual planning procedure and splint-based surgery (Fig. 14.20). Special attention should also be placed to the position of the TMJ (Fig. 14.21).

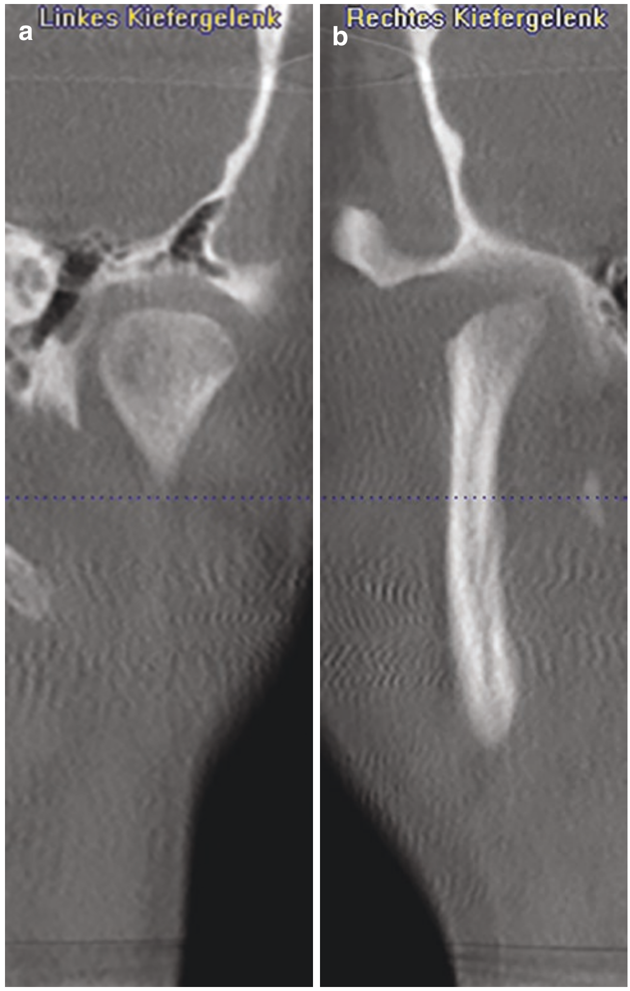



**Fig. 14.21** Condylar positioning demonstrates a regular position of both (**a**) unaffected and **b**) newly created) condyles

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